Lecture 20: Review
Your Grade

- Projects: 70%
- Final: 30%
- If you have 70% right now, you have already passed the class.
  - I understand the grader is behind.
Applying Late Passes

• Look at your homework scores
• Decide which homeworks would most benefit from late passes
• There will be a place to write in where on the Final
• If the situation changes based on grades for Proj.3, I will accept emails to change application of late passes
Name: ____________________________

Answer the questions in the spaces provided below the questions. If you run out of room for an answer, continue on the back of the page.

Please write your name on every page!

This is a closed-book test. No notes, no calculators, no computers.

Apply Late Pass #1 To:
Apply Late Pass #2 To:

List Projects That You Feel Have Been Improperly Graded:
Late Homeworks

• 1 pass = ~2 days late
  – Monday deadline becomes Weds,
  – Tuesday deadline becomes Thurs,
  – Weds deadline becomes Fri,
  – Thurs deadline becomes Sun,
  – Fri deadline becomes Mon,
  – Saturday deadline becomes Mon,
  – Sunday deadline becomes Tues,

Want to apply two late passes to one HW? Recurse...
Homeworks

• 3H, 4B, 4C
  – due Tuesday June 13th
    • not late until 6am Weds June 14th
• And: no work accepted after 6am Weds June 14th
  – Late passes don’t help
  – And this goes for all projects, not just 3H/4B/4C
What’s on the final?

• HW 2A is likely
• “What does this print?”
  – Or related questions like “what is the value of this?”
• What is a dangling pointer?
  – (i.e., true/false or vocab)
• Write code!
What Will NOT Be On The Final

• Makefiles
  – but other aspects of compilation are fair game
• vi
• templates / STL
• performance analysis
• debuggers
• specific filters from Proj3 (i.e., no “implement blur”)
Notes

• No notes
• Closed book
Will the Final Be Hard?

- I used to say “no”...
  but now I say “yes”...

I want to understand what you have learned about C/C++/Unix

Everything in lecture is fair game
But: almost all parts of lecture are reinforced in the homeworks
Is This Review Exhaustive?

• No.
• Things not in the review are fair game
Review
Directories are hierarchical

• Directories can be placed within other directories
• “/” -- The root directory
  – Note “/”, where Windows uses “\”
• “/dir1/dir2/file1”
  – What does this mean?

File file1 is contained in directory dir2, which is contained in directory dir1, which is in the root directory
Home directory

- Unix supports multiple users
- Each user has their own directory that they control
- Location varies over Unix implementation, but typically something like “/home/username”
- Stored in environment variables

```
fawcett:~ childs$ echo $HOME
/Users/childs
```
File manipulation

New commands: mkdir, cd, touch, ls, rmdir, rm
There are 9 file permission attributes

- Can user read?
- Can user write?
- Can user execute?
- Can group read?
- Can group write?
- Can group execute?
- Can other read?
- Can other write?
- Can other execute?

A bunch of bits ... we could represent this with binary

User = “owner”
Other = “not owner, not group”
Translating R/W/E permissions to binary

<table>
<thead>
<tr>
<th>#</th>
<th>Permission</th>
<th>rwx</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>full</td>
<td>111</td>
</tr>
<tr>
<td>6</td>
<td>read and write</td>
<td>110</td>
</tr>
<tr>
<td>5</td>
<td>read and execute</td>
<td>101</td>
</tr>
<tr>
<td>4</td>
<td>read only</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>write and execute</td>
<td>011</td>
</tr>
<tr>
<td>2</td>
<td>write only</td>
<td>010</td>
</tr>
<tr>
<td>1</td>
<td>execute only</td>
<td>001</td>
</tr>
<tr>
<td>0</td>
<td>none</td>
<td>000</td>
</tr>
</tbody>
</table>

Which of these modes make sense? Which don’t?

We can have separate values (0-7) for user, group, and other.
Unix command: chmod

• chmod: change file mode

• chmod 750 <filename>
  – User gets 7 (rwx)
  – Group gets 5 (rx)
  – Other gets 0 (no access)

Lots of options to chmod
(usage shown here is most common)
Build: The Actors

- File types
  - Source code
  - Object code
  - Executable code

- Programs
  - Compiler
  - Linker
Compilers, Object Code, and Linkers

• Compilers transform source code to object code
  – Confusing: most compilers also secretly have access to linkers and apply the linker for you.

• **Object code**: statements in machine code
  – not executable
  – intended to be part of a program

• Linker: turns object code into executable programs
Our first gcc program: named output

```bash
C02LN00GFD58:CIS330 hank$ cat t.c
#include <stdio.h>
int main()
{
    printf("hello world!\n");
}
```

```
C02LN00GFD58:CIS330 hank$ gcc t.c
```

```
C02LN00GFD58:CIS330 hank$ ./a.out
hello world!
```

```
C02LN00GFD58:CIS330 hank$ gcc -o helloworld t.c
```

```
C02LN00GFD58:CIS330 hank$ ./helloworld
hello world!
```

```
C02LN00GFD58:CIS330 hank$ ls -l helloworld
-rwxr-xr-x 1 hank staff 8496 Apr 3 15:15 helloworld
```

"-o" sets name of output

Output name is different

Output has execute permissions
Character strings example

```
128-223-223-72-wireless:330 hank$ cat string.c
#include <stdio.h>

int main()
{
    char str[12] = "hello world";
    char *str2 = str+6;

    printf("str is \"%s\" and str2 is \"%s\"\n", str, str2);

    str[5] = '\0';

    printf("Now str is \"%s\" and str2 is \"%s\"\n", str, str2);
}
```

```
128-223-223-72-wireless:330 hank$ gcc string.c
128-223-223-72-wireless:330 hank$ ./a.out
str is "hello world" and str2 is "world"
Now str is "hello" and str2 is "world"
```
```c
#include <stdio.h>
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char *argv[])
{
    FILE *f_in, *f_out;
    int buff_size;
    char *buffer;

    if (argc != 3)
    {
        printf("Usage: %s <file1> <file2>\n", argv[0]);
        exit(EXIT_FAILURE);
    }

    f_in = fopen(argv[1], "r");
    fseek(f_in, 0, SEEK_END);
    buff_size = ftell(f_in);
    fseek(f_in, 0, SEEK_SET);

    buffer = malloc(buff_size);
    fread(buffer, sizeof(char), buff_size, f_in);

    printf("Copying %d bytes from %s to %s\n", buff_size, argv[1], argv[2]);

    f_out = fopen(argv[2], "w");
    fwrite(buffer, sizeof(char), buff_size, f_out);

    fclose(f_in);
    fclose(f_out);

    return 0;
}
```
fprintf

- Just like printf, but to streams
  - `fprintf(stdout, “helloworld\n”);`
    - → same as printf
  - `fprintf(stderr, “helloworld\n”);`
    - prints to “standard error”
  - `fprintf(f_out, “helloworld\n”);`
    - prints to the file pointed to by FILE *f_out.
Enums

• Enums make your own type
  – Type is “list of key words”

• Enums are useful for code clarity
  – Always possible to do the same thing with integers

• Be careful with enums
  – ... you can “contaminate” a bunch of useful words
enum example

C keyword “enum” – means enum definition is coming

```c
enum StudentType {
    HighSchool,
    Freshman,
    Sophomore,
    Junior,
    Senior,
    GradStudent
};
```

This enum contains 6 different student types

semi-colon!!!
Structs: a complex data type

• Construct that defines a group of variables
  – Variables must be grouped together in contiguous memory

• Also makes accessing variables easier ... they are all part of the same grouping (the struct)
C keyword “struct” — means struct definition is coming

```
struct Ray
{
    double origin[3];
    double direction[3];
};
```

This struct contains 6 doubles, meaning it is 48 bytes

```
int main()
{
    struct Ray r;
    r.origin[0] = 0;
    r.origin[1] = 0;
    r.origin[2] = 0;
    r.direction[0] = 1;
    r.direction[1] = 0;
    r.direction[2] = 0;
}
```

Declaring an instance

“.” accesses data members for a struct
Unions

Why are unions useful?

128-223-223-72-wireless:330 hank$ cat union.c
#include <stdio.h>

typedef union
{
    float x;
    int y;
    char z[4];
} cis330_union;

int main()
{
    cis330_union u;
    u.x = 3.5; /* u.x is 3.5, u.y and u.z are not meaningful */
    u.y = 3;  /* u.y is 3, now u.x and u.z are not meaningful */
    printf("As u.x = %f, as u.y = %d\n", u.x, u.y);
}

128-223-223-72-wireless:330 hank$ gcc union.c
128-223-223-72-wireless:330 hank$ ./a.out
As u.x = 0.000000, as u.y = 3
Why are Unions useful?

• Allows you to represent multiple data types simultaneously
  – But only if you know you want exactly one of them

• Benefit is space efficiency, which leads to performance efficiency

Unions are also useful for abstracting type. We will re-visit this when we talk about C++’s templates.
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

```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]);
}
```

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.
Definition of Rectangle in rectangle.c
Why is this a problem?

prototypes.h

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

rectangle.c

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

“gcc –c driver.c” needs to make an object file. It needs info about Rectangle then, not later.

driver.c

```
#include <prototypes.h>

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

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

```
#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++. 
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
References vs Pointers vs Call-By-Value

```c
#include <stdio.h>

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

int main()
{
    int x1 = 2, x2 = 2, x3 = 2;
    ref_doubler(x1);
    ptr_doubler(&x2);
    val_doubler(x3);
    printf("Vals are %d, %d, %d\n", x1, x2, x3);
}
```

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

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

- Default constructor
- Parameterized constructor
- Copy constructor
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.
# Public, private, protected

<table>
<thead>
<tr>
<th>Access</th>
<th>Accessed by derived types*</th>
<th>Accessed outside object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Protected</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Private</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

* = with public inheritance
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
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 ...
Simple inheritance example

```c
struct A {
    int x;
};

struct B : A {
    int y;
};

int main() {
    B b;
    b.x = 3;
    b.y = 4;
}
```

• Terminology
  – B inherits from A
  – A is a base type for B
  – B is a derived type of A

• Noteworthy
  – “:” (during struct definition) \rightarrow inherits from
  • Everything from A is accessible in B
    – (b.x is valid!!)
Virtual functions: example

Virtual function example:

```c
#include <stdio.h>

struct SimpleID
{
    int id;
    virtual int GetIdentifier() { return id; ; }
};

struct ComplexID : SimpleID
{
    int extraId;
    virtual int GetIdentifier() { return extraId*128+id; ; }
};

struct C3 : ComplexID
{
    int extraExtraId;
};

int main()
{
    C3 cid;
    cid.id = 3;
    cid.extraId = 3;
    cid.extraExtraId = 4;
    printf("ID = %d\n", cid.GetIdentifier());
}
```

You get the method furthest down in the inheritance hierarchy

```
#include <stdio.h>

struct SimpleID
{
    int id;
    virtual int GetIdentifier() { return id; ; }
};

struct ComplexID : SimpleID
{
    int extraId;
    virtual int GetIdentifier() { return extraId*128+id; ; }
};

struct C3 : ComplexID
{
    int extraExtraId;
};

int main()
{
    C3 cid;
    cid.id = 3;
    cid.extraId = 3;
    cid.extraExtraId = 4;
    printf("ID = %d\n", cid.GetIdentifier());
}
```

```
128-223-223-72-wireless:330 hank$ g++ virtual2.C
128-223-223-72-wireless:330 hank$ ./a.out
```
C++ memory management

• C++ provides new constructs for requesting heap memory from the memory manager
  – stack memory management is not changed
    • (automatic before, automatic now)

• Allocate memory: “new”

• Deallocate memory: “delete”
new / delete syntax

```c
fawcett:330 child$ cat new.C
int main()
{
    int *oneInt = new int;
    *oneInt = 3;
    int *intArray = new int[3];
    delete oneInt;
    delete [] intArray;
}
```

No header necessary

Allocating array and single value is the same.

new knows the type and allocates the right amount.

Deleting array takes [], deleting single value doesn’t.

new int → 4 bytes
new int[3] → 12 bytes
new calls constructors for your classes

• Declare variable in the stack: constructor called
• Declare variable with “malloc”: constructor not called
  – C knows nothing about C++!
• Declare variable with “new”: constructor called
Pure Virtual Functions

- **Pure Virtual Function**: define a function to be part of the interface for a class, but do not provide a definition.
- **Syntax**: add “=0” after the function definition.
- This makes the class be “abstract”
  - It cannot be instantiated
- When derived types define the function, then are “concrete”
  - They can be instantiated
Pure Virtual Functions Example

class Shape
{
    public:
        virtual double GetArea(void) = 0;
};

class Rectangle : public Shape
{
    public:
        virtual double GetArea() { return 4; }
};

int main()
{
    Shape s;
    Rectangle r;
}

fawcett:330 child$ g++ pure_virtual.C
pure_virtual.C: In function ‘int main()’:
pure_virtual.C:15: error: cannot declare variable ‘s’ to be of abstract type ‘Shape’
pure_virtual.C:2: note: because the following virtual functions are pure within ‘Shape’:
pure_virtual.C:4: note: virtual double Shape::GetArea()
Example of operator overloading

class MyInt
{
public:
    MyInt(int x) { myInt = x; }
    MyInt& operator++();
    int GetValue(void) { return myInt; }
};

int main()
{
    MyInt mi(6);
    ++mi;
    ++mi;
    printf("Value is %d\n", mi.GetValue());
}

fawcett:330 childs$ ./a.out
Value is 8

Declare operator ++ will be overloaded for MyInt

Define operator ++ for MyInt

Call operator ++ on MyInt.
Virtual Function Table

• Let C be a class and X be an instance of C.
• Let C have 3 virtual functions & 4 non-virtual functions
• Let D be a class that inherits from C and Y be an instance of D.
  – Let D add a new virtual function
• D’s virtual function table has 4 rows
  – Each row has the correct definition of the virtual function to call for a “D”.
Exceptions

```cpp
fawcett:330 childs$ cat exceptions.C
#include <iostream>
using std::cout;
using std::endl;

int main()
{
  try
  {
    cout << "About to throw 105" << endl;
    throw 105;
    cout << "Done throwing 105" << endl;
  }
  catch (int &theInt)
  {
    cout << "Caught an int: " << theInt << endl;
  }
}

fawcett:330 childs$ g++ exceptions.C
```
• Assume a pointer named “P”

• Two distinct ideas:
  – P points to something that is constant
    • P may change, but you cannot modify what it points to via P
  – P must always point to the same thing, but the thing P points to may change.
**Idea #1:** violates const:

```
  "*P = 3;"
```

**OK:**

```
  "int Y = 5; P = &Y;"
```

---

**Idea #2:** violates const:

```
  "int Y = 5; P = &Y;"
```

**OK:**

```
  "*P = 3;"
```

**pointer can change,** but you **can’t modify the thing it points to**
const pointers

int X = 4;
int *P = &X;

Idea #3: violates const:
  "*P = 3;"
  "int Y = 5; P = &Y;"
OK:
  none

pointer can’t change, and you can’t modify the thing it points to
const pointers

```
int X = 4;
int *P = &X;
```

Idea #1: violates const:
"*P = 3;"

OK:
"int Y = 5; P = &Y;"

pointer can change, but you can’t modify the thing it points to
const pointers

```
int X = 4;
int *P = &X;
```

Idea #2: violates const:
```
int Y = 5; P = &Y;
```

OK:
```
*P = 3;
```

pointer can't change, but you can modify the thing it points to
const pointers

int X = 4;
int *P = &X;

Idea #3: violates const:
  "*P = 3;"
  "int Y = 5; P = &Y;"

OK: none

pointer can’t change, and you can’t modify the thing it points to
Very common issue with const and objects

How does compiler know `GetNumberOfPixels` doesn’t modify an Image?

We know, because we can see the implementation.

But, in large projects, compiler can’t see implementation for everything.
Chance to Discuss Homeworks

• Your questions?
Final Comments

• Weird term
• Even if this class was a struggle, I hope you all feel encouraged coming out of this term
  – You have done something significant
  – Put it on github (*)
• Thank you for a great term!
Assignment:
Make your 3E project run memory error and leak free

Tasks:
1) start with your 3E source code. (Don’t use 3F, since it has exceptions and
   a. Don’t forget to use your 3E code ... not 3F code.
2) Re memory leaks: “All heap blocks were freed” is the magic statement ... that
   means no memory leaks.

Submit:
1) a screenshot of the valgrind output (see mine below)
2) your source code

hank@ix: ~/3F/3F 65$ valgrind proj3F ~/3A_input.pnm 3F_output.pnm
==16125== Memcheck, a memory error detector
==16125== Copyright (C) 2002-2011, and GNU GPL'd, by Julian Seward et al.
==16125== Using Valgrind-3.7.0 and LibVEX; rerun with -h for copyright info
==16125== Command: proj3F /home/users/hank/3A_input.pnm 3F_output.pnm
==16125==
==16125== HEAP SUMMARY:
==16125==    in use at exit: 0 bytes in 0 blocks
==16125== Total heap usage: 33 allocs, 33 frees, 108,022,422 bytes allocated
==16125==
==16125== All heap blocks were freed -- no leaks are possible
==16125==
==16125== For counts of detected and suppressed errors, rerun with: -v
==16125== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 2 from 2)
1) Extend your project 3 to having timing information
   a. The timings should be added to logger
   b. The timing for each Execute method should be logged individually
      i. Note: if you do the inheritance stuff cleverly, you should only have to add two gettimeofday calls total
2) Run a small performance study using your time
   a. Create the following pipeline: one source that creates a solid red image, one source that creates a solid blue image, and one Blender (who’s inputs are the red image and blue image).
   b. Run the program multiple times. The first time make the solid colored images be 250x250. Then 500x500. Then 1000x1000. Then 2000x2000. Study the timings.
   c. Write a short report (i.e., several sentences) about your findings. Please do not use MS Word or RTF. This short report should be in a text file, so that I can easily view it with my “vi” program.
• Will look at this together now
Stress Test Project (3H)

• We will have ~60 stress tests
• We can’t check in 60 baseline images and difference them all
  – Will slow ix to a grind
• Solution:
  – We commit “essence of the solution”
  – We also complement that all images posted if needed.
Checksums

From Wikipedia

Most useful when input is very large and checksum is very small