Lecture 8: multiple inheritance, objects in objects, and more
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

No header necessary

Allocating array and single value is the same.

new knows the type and allocates the right amount.

new int → 4 bytes
new int[3] → 12 bytes

Deleting array takes [], deleting single value doesn’t.
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
More on Classes
Destructors

• A destructor is called automatically when an object goes out of scope (via stack or delete)
• A destructor’s job is to clean up before the object disappears
  – Deleting memory
  – Other cleanup (e.g., linked lists)
• Same naming convention as a constructor, but with a prepended ~ (tilde)
Destructors example

```cpp
struct Pixel
{
    unsigned char R, G, B;
};

class Image
{
    public:
        Image(int w, int h);
        ~Image();

    private:
        int width, height;
        Pixel *buffer;
};

Image::Image(int w, int h)
{
    width = w; height = h;
    buffer = new Pixel[width*height];
}

Image::~Image()
{
    delete [] buffer;
}
```

Class name with ~ prepended

Defined like any other method, does cleanup

If Pixel had a constructor or destructor, it would be getting called (a bunch) by the new’s and delete’s.
Inheritance and Constructors/Destructors: Example

• Constructors from base class called **first**, then next derived type second, and so on.

• Destructor from base class called **last**, then next derived type second to last, and so on.

• Derived type always assumes base class exists and is set up
  – ... base class never needs to know anything about derived types
Inheritance and Constructors/Destructors: Example

```c
#include <stdio.h>

class C
{
    public:
        C() { printf("Constructing C\n"); }
        ~C() { printf("Destructing C\n"); }
};

class D : public C
{
    public:
        D() { printf("Constructing D\n"); }
        ~D() { printf("Destructing D\n"); }
};

int main()
{
    printf("Making a D\n");
    { D b;
    }

    printf("Making another D\n");
    { D b;
    }
```
Possible to get the wrong destructor

• With a constructor, you always know what type you are constructing.

• With a destructor, you don’t always know what type you are destructing.

• This can sometimes lead to the wrong destructor getting called.
Getting the wrong destructor

#include <stdio.h>

class C
{
    public:
        C() { printf("Constructing C\n"); }
        ~C() { printf("Destructing C\n"); }
};

class D : public C
{
    public:
        D() { printf("Constructing D\n"); }
        ~D() { printf("Destructing D\n"); }
};

D* D_as_D_Creator() { return new D; }
C* D_as_C_Creator() { return new D; }

int main()
{
    C* c = D_as_C_Creator();
    D* d = D_as_D_Creator();

    delete c;
    delete d;
}
Virtual destructors

• Solution to this problem:
  Make the destructor be declared virtual
• Then existing infrastructure will solve the problem
  – ... this is what virtual functions do!
Virtual destructors

```cpp
#include <stdio.h>

class C {
  public:
    C() { printf("Constructing C\n"); }
    virtual ~C() { printf("Destructing C\n"); }
};

class D : public C {
  public:
    D() { printf("Constructing D\n"); }
    virtual ~D() { printf("Destructing D\n"); }

    D* D_as_D_Creator() { return new D; }
    C* D_as_C_Creator() { return new D; }

  int main()
  {
    C* c = D_as_C_Creator();
    D* d = D_as_D_Creator();

    delete c;
    delete d;
  }
```
Objects in objects

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

class A {
    public:
    A() { printf("Constructing A\n"); }
    ~A() { printf("Destructing A\n"); }
};

class B {
    public:
    B() { printf("Constructing B\n"); }
    ~B() { printf("Destructing B\n"); }
    private:
    A a1, a2;
};

int main() {
    printf("Making a B\n");
    B b;
    printf("Making another B\n");
    B b;
    printf("Making another B\n");
    B b;
    printf("Making another B\n");
    B b;
}
```

By the time you enter B’s constructor, a1 and a2 are already valid.
Objects in objects

#include <stdio.h>

class A
{
    public:
        A() { printf("Constructing A\n"); }
        ~A() { printf("Destructing A\n"); }
};

class B
{
    public:
        B() { printf("Constructing B\n"); }
        ~B() { printf("Destructing B\n"); }
};

class C
{
    public:
        C() { printf("Constructing C\n"); }
        ~C() { printf("Destructing C\n"); }
    private:
        A a;
        B b;
};

int main()
{
    C c;
}
Objects in objects: order is important

#include <stdio.h>

class A
{
    public:
        A() { printf("Constructing A\n"); }
        ~A() { printf("Destructing A\n"); }
};

class B
{
    public:
        B() { printf("Constructing B\n"); }
        ~B() { printf("Destructing B\n"); }
};

class C
{
    public:
        C() { printf("Constructing C\n"); }
        ~C() { printf("Destructing C\n"); }
    private:
        B b;
        A a;
};

int main()
{
    C c;
}
Initializers

- New syntax to have variables initialized before even entering the constructor

```c
#include <stdio.h>

class A
{
    public:
        A() : x(5)
        {
            printf("x is %d\n", x);
        }
    private:
        int x;
};

int main()
{
    A a;
}
```
Initializers

• Initializers are a mechanism to have a constructor pass arguments to another constructor

• Needed because
  – Base class constructors are called before derived constructors & need to pass arguments in derived constructor to base class
  – Constructors for objects contained in a class are called before the container class & need to pass arguments in container class’s destructor
Initializers

- Needed because
  - Constructors for objects contained in a class are called before the container class & need to pass arguments in container class’s destructor

```c
#include <stdio.h>

class A
{
    public:
        A(int x) { v = x; }
    private:
        int v;
};
class B
{
    public:
        B(int x) { v = x; }
    private:
        int v;
};
class C
{
    public:
        C(int x, int y) : b(x), a(y) { }
    private:
        B b;
        A a;
};

int main()
{
    C c(3,5);
}
```
Initializers

- Needed because
  - Base class constructors are called before derived constructors & need to pass arguments in derived constructor to base class
Quiz

#include <stdio.h>

int doubler(int X)
{
    printf("In doubler\n");
    return 2*X;
}

class A
{
    public:
        A(int x) { printf("In A's constructor\n"); }
};

class B : public A
{
    public:
        B(int x) : A(doubler(x)) { printf("In B's constructor\n"); }
};

int main()
{
    B b(3);
}
The “is a” test

• Inheritance should be used when the “is a” test is true
• Base class: Shape
• Derived types: Triangle, Rectangle, Circle
  – A triangle “is a” shape
  – A rectangle “is a” shape
  – A circle “is a” shape

You can define an interface for Shapes, and the derived types can fill out that interface.
Multiple inheritance

• A class can inherit from more than one base type
• This happens when it “is a” for each of the base types
  – Inherits data members and methods of both base types
Multiple inheritance

class Professor
{
    void Teach();
    void Grade();
    void Research();
};

class Father
{
    void Hug();
    void Discipline();
};

class Hank : public Father, public Professor
{  
};
Diamond-Shaped Inheritance

• Base A, has derived types B and C, and D inherits from both B and C.
  – Which A is D dealing with??

• Diamond-shaped inheritance is controversial & really only for experts
  – (For what it is worth, we make heavy use of diamond-shaped inheritance in my project)
Diamond-Shaped Inheritance Example

class Person
{
    int X;
};

class Professor : public Person
{
    void Teach();
    void Grade();
    void Research();
};

class Father : public Person
{
    void Hug();
    void Discipline();
};

class Hank : public Father, public Professor
{
};
# include <stdio.h>

class Person
{
   public:
      Person(int h) { hoursPerWeek = h; }

   protected:
      int hoursPerWeek;
};

class Professor : public Person
{
   public:
      Professor() : Person(90) { ; }

   void Teach();
   void Grade();
};

class Hank : public Father, public Professor
{
   public:
      int GetHoursPerWeek() { return hoursPerWeek; };
};

int main()
{
   Hank hrc;
   printf("HPW = %d\n", hrc.GetHoursPerWeek());
}

fawcett:330 childs$ g++ diamond_inheritance.C
diamond_inheritance.C: In member function ‘int Hank::GetHoursPerWeek()’:
diamond_inheritance.C:31: error: reference to ‘hoursPerWeek’ is ambiguous
diamond_inheritance.C:8: error: candidates are: int Person::hoursPerWeek
diamond_inheritance.C:8: error: int Person::hoursPerWeek
};
Diamond-Shaped Inheritance Pitfalls

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

class Person {
    public:
        Person(int h) { hoursPerWeek = h; }
    protected:
        int hoursPerWeek;
};

class Professor : public Person {
    public:
        Professor() : Person(90) { ; }
    void Teach();
    void Grade();
    void Research();
};

class Father : public Person {
    public:
        Father() : Person(20) { ; }
    void Hug();
    void Discipline();
};

class Hank : public Father, public Professor {
    public:
        int GetHoursPerWeek() { return Professor::hoursPerWeek+
                               Father::hoursPerWeek; }
    }

    int main()
    {   
        Hank hrc;
        printf("HPW = %d
", hrc.GetHoursPerWeek());
    }

fawcett:330 child$s ./a.out
HPW = 110
```

This can get stickier with virtual functions.

You should avoid diamond-shaped inheritance until you feel really comfortable with OOP.
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 childs$ 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()
Topics for 3D
C++ lets you define operators

• You declare a method that uses an operator in conjunction with a class
  – +, -, /, !, ++, etc.
• You can then use your operator in your code, since the compiler now understands how to use the operator with your class
• This is called “operator overloading”
  – ... we are overloading the use of the operator for more than just the simple types.

You can also do this with functions.
Example of operator overloading

```cpp
class MyInt
{
public:
    MyInt(int x) { myInt = x; }
    MyInt& operator++();

    int GetMyInt() { return myInt; }
private:
    int myInt;
};

MyInt & MyInt::operator++()
{
    myInt++; return *this;
}
```

Declare operator ++ will be overloaded for MyInt

We will learn more about operator overloading later in the quarter.

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

Call operator ++ on MyInt.

```bash
fawcett:330 child$ ./a.out
Value is 8
```

Define operator ++ for MyInt
New operators: «<< and >>»

• “<<”: Insertion operator
• “>>”: Extraction operator
  – Operator overloading: you can define what it means to insert or extract your object.

• Often used in conjunction with “streams”
  – Recall our earlier experience with C streams
    • stderr, stdout, stdin
  – Streams are communication channels
cout: the C++ way of accessing stdout

New header file (and no "h"!)

New way of accessing stdout stream.

Insertion operation (<<)
cout is in the “standard” namespace

```cpp
#include <iostream>
using std::cout;

int main()
{
    cout << "The answer is: ";
    cout << 8;
    cout << "\n";
}
```

“using” command puts the “cout” portion of the standard namespace (“std”) in the global namespace.

Don’t need “std::cout” any more...
endl: the C++ endline mechanism

• prints a newline
• flushes the stream
  – C version: fflush(stdout)
  – This is because printf doesn’t always print when you ask it to.
    • It buffers the requests when you make them.
    • This is a problem for debugging!!
endl in action

```cpp
#include <iostream>

using std::cout;
using std::endl;

int main()
{
    cout << "The answer is: ";
    cout << 8;
    cout << endl;
}
```

fawcett:330 childs$ g++ printCPP.C
fawcett:330 childs$  

<< and >> have a return value

• `ostream & ostream::operator<<(int);`
  – (The signature for a function that prints an integer)

• The return value is itself
  – i.e., the cout object returns “cout”

• This allows you to combine many insertions (or extractions) in a single line.
  – This is called “cascading”.
Cascading in action

```c++
fawcett:330 child$ cat printCPP.C
#include <iostream>

using std::cout;
using std::endl;

int main()
{
    cout << "The answer is: " << 8 << endl;
}
fawcett:330 child$ g++ printCPP.C
fawcett:330 child$  
```
Putting it all together

```c
#include <stdio.h>

int main()
{
    printf("The answer is: ");
    printf("%d", 8);
    printf("\n");
}
```

```cpp
#include <iostream>

int main()
{
    std::cout << "The answer is: ";
    std::cout << 8;
    std::cout << "\n";
}
```

```c
#include <stdio.h>

int main()
{
    printf("The answer is: %d\n", 8);
}
```

```cpp
#include <iostream>

using std::cout;
using std::endl;

int main()
{
    cout << "The answer is: " << 8 << endl;
}
```
Three pre-defined streams

- `cout <= => fprintf(stdout, ...`
- `cerr <= => fprintf(stderr, ...`
- `cin <= => fscanf(stdin, ...`
cin in action

```cpp
#include <iostream>

using std::cin;
using std::cout;
using std::endl;

int main()
{
    int X, Y, Z;
    cin >> X >> Y >> Z;
    cout << Z << "," << Y << "," << X << endl;
}
```

```
fawcett:330 childs$ ./a.out
3 5
4
4, 5, 3
```
cerr

- Works like cout, but prints to stderr
- Always flushes everything immediately!

```
#include <iostream>

using std::cerr;
using std::cout;
using std::endl;

int main()
{
    int *X = NULL;
    stream << "The value is ";
    stream << *X << endl;
}
```

```
fawcett:330 childs$ cat cerr.C
#include <iostream>

using std::cerr;
using std::cout;
using std::endl;

int main()
{
    int *X = NULL;
    stream << "The value is ";
    stream << *X << endl;
}
```

```
fawcett:330 childs$ g++ -Dstream= cerr cerr.C
fawcett:330 childs$ ./a.out
The value is Segmentation fault
fawcett:330 childs$ g++ -Dstream= cout cerr.C
fawcett:330 childs$ ./a.out
Segmentation fault
```

“See the error”
fstream

• ifstream: input stream that does file I/O
• ofstream: output stream that does file I/O

• Not lecturing on this, since it follows from:
  – C file I/O
  – C++ streams

http://www.tutorialspoint.com/cplusplus/cpp_files_streams.htm
Project 3D

• Assigned: today, 5/9
• Due: Weds, 5/16
• Important: if you skip this project, you will still be able to do future projects (3E, 3F, etc)
• Assignment:
  – Write PNMreaderCPP and PNMwriterCPP ... new version of the file reader and writer that use fstream.
Inline function

• inlined functions:
  – hint to a compiler that can improve performance
  – basic idea: don’t actually make this be a separate function that is called
    • Instead, just pull the code out of it and place it inside the current function
  – new keyword: inline

```c
inline int doubler(int X)
{
    return 2*X;
}

int main()
{
    int Y = 4;
    int Z = doubler(Y);
}
```

The compiler sometimes refuses your inline request (when it thinks inlining won’t improve performance), but it does it silently.
Inlines can be automatically done within class definitions

• Even though you don’t declare this as inline, the compiler treats it as an inline

    class MyDoublerClass
    {
        int doubler(int X) { return 2*X; }
    };
You should only do inlines within header files

Left: function is inlined in every .C that includes it  
... no problem

Right: function is defined in every .C that includes it  
... duplicate symbols
Data Flow Networks

• This is not a C++ idea
• It is used for image processing, visualization, etc
• So we need to know it for Project 3
Data Flow Overview

• Basic idea:
  – You have many modules
    • Hundreds!!
  – You compose modules together to perform some desired functionality

• Advantages:
  – Customizability
  – Design fosters interoperability between modules to the extent possible
Data Flow Overview

• Participants:
  – Source: a module that produces data
    • It creates an output
  – Sink: a module that consumes data
    • It operates on an input
  – Filter: a module that transforms input data to create output data

• Nominal inheritance hierarchy:
  – A filter “is a” source
  – A filter “is a” sink
Example of data flow (image processing)

• Sources:
  – FileReader: reader from file
  – Color: generate image with one color

• Filters:
  – Crop: crop image, leaving only a sub-portion
  – Transpose: view image as a 2D matrix and transpose it
  – Invert: invert colors
  – Concatenate: paste two images together

• Sinks:
  – FileWriter: write to file
Example of data flow (image processing)

FileReader → Crop → Transpose → Invert → Color → Concatenate → FileWriter
Example of data flow (image processing)

- **Participants:**
  - **Source:** a module that produces data
    - It creates an output
  - **Sink:** a module that consumes data
    - It operates on an input
  - **Filter:** a module that transforms input data to create output data

- **Pipeline:** a collection of sources, filters, and sinks connected together
Benefits of the Data Flow Design

• Extensible!
  – write infrastructure that knows about abstract types (source, sink, filter, and data object)
  – write as many derived types as you want

• Composable!
  – combine filters, sources and sinks in custom configurations

What do you think the benefits are?
Drawbacks of Data Flow Design

What do you think the drawbacks are?

• Operations happen in stages
  – Extra memory needed for intermediate results
  – Not cache efficient

• Compartmentalization can limit possible optimizations
Data Flow Networks

• Idea:
  – Many modules that manipulate data
    • Called filters
  – Dynamically compose filters together to create “networks” that do useful things
  – Instances of networks are also called “pipelines”
    • Data flows through pipelines
  – There are multiple techniques to make a network “execute” ... we won’t worry about those yet
Data Flow Network: the players

- **Source**: produces data
- **Sink**: accepts data
  - Never modifies the data it accepts, since that data might be used elsewhere
- **Filter**: accepts data and produces data
  - A filter “is a” sink and it “is a” source

Source, Sink, and Filter are abstract types. The code associated with them facilitates the data flow.

There are concrete types derived from them, and they do the real work (and don’t need to worry about data flow!).
Project 3C

• Due in one week
• 3D also due in one week
  – 3D not needed for 3E, 3F, etc.
  – So you can “skip”
  – But you will get 0 points for 3D if you “skip”
Assignment: make your code base be data flow networks with OOP

Source → PNMreader → Filter → LRConcat → Shrinker → Blender → PNMwriter

Sink → PNMwriter
Unions

• Union: special data type
  – store many different memory types in one memory location

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

When dealing with this union, you can treat it as a float, as an int, or as 4 characters.

This data structure has 4 bytes
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
Unions Example

typedef struct
{
    int firstNum;
    char letters[3];
    int endNums[3];
} CA_LICENSE_PLATE;

typedef struct
{
    char letters[3];
    int nums[3];
} OR_LICENSE_PLATE;

typedef struct
{
    int nums[6];
} WY_LICENSE_PLATE;

typedef union
{
    CA_LICENSE_PLATE ca;
    OR_LICENSE_PLATE or;
    WY_LICENSE_PLATE wy;
} LicensePlate;
Unions Example

typedef enum
{
    CA,
    OR,
    WY
} US_State;

typedef struct
{
    char *carMake;
    char *carModel;
    US_State state;
    LicensePlate lp;
} CarInfo;

int main()
{
    CarInfo c;
    c.carMake = "Chevrolet";
    c.carModel = "Camaro";
    c.state = OR;
    c.lp.or.letters[0] = 'X';
    c.lp.or.letters[1] = 'S';
    c.lp.or.letters[2] = 'Z';
    c.lp.or.nums[0] = 0;
    c.lp.or.nums[1] = 7;
    c.lp.or.nums[2] = 5;
}
Function Pointers
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

```
#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
```
What are the pros and cons of each approach?
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.
Callbacks

• Callbacks: function that is called when a condition is met
  – Commonly used when interfacing between modules that were developed separately.
  – ... libraries use callbacks and developers who use the libraries “register” callbacks.
Callback example

```c
128-223-223-72-wireless:callback hank$ cat mylog.h

#include <mylog.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

/* NULL is an invalid memory location. * Useful for setting to something known, rather than leaving uninitialized */
void (*error_handler)(char *) = NULL;

void RegisterErrorHandler(void (*eh)(char *))
{
    error_handler = eh;
}

void Error(char *msg)
{
    if (error_handler != NULL)
        error_handler(msg);
}

double mylogarithm(double x)
{
    if (x <= 0)
    {
        char msg[1024];
        sprintf(msg, "Logarithm of a negative number: %f !!", x);
        Error(msg);
        return 0;
    }

    return log(x);
}
```
Callback example

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

FILE *F1 = NULL;
void HanksErrorHandler(char *msg)
{
    if (F1 == NULL)
    {
        F1 = fopen("error", "w");
    }
    fprintf(F1, "Error: %s\n", msg);
}

int main()
{
    RegisterErrorHandler(HanksErrorHandler);

    mylogarithm(3);
    mylogarithm(0);
    mylogarithm(-2);
    mylogarithm(5);
    if (F1 != NULL)
        fclose(F1);
}
```

```bash
128-223-223-72-wireless:callback hank$
cat program.c
128-223-223-72-wireless:callback hank$
#include <mylog.h>
#include <stdio.h>

FILE *F1 = NULL;
void HanksErrorHandler(char *msg)
{
    if (F1 == NULL)
    {
        F1 = fopen("error", "w");
    }
    fprintf(F1, "Error: %s\n", msg);
}

int main()
{
    RegisterErrorHandler(HanksErrorHandler);

    mylogarithm(3);
    mylogarithm(0);
    mylogarithm(-2);
    mylogarithm(5);
    if (F1 != NULL)
        fclose(F1);
}
```
Function Pointers

• We are going to use function pointers to accomplish “sub-typing” in Project 2D.