Lecture 10: building large projects, beginning C++, C++ and structs
Announcements

• Projects
  – 3A assigned 4/24, due Weds 5/3
  – 2D assigned today, due Saturday 5/6
  – 3B assigned today, due Tuesday 5/9
    • BUT: probably need Weds lecture to know enough to do it ("constructors")
  – And: lecture on Weds
Outline

• Review
• Building Large Projects
• Beginning C++
• C++ & Structs
Outline

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• Beginning C++
• C++ & Structs
Function Pointers

• Idea:
  – You have a pointer to a function
  – This pointer can change based on circumstance
  – When you call the function pointer, it is like calling a known function
Function Pointer Example

128-223-223-72-wireless:cli hank$ cat function_ptr.c
#include <stdio.h>
int doubler(int x) { return 2*x; }
int tripler(int x) { return 3*x; }
int main()
{
    int (*multiplier)(int);
multiplier = doubler;
printf("Multiplier of 3 = %d\n", multiplier(3));
multiplier = tripler;
printf("Multiplier of 3 = %d\n", multiplier(3));
}
128-223-223-72-wireless:cli hank$ gcc function_ptr.c
128-223-223-72-wireless:cli hank$ ./a.out
Multiplier of 3 = 6
Multiplier of 3 = 9
Function Pointer Example #2

128-223-223-72-wireless:cli hank$ cat array_fp.c
#include <stdio.h>
void doubler(int *X) { X[0] *= 2; X[1] *= 2; }
void tripler(int *X) { X[0] *= 3; X[1] *= 3; }
int main()
{
    void (*multiplier)(int *);
    multiplier = doubler;
    multiplier(A);
    printf("Multiplier of 3 = %d, %d\n", A[0], A[1]);
    multiplier = tripler;
    multiplier(A);
    printf("Multiplier of 3 = %d, %d\n", A[0], A[1]);
}
128-223-223-72-wireless:cli hank$ gcc array_fp.c
128-223-223-72-wireless:cli hank$ ./a.out

Don’t be scared of extra ‘*’s ... they just come about because of pointers in the arguments or return values.
Simple-to-Exotic Function Pointer Declarations

void (*foo)(void);
void (*foo)(int **, char ***);
char ** (*foo)(int **, void (*)(int));

These sometimes come up on interviews.
Subtyping

• Type: a data type (int, float, structs)
• Subtype / supertype:
  – Supertype: the abstraction of a type
    • (not specific)
  – Subtype: a concrete implementation of the supertype
    • (specific)

The fancy term for this is “subtype polymorphism”
Subtyping: example

• Supertype: Shape

• Subtypes:
  – Circle
  – Rectangle
  – Triangle
Subtyping works via interfaces

• Must define an interface for supertype/subtypes
  – Interfaces are the functions you can call on the supertype/subtypes

• The set of functions is fixed
  – Every subtype must define all functions
Subtyping

• I write my routines to the supertype interface
• All subtypes can automatically use this code
  – Don’t have to modify code when new subtypes are added

• Example:
  – I wrote code about Shapes.
  – I don’t care about details of subtypes (Triangle, Rectangle, Circle)
  – When new subtypes are added (Square), my code doesn’t change
Project 2D

- You will extend Project 2C
- You will do Subtyping
  - You will make a union of all the structs
  - You will make a struct of function pointers
- This will enable subtyping
- Goal: driver program works on “Shape”s and doesn’t need to know if it is a Circle, Triangle, or Rectangle.
Outline

• Review
• Building Large Projects
• Beginning C++
• C++ & Structs
3 files: prototypes.h, rectangle.c, driver.c

prototypes.h

```c
struct Rectangle;
void InitializeRectangle(struct Rectangle *r, double v1, double v2, double v3, double v4);
```

rectangle.c

```c
struct Rectangle
{
    double minX, maxX, minY, maxY;
};

void InitializeRectangle(struct Rectangle *r, double v1, double v2, double v3, double v4)
{
    r->minX = v1;  r->maxX = v2;  r->minY = v3;  r->maxY = v4;
}
```

driver.c

```c
#include <prototypes.h>

int main()
{
    struct Rectangle r;
    InitializeRectangle(r, 0, 1, 0, 1.5);
}
```
Review on compilation

• gcc –c: build an object file (.o), i.e., binary code that can directly run on the architecture
• Then the binary can be generated from the object files.
• Libraries are a mechanism for grouping up a bunch of related object files
  – They are assembled together using a program called an archiver (ar)
• You can also just use object files directly when linking.
Makefiles

• Consists of rules
• Rule syntax:
  target: dependency1 dep2 ... depN
  <tab>command1
  <tab>command2

Quiz: write down a Makefile for a program called proj2B. Again, the file names are prototypes.h, driver.c, rectangle.c
proj2B: driver.c rectangle.c prototypes.h
  gcc -I. -c rectangle.c
  gcc -I. -c driver.c
  gcc -o proj2B driver.o rectangle.o

Is this a good Makefile?
What’s the problem with it?
proj2B: rectangle.o driver.o
    gcc -o proj2B driver.o rectangle.o

driver.o: prototypes.h driver.c
    gcc -I. -c driver.c

rectangle.o: prototypes.h rectangle.c
    gcc -I. -c rectangle.c
Definition of Rectangle in rectangle.c
Why is this a problem?

```
struct Rectangle;
void InitializeRectangle(struct Rectangle *r, double v1, double v2, double v3, double v4);
```

```
struct Rectangle
{
    r->minX = v1;  r->maxX = v2;  r->minY = v3;  r->maxY = v4;
}
```

```
#include <prototypes.h>

int main()
{
    struct Rectangle r;
    InitializeRectangle(&r, 0, 1, 0, 1.5);
}
```

“gcc –c driver.c” needs to make an object file. It needs info about Rectangle then, not later.
The fix is to make sure driver.c has access to the Rectangle struct definition.

```c
#include <prototypes.h>

int main()
{
    struct Rectangle r;
    InitializeRectangle(r, 0, 1, 0, 1.5);
}
```

gcc –E shows what the compiler sees after satisfying “preprocessing”, which includes steps like “#include”.

```c
#include <prototypes.h>

struct Rectangle;

void InitializeRectangle(struct Rectangle *r, double v1, double v2, double v3, double v4);

int main()
{
    struct Rectangle r;
    InitializeRectangle(r, 0, 1, 0, 1.5);
}
```

This is it. If the compiler can’t figure out how to make object file with this, then it has to give up.
Preprocessor

• Preprocessor:
  – takes an input program
  – produces another program (which is then compiled)

• C has a separate language for preprocessing
  – Different syntax than C
  – Uses macros ("#")

Macro ("macroinstruction"): rule for replacing input characters with output characters
Preprocessor Phases

• Resolve `#includes`
  – (we understand `#include` phase)
• Conditional compilation (`#ifdef`)
• Macro replacement
• Special macros
This is an example of macro replacement.
#define via gcc command-line option

```c
int main()
{
    return RV;
}
```

```bash
hank$ cat defines.c
int main()
{
    return RV;
}
```

```bash
hank$ gcc -DRV=4 defines.c
```

```bash
hank$ ./a.out
```

```bash
hank$ echo $?
4
```
Conflicting –D and #define

```c
#define RV 2
int main()
{
    return RV;
}
```

```bash
hank$ cat defines.c
#define RV 2
int main()
{
    return RV;
}
```

```bash
hank$ gcc -DRV=4 defines.c
```

```bash
defines.c:1:9: warning: 'RV' macro redefined
#define RV 2
^  
<command line>:1:9: note: previous definition is here
#define RV 4
^  
1 warning generated.
```

```bash
hank$ ./a.out
C02LN00GFD58:330 hank$ echo $? 
2
```
Conditional compilation

```
C02LN00GFD58:330 hank$ cat conditional.c
#define USE_OPTION 1

int main()
{
    DoMainCode();
    #ifndef USE_OPTION
        UseOption();
    #endif
    DoCleanupCode();
}
```
Conditional compilation controlled via compiler flags

```
C02LN00GFD58:330 hank$ cat conditional_printf.c
#include <stdio.h>

int main()
{
  ifndef DO_PRINTF
    printf("I am doing PRINTF!!\n");
  endif
}
```

```
C02LN00GFD58:330 hank$ gcc conditional_printf.c
C02LN00GFD58:330 hank$ ./a.out
C02LN00GFD58:330 hank$ gcc -DDO_PRINTF conditional_printf.c
C02LN00GFD58:330 hank$ ./a.out
I am doing PRINTF!!
```

This is how configure/cmake controls the compilation.
What is the problem with this configuration?
Compilation error

C02LN00GFD58:project hank$ make
gcc -I. -c rectangle.c
In file included from rectangle.c:2:
In file included from ./prototypes.h:2:
./struct.h:2:8: **error:** redefinition of 'Rectangle'
struct Rectangle
   ^
./struct.h:2:8: **note:** previous definition is here
struct Rectangle
   ^
1 error generated.
make: *** [rectangle.o] Error 1
gcc -E rectangle.c

```c
C02LN00GFD58:project hank$ gcc -E -I. rectangle.c
# 1 "rectangle.c"
# 1 "<built-in>" 1
# 1 "<built-in>" 3
# 162 "<built-in>" 3
# 1 "<command line>" 1
# 1 "<built-in>" 2
# 1 "rectangle.c" 2
# 1 "/struct.h" 1

struct Rectangle
{
    double minX, maxX, minY, maxY;
};
# 2 "rectangle.c" 2
# 1 "/prototypes.h" 1
# 1 "/struct.h" 1

struct Rectangle
{
    double minX, maxX, minY, maxY;
};
# 3 "/prototypes.h" 2

void InitializeRectangle(struct Rectangle *r, double v1, double v2, double v3, double v4);
# 3 "rectangle.c" 2

void InitializeRectangle(struct Rectangle *r, double v1, double v2, double v3, double v4)
{
    r->minX = v1;
    r->maxX = v2;
    r->minY = v3;
    r->maxY = v4;
}
```
#ifndef
#define to the rescue
#endif

#ifndef RECTANGLE_330
#define RECTANGLE_330

struct Rectangle
{
  double minX, maxX, minY, maxY;
};
#endif

Why does this work?

This problem comes up a lot with big projects, and especially with C++. 
There is more to macros...

- Macros are powerful & can be used to generate custom code.
  - Beyond what we will do here.
- Two special macros that are useful:
  - __FILE__ and __LINE__

```c
#include <stdio.h>

int main()
{
    printf("This print happens on line %d of file %s\n", __LINE__, __FILE__);
    printf("But this print happens on line %d\n", __LINE__);
}
```

(Do an example with __LINE__, __FILE__)
Outline

• Review
• Building Large Projects
• Beginning C++
• C++ & Structs
Relationship between C and C++

• C++ adds new features to C
  – Increment operator!
• For the most part, C++ is a superset of C
  – A few invalid C++ programs that are valid C programs
• Early C++ “compilers” just converted programs to C
A new compiler: g++

- g++ is the GNU C++ compiler
  - Flags are the same
  - Compiles C programs as well
    - (except those that aren’t valid C++ programs)
.c vs .C

• Unix is case sensitive
  – (So are C and C++)

• Conventions:
  – .c: C file
  – .C: C++ file
  – .cxx: C++ file
  – .cpp: C++ file (this is pretty rare)

Gnu compiler will sometimes assume the language based on the extension ... CLANG won’t.
Variable declaration (1/2)

• You can declare variables anywhere with C++!

```c++
void line_C(double X1, double X2, double Y1, double Y2) {
    double slope;
    double intercept;

    slope     = (Y2-Y1)/(X2-X1);
    intercept = Y1-slope*X1;
}

void line_CPP(double X1, double X2, double Y1, double Y2) {
    double slope     = (Y2-Y1)/(X2-X1);
    double intercept = Y1-slope*X1;
}
```
Variable declaration (2/2)

• You can declare variables anywhere with C++!

```cpp
int C_fun(void)
{
    int sum += i;
    ~
    =

    t.C:16:17: error: invalid '+=' at end of declaration; did you mean '=='?
        int sum += i;
        ~
        =
    t.C:18:12: error: use of undeclared identifier 'sum'
        return sum;
        ~
    2 errors generated.
}
```

```cpp
int CPP_fun(void)
{
    int sum = 0;
    for (int i = 0; i < 10; i++)
    {
        sum += i;
    }
    return sum;
}
```
C-style Comments

/* Here is a single line comment */

/*
   Here is a multi-line comment */

/*
 * Here is a
 * multi-line comment
 * that makes it clearer
 * that each line is a
 * comment
 * ... because of the *'s
 */
C++-style comments

// this is a comment

/* this is still a comment */

// this is a
// multi-line C++ comment

When you type “//”, the rest of the line is a comment, whether you want it to be or not.
Valid C program that is not a valid C++ program

• We have now learned enough to spot one (the?) valid C program that is not a valid C++ program
  – (lectured on this earlier)

```c
int main()
{
    int y = 2;
    int x = 3 /* 2 */ /y;
}
```
Problem with C...

```c
#include <stdio.h>

float doubler(float f) { return 2*f; }

int doubler(int);

int main()
{
    printf("Doubler of 10 is %d\n", doubler(10));
}
```

Doubler of 10 is 2
Problem with C...

C02LN00GFD58:330 hank$ nm doubler.o
0000000000000000 s EH_frame0
0000000000000000 T _doubler
000000000000000060 S _doubler.eh
C02LN00GFD58:330 hank$ nm doubler
  doubler.c   doubler_example   doubler_example.o
  doubler.o   doubler_example.c   doubler_user.o
C02LN00GFD58:330 hank$ nm doubler_example.o
  s EH_frame0
  s L_.str
  U _doubler
  T _main
  S _main.eh
  U _printf

No checking of type...
Problem is fixed with C++...

```c
C02L000GFD58:330 hank$ cat doubler.c
float doubler(float f) { return 2*f; }
C02L000GFD58:330 hank$ g++ -c doubler.c
clang: warning: treating 'c' input as 'c++' when in C++ mode, this behavior is deprecated
C02L000GFD58:330 hank$ cat doubler_example.c
#include <stdio.h>

int doubler(int);

int main()
{
    printf("Doubler of 10 is %d\n", doubler(10));
}
C02L000GFD58:330 hank$ g++ -c doubler_example.c
clang: warning: treating 'c' input as 'c++' when in C++ mode, this behavior is deprecated
C02L000GFD58:330 hank$ g++ -o doubler_example doubler_example.o doubler.o
Undefined symbols for architecture x86_64:
   "doubler(int)", referenced from:
   _main in doubler_example.o
ld: symbol(s) not found for architecture x86_64
clang: error: linker command failed with exit code 1 (use -v to see invocation)
C02L000GFD58:330 hank$
```
Problem is fixed with C++...

This will affect you with C++. Before you got unresolved symbols when you forgot to define the function. Now you will get it when the arguments don’t match up. Is this good?
Mangling

• Mangling refers to combining information about arguments and “mangling” it with function name.
  – Way of ensuring that you don’t mix up functions.
  – Return type not mangled, though

• Causes problems with compiler mismatches
  – C++ compilers haven’t standardized.
  – Can’t take library from icpc and combine it with g++. 
C++ will let you overload functions with different types

```cpp
C02LN00GFD58:330 hank$ cat t.c
float doubler(float f) { return 2*f; }
int doubler(int f) { return 2*f; }
C02LN00GFD58:330 hank$ gcc -c t.c
t.c:2:5: error: conflicting types for 'doubler'
int doubler(int f) { return 2*f; }
  ^
t.c:1:7: note: previous definition is here
float doubler(float f) { return 2*f; }
  ^
1 error generated.
C02LN00GFD58:330 hank$ g++ -c t.C
C02LN00GFD58:330 hank$
```
C++ also gives you access to mangling via “namespaces”

```c
#include <stdio.h>

namespace CIS330 {
   int GetNumberOfStudents(void) { return 56; }
}

namespace CIS610 {
   int GetNumberOfStudents(void) { return 9; }
}

int main() {
   printf("Number of students in 330 is %d, but in 610 was %d\n", 
            CIS330::GetNumberOfStudents(),
            CIS610::GetNumberOfStudents());
}
```

Functions or variables within a namespace are accessed with “::”
“::” is called “scope resolution operator”
C++ also gives you access to mangling via “namespaces”

The “using” keyword makes all functions and variables from a namespace available without needing “::”. And you can still access other namespaces.

```cpp
namespace CIS610
{
    int GetNumberOfStudents(void) { return 9; }
}

using namespace CIS330;

int main()
{
    printf("Number of students in 330 is %d, but in 610 was %d\n",
            CIS610::GetNumberOfStudents(),
            CIS610::GetNumberOfStudents());
}
```
References

• A reference is a simplified version of a pointer.

• Key differences:
  – You cannot do pointer manipulations
  – A reference is always valid
    • a pointer is not always valid

• Accomplished with & (ampersand)
  – &: address of variable (C-style, still valid)
  – &: reference to a variable (C++-style, also now valid)

You have to figure out how ‘&’ is being used based on context.
Examples of References

```c
C02LN00GFD58:330 hank$ cat ref.C
#include <stdio.h>

void ref_doubler(int &x) { x = 2*x; }

int main()
{
    int x1 = 2;
    ref_doubler(x1);
    printf("Val is %d\n", x1);
}
C02LN00GFD58:330 hank$ g++ ref.C
C02LN00GFD58:330 hank$ ./a.out
Val is 4
```
References vs Pointers vs Call-By-Value

ref_doubler and ptr_doubler are both examples of call-by-reference. val_doubler is an example of call-by-value.
References

• Simplified version of a pointer.

• Key differences:
  – You cannot manipulate it
    • Meaning: you are given a reference to exactly one instance ... you can’t do pointer arithmetic to skip forward in an array to find another object
  – A reference is always valid
    • No equivalent of a NULL pointer ... must be a valid instance
Different Misc C++ Topic: initialization during declaration using parentheses

```c
#include <stdio.h>

int main()
{
    int x(3);
    printf("X is %d\n", x);
}
```

This isn’t that useful for simple types, but it will be useful when we start dealing with objects.
Outline

• Review
• Building Large Projects
• Beginning C++
• C++ & Structs
Learning classes via structs

• structs and classes are closely related in C++
• I will lecture today on changes on how “structs in C++” are different than “structs in C”
• … at the end of the lecture, I will describe how classes and structs in C++ differ.
3 Big changes to structs in C++

1) You can associate “methods” (functions) with structs
Methods vs Functions

• Methods and Functions are both regions of code that are called by name (“routines”)

• With functions:
  – the data it operates on (i.e., arguments) are explicitly passed
  – the data it generates (i.e., return value) is explicitly passed
  – stand-alone / no association with an object

• With methods:
  – associated with an object & can work on object’s data
  – still opportunity for explicit arguments and return value
Function vs Method

(left) function is separate from struct
(right) function (method) is part of struct

C02LN00GFD58:330 hank$ cat function.c
typedef struct
{
    int i;
} Integer;

int doubler(int x) { return 2*x; };

int main() {
    Integer i;
    i.i = 3;
    i.i = doubler(i.i);
}

typedef struct
{
    int i;
    void doubler(void) { i = 2*i; };
} Integer;

int main() {
    Integer i;
    i.i = 3;
    i.doubler();
}

(left) arguments and return value are explicit
(right) arguments and return value are not necessary, since they are associated with the object
Tally Counter

3 Methods:
Increment Count
Get Count
Reset
Methods & Tally Counter

• Methods and Functions are both regions of code that are called by name (“routines”)

• With functions:
  – the data it operates on (i.e., arguments) are explicitly passed
  – the data it generates (i.e., return value) is explicitly passed
  – stand-alone / no association with an object

• With methods:
  – associated with an object & can work on object’s data
  – still opportunity for explicit arguments and return value
C-style implementation of TallyCounter

```c
#include <stdio.h>

typedef struct
{
    int count;
} TallyCounter;

void ResetTallyCounter(TallyCounter *tc) { tc->count = 0; }
int GetCountFromTallyCounter(TallyCounter *tc) { return tc->count; }
void TallyCounterIncrementCount(TallyCounter *tc) { tc->count++; }

int main()
{
    TallyCounter tc;
    tc.count = 0;
    TallyCounterIncrementCount(&tc);
    TallyCounterIncrementCount(&tc);
    TallyCounterIncrementCount(&tc);
    TallyCounterIncrementCount(&tc);
    printf("Count is %d\n", GetCountFromTallyCounter(&tc));
}
```

C02LN00GFD58:TC hank$ gcc tallycounter_c.c
C02LN00GFD58:TC hank$ ./a.out
Count is 4
C++-style implementation of TallyCounter

```c
#include <stdio.h>

typedef struct
{
    int count;

    void Reset() { count = 0; }
    int GetCount() { return count; }
    void IncrementCount() { count++; }
} TallyCounter;

int main()
{
    TallyCounter tc;
    tc.count = 0;
    tc.IncrementCount();
    tc.IncrementCount();
    tc.IncrementCount();
    tc.IncrementCount();
    printf("Count is %d\n", tc.GetCount());
}
```

```
C02LN00GFD58:330  hank$  cat tallycounter.C
C02LN00GFD58:330  hank$  g++ tallycounter.C
C02LN00GFD58:330  hank$  ./a.out
Count is 4
```
```c
typedef struct
{
    int    count;

    void   Initialize() { count = 0; }
    void   Reset() { count = 0; }
    int    GetCount() { return count; }
    void   IncrementCount() { count++; }
} TallyCounter;

int main()
{
    TallyCounter tc;
    tc.Initialize();
    tc.IncrementCount();
    tc.IncrementCount();
    tc.IncrementCount();
    tc.IncrementCount();
    printf("Count is %d\n", tc.GetCount());
}
```
Constructors

• Constructor: method for constructing object.
  – Called automatically

• There are several flavors of constructors:
  – Parameterized constructors
  – Default constructors
  – Copy constructors
  – Conversion constructors

I will discuss these flavors in upcoming slides
typedef struct {
  int count;
} TallyCounter;

void Initialize() { count = 0; }
void Reset() { count = 0; }
int GetCount() { return count; }
void IncrementCount() { count++; }
} TallyCounter;

int main()
{
  TallyCounter tc;
  tc.Initialize();
  tc.IncrementCount();
  tc.IncrementCount();
  tc.IncrementCount();
  tc.IncrementCount();
  printf("Count is %d\n", tc.GetCount());
}

#include <stdio.h>

struct TallyCounter {
  int count;
  TallyCounter(void) { count = 0; }
  void Reset() { count = 0; }
  int GetCount() { return count; }
  void IncrementCount() { count++; }
};

int main()
{
  TallyCounter tc;
  tc.IncrementCount();
  tc.IncrementCount();
  tc.IncrementCount();
  tc.IncrementCount();
  tc.IncrementCount();
  printf("Count is %d\n", tc.GetCount());

Note the typedef went away ... not needed with C++.  
(This is the flavor called “default constructor”)
Argument can be passed to constructor.
(This is the flavor called “parameterized constructor”)

```c
#include <stdio.h>

struct TallyCounter
{
    int count;

    TallyCounter(void) { count = 0; }
    TallyCounter(int c) { count = c; }

    void Reset() { count = 0; }
    int GetCount() { return count; }
    void IncrementCount() { count++; }
};

int main()
{
    TallyCounter tc(10);
    tc.IncrementCount();
    tc.IncrementCount();
    tc.IncrementCount();
    tc.IncrementCount();
    printf("Count is %d\n", tc.GetCount());
}
```
More traditional file organization

• struct definition is in .h file
  – #ifndef / #define
• method definitions in .C file
• driver file includes headers for all structs it needs
More traditional file organization

Methods can be defined outside the struct definition. They use C++’s namespace concept, which is automatically in place. (e.g., TallyCounter::IncrementCount)
“this”: pointer to current object

- From within any struct’s method, you can refer to the current object using “this”
Copy Constructor

• Copy constructor: a constructor that takes an instance as an argument
  – It is a way of making a new instance of an object that is identical to an existing one.

```cpp
struct TallyCounter
{
    int count;

    TallyCounter(void);
    TallyCounter(int c);
    TallyCounter(TallyCounter &);

    void Reset();
    int GetCount();

    void IncrementCount()
    {
        count = c.count;
    }
};
```
Constructor Types

```
struct TallyCounter
{
    int    count;

    TallyCounter(void);
    TallyCounter(int c);
    TallyCounter(TallyCounter &);

    void Reset();
    int  GetCount();
    void IncrementCount();
};
```
Example of 3 Constructors

```c
C02LN00GFD58:TC hank$ cat main.C
#include <stdio.h>
#include <TallyCounter.h>

int main()
{
    TallyCounter tc;      /* Default constructor */
    tc.IncrementCount();

    TallyCounter tc2(10); /* Parameterized constructor */
    tc2.IncrementCount(); tc2.IncrementCount();

    TallyCounter tc3(tc); /* copy constructor */
    tc3.IncrementCount(); tc3.IncrementCount(); tc3.IncrementCount();

    printf("Counts are %d, %d, %d\n", tc.GetCount(),
            tc2.GetCount(), tc3.GetCount());
}
C02LN00GFD58:TC hank$ ./main
 ?????????????????
```
Conversion Constructor

```c
struct ImperialDistance
{
    double miles;
};

struct MetricDistance
{
    double kilometers;

    MetricDistance() { kilometers = 0; };
    MetricDistance(ImperialDistance &id)
    {
        kilometers = id.miles*1.609;
    }
};
```
3 big changes to structs in C++

1) You can associate “methods” (functions) with structs

2) You can control access to data members and methods
Access Control

• New keywords: public and private
  – public: accessible outside the struct
  – private: accessible only inside the struct
  • Also “protected” ... we will talk about that later

```cpp
struct TallyCounter {
    private:
    int count;
    public:
    TallyCounter(void);
    TallyCounter(int c);
    TallyCounter(TallyCounter &);
    void Reset();
    int GetCount();
    void IncrementCount();
};
```

Everything following is private. Only will change when new access control keyword is encountered.

Everything following is now public. Only will change when new access control keyword is encountered.
You can issue public and private as many times as you wish...

```c++
struct TallyCounter {
    
    public:
    
    TallyCounter(void);
    TallyCounter(int c);
    TallyCounter(TallyCounter &);

    private:
    
    int count;

    public:
    
    void Reset();
    int GetCount();
    void IncrementCount();

};
```
The compiler prevents violations of access controls.

```c
#include <stdio.h>
#include <TallyCounter.h>

int main()
{
    TallyCounter tc;
    tc.count = 10;
}
```

```
128-223-223-72-wireless:TC hank$ cat main.C
128-223-223-72-wireless:TC hank$ make
g++ -I. -c main.C
main.C:7:8: error: 'count' is a private member of 'TallyCounter'
    tc.count = 10;
    ^
./TallyCounter.h:12:12: note: declared private here
    int    count;
        ^
1 error generated.
make: *** [main.o] Error 1
```
The friend keyword can override access controls.

```
struct TallyCounter
{
    friend int main();

public:
    TallyCounter(void);
    TallyCounter(int c);
    TallyCounter(TallyCounter &);

private:
    int count;
```

- Note that the struct declares who its friends are, not vice-versa
  - You can’t declare yourself a friend and start accessing data members.
- friend is used most often to allow objects to access other objects.

This will compile, since main now has access to the private data member “count”.
class vs struct

- class is new keyword in C++
- classes are very similar to structs
  - the only differences are in access control
    - primary difference: struct has public access by default, class has private access by default
- Almost all C++ developers use classes and not structs
  - C++ developers tend to use structs when they want to collect data types together (i.e., C-style usage)
  - C++ developers use classes for objects ... which is most of the time

You should use classes!
Even though there isn’t much difference ...
### 3 big changes to structs in C++

1) You can associate “methods” (functions) with structs

2) You can control access to data members and methods

3) Inheritance

---

We will discuss inheritance next week.
Bonus Topics
Backgrounding

• “&”: tell shell to run a job in the background
  – Background means that the shell acts as normal, but the command you invoke is running at the same time.

• “sleep 60” vs “sleep 60 &”

When would backgrounding be useful?
Suspending Jobs

• You can suspend a job that is running
  Press “Ctrl-Z”

• The OS will then stop job from running and not schedule it to run.

• You can then:
  – make the job run in the background.
    • Type “bg”
  – make the job run in the foreground.
    • Type “fg”
      – like you never suspended it at all!!
Web pages

- ssh –l <user name> ix.cs.uoregon.edu
- cd public_html
- put something in index.html
- it will show up as

http://ix.cs.uoregon.edu/~<username>
Web pages

- You can also exchange files this way
  - scp file.pdf <username>@ix.cs.uoregon.edu:~/public_html
  - point people to http://ix.cs.uoregon.edu/~<username>/file.pdf

Note that ~/public_html/dir1 shows up as http://ix.cs.uoregon.edu/~<username>/dir1

("~/dir1" is not accessible via web)