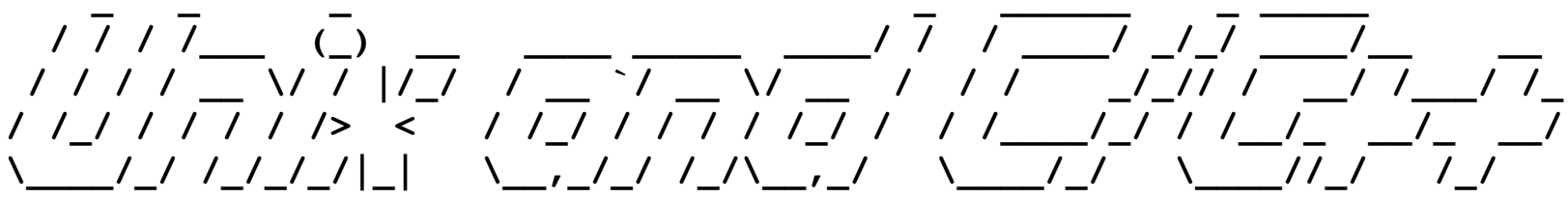
UNIVERSITY OF OREGON

CIS 330:



Lecture 12:
more classes,
C++ memory management

May 6th, 2016

Hank Childs, University of Oregon

Announcements

- OH today: only 1-1:30 (not 12:30-1:30)
- Weekend OH?

Project 3B

- Add useful routines for manipulating an image
  - Halve in size
  - Concatenate
  - Crop
  - Blend
- Assigned: April 30th
- Due: tomorrow

Review

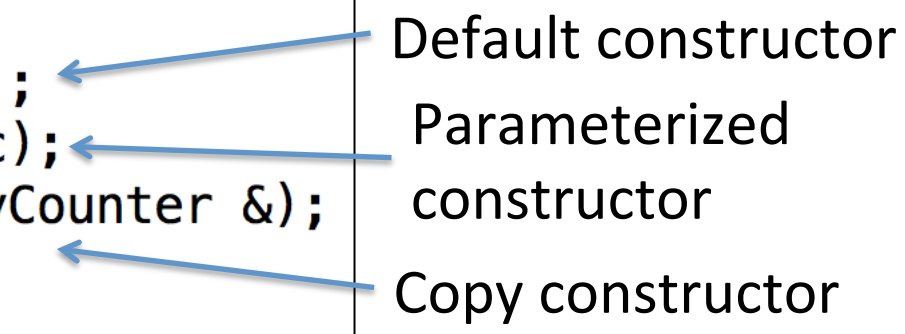
“this”: pointer to current object

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

```
TallyCounter::TallyCounter(int c)
{
    count = c;
}

     <------>

TallyCounter::TallyCounter(int c)
{
    this->count = c;
}
```

Constructor Types

```
struct TallyCounter
{
    int     count;

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



Example of 3 Constructors

```
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
     ??????????????
```

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

```
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

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

  private:
    int    count;

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

You can issue public and private as many times as you wish…

The compiler prevents violations of access controls.

```
128-223-223-72-wireless:TC hank$ cat main.C
#include <stdio.h>
#include <TallyCounter.h>

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

This will compile, since main now has access to the private data member “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.

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

Simple inheritance example

```
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) → inherits from
    - Everything from A is accessible in B
      - (b.x is valid!!)

Object sizes

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

struct A
{
    int x;
};

struct B : A
{
    int y;
};

int main()
{
    B b;
    b.x = 3;
    b.y = 4;
    printf("Size of A = %lu, size of B = %lu\n", sizeof(A), sizeof(B));
}
128-223-223-72-wireless:330 hank$ g++ simple_inheritance.C
128-223-223-72-wireless:330 hank$ ./a.out
Size of A = 4, size of B = 8
```

Inheritance + TallyCounter

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

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

  private:
    int    count;

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

struct FancyTallyCounter : TallyCounter
{
    void   DecrementCount() { count--; }
}
```

FancyTallyCounter inherits all of TallyCounter, and adds a new method: DecrementCount

Virtual functions

- Virtual function: function defined in the base type, but can be re-defined in derived type.
- When you call a virtual function, you get the version defined by the derived type

Virtual functions: example

```
128-223-223-72-wireless:330 hank$ cat virtual.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; };
};

int main()
{
   ComplexID cid;
   cid.id = 3;
   cid.extraId = 3;
   printf("ID = %d\n", cid.GetIdentifier());
}
128-223-223-72-wireless:330 hank$ g++ virtual.C
128-223-223-72-wireless:330 hank$ ./a.out
ID = 387
```

Virtual functions: example

```
128-223-223-72-wireless:330 hank$ cat virtual2.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());
}
128-223-223-72-wireless:330 hank$ g++ virtual2.C
128-223-223-72-wireless:330 hank$ ./a.out
```

You get the method furthest down in the inheritance hierarchy

Virtual functions: example

```
128-223-223-72-wireless:330 hank$ cat virtual3.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, %d\n", cid.SimpleID::GetIdentifier(), cid.GetIdentifier());
}
128-223-223-72-wireless:330 hank$ g++ virtual3.C
128-223-223-72-wireless:330 hank$ ./a.out
ID = 3, 387
```

You can specify the method you want to call by specifying it explicitly

Access controls and inheritance

```
C02LN00GFD58:330 hank$ cat inheritance.C
struct A { int x; };
struct B : A { int y; };
struct C : public A { int y; };
struct D : private A { int y; };

int main()
{
    C c;
    c.x = 2;
    D d;
    d.x = 2;
}
```

B and C are the same. public is the default inheritance for structs

Public inheritance: derived types gets access to base type's data members and methods

Private inheritance: derived types don't get access.

New Stuff

public / private inheritance

- class A : [public|protected|private] B

- For P, base class's public members will be P
- e.g.,
  - For public, base class's public members will be public

- Public common
  - I've never personally used anything else

public / private inheritance

- class A : public B
  - A “is a” B
- class A : private B
  - A “is implemented using” B
    - And: !(A “is a” B)
    - … you can’t treat A as a B
- class A : protected B
  - …. can’t find practical reasons to do this

One more access control word: protected

- Protected means:
  - It cannot be accessed outside the object
    - Modulo “friend”
  - But it can be accessed by derived types
    - (assuming public inheritance)

protected example

```
fawcett:330 childs$ cat protected.C
class A
{
   protected:
     int x;
};

class B : public A
{
   int foo() { return x; };
};

int main()
{
    B b;
    b.x = 2;
    int y = foo();
}
fawcett:330 childs$ g++ protected.C
protected.C: In function ‘int main()’:
protected.C:4: error: ‘int A::x’ is protected
protected.C:15: error: within this context
protected.C:16: error: ‘foo’ was not declared in this scope
```

Public, private, protected

	Accessed by derived types*	Accessed outside object
Public	Yes	Yes
Protected	Yes	No
Private	No	No

* = with public inheritance

More on virtual functions upcoming

- "Is A"
- Multiple inheritance
- Virtual function table
- Examples
  - (Shape)

Memory Management

C memory management

- Malloc: request memory manager for memory from heap
- Free: tell memory manager that previously allocated memory can be returned

- All operations are in bytes

```
Struct *image = malloc(sizeof(image)*1);
```

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”
- Allocate memory: “delete”

new / delete syntax

No header necessary

```
fawcett:330 childs$ cat new.C
int main()
{
    int *oneInt = new int;
    *oneInt = 3;
    int *intArray = new int[3];
    intArray[0] = intArray[1] = intArray[2] = 5;

    delete oneInt;
    delete [] intArray;
}
```

Allocating array and single value is the same.

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

new knows the type and allocates the right amount.

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

new calls constructors for your classes

```
fawcett:330 childs$ cat counter.C
#include <stdio.h>

int counter = 0;
class Counter
{
 public:
   Counter() { counter++; };
};

void PrintCount(char *location)
{
   printf("Count at %s is %d\n",
              location, counter);
}
```

```
int main()
{
    PrintCount("beginning");
    Counter c;
    PrintCount("after one");
    Counter *c2 = new Counter;
    PrintCount("after heap one");
    Counter *c3 = new Counter[10];
    PrintCount("after heap ten");
    Counter **c4 = new Counter*[10];
    PrintCount("after heap-pointer-ten");
    for (int i = 0 ; i < 10 ; i++)
    {
        c4[i] = new Counter;
    }
    PrintCount("after allocating heap-pointer-ten");
}
```

```
fawcett:330 childs$ ./a.out
Count at beginning is 0
Count at after one is 1
Count at after heap one is 2
Count at after heap ten is 12
Count at after heap-pointer-ten is 12
Count at after allocating heap-pointer-ten is 22
```

new & malloc

- Never mix new/free & malloc/delete.
- They are different & have separate accesses to heap.
- New error code: FMM (Freeing mismatched memory)

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

```
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

```
#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;
    }
}
```

```
Making a D
Constructing C
Constructing D
Destructing D
Destructing C
Making another D
Constructing C
Constructing D
Destructing D
Destructing C
```

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;
}
```

```
fawcett:330 childs$ ./a.out
Constructing C
Constructing D
Constructing C
Constructing D
Destructing C
Destructing D
Destructing C
```

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

```
#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;
}
```

```
fawcett:330 childs$ ./a.out
Constructing C
Constructing D
Constructing C
Constructing D
Destructing D
Destructing C
Destructing D
Destructing C
```

Virtual inheritance is forever

```
#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;
}
```

I didn't need to put virtual there.
If the base class has a virtual function, then the derived function is virtual, whether or not you put the keyword in.

I recommend you still put it in … it is like a comment, reminding anyone who looks at the code.

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"); };
  private:
    A a1, a2;
};

int main()
{
    printf("Making a 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.

```
ut
Destructing A
Destructing A
Making another B
Constructing A
Constructing A
Constructing B
Destructing B
Destructing A
Destructing A
```

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;
}
```

```
fawcett:330 childs$ ./a.out
Constructing A
Constructing B
Constructing C
Destructing C
Destructing B
Destructing A
```

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;
}
```

```
fawcett:330 childs$ ./a.out
Constructing B
Constructing A
Constructing C
Destructing C
Destructing A
Destructing B
```

Initializers

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

```
#include <stdio.h>

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

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

```
fawcett:330 childs$ ./a.out
x is 5
```

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

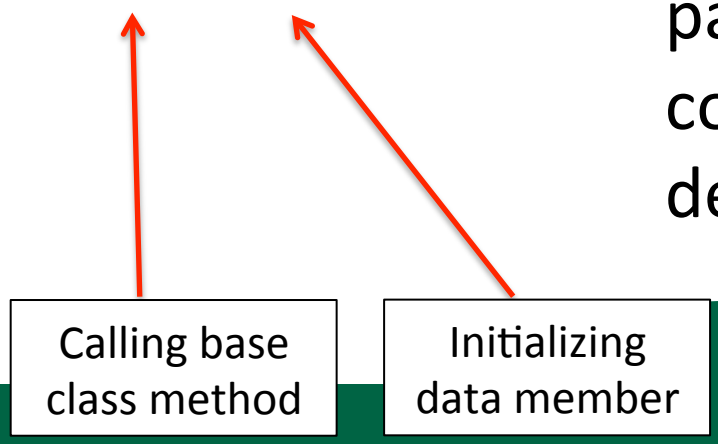
Initializers

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

```
#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

```
class A
{
  public:
    A(int x)  { v = x; };
  private:
    int v;
};

class C : public A
{
  public:
    C(int x, int y) : A(y), z(x)  { };
  private:
    int z;
};

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



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

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);
}
```

```
fawcett:330 childs$ ./a.out
In doubler
In A's constructor
In B's constructor
```

What's the output?

The “is a” test

- Inhe… …s a” test
- Base class: Shape
- Derived types: Triangle, Rectangle, Circle
  - A triangle “is a” shape
  - A rectangle “is a” shape
  - A circle “is a” shape

I will do a live coding example of this next week, and will discuss how C++ implements virtual functions.

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

Multiple inheritance

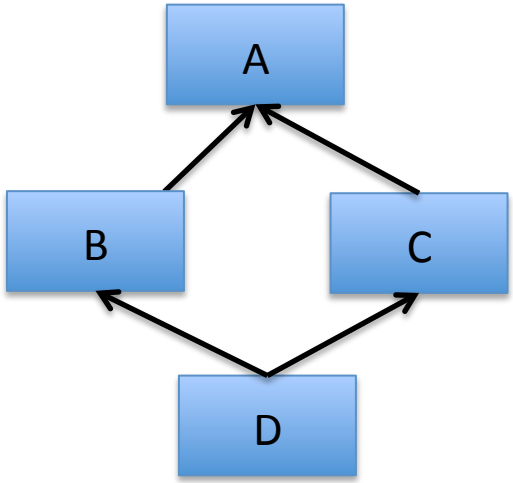
- A class can inherit from more than one base type
- This happens when it “is a” for each of the base types
  - Inherits data members and methods of both base types

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
{
};
```

Diamond-Shaped Inheritance Pitfalls

```
#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();
};

cla
{
  p
};
```

```
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_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

```
#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\n", hrc.GetHoursPerWeek());
}
```

```
fawcett:330 childs$ ./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()
```

Data Flow Networks

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

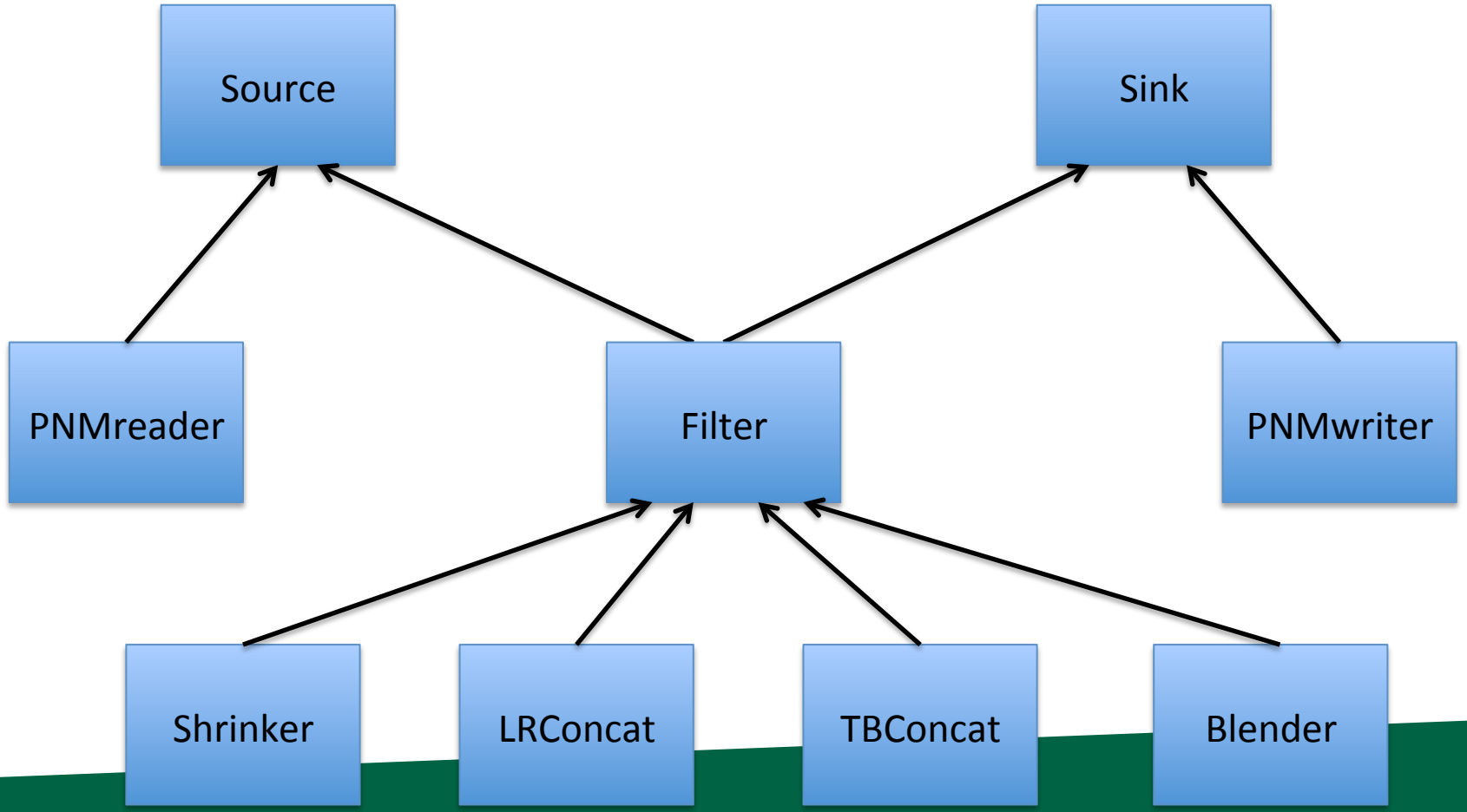
- Source: produces data
- Sink: accepts data
  - Never modifies the data it accepts, since that data might be used elsewhere
- Filter: accepts data and produces data
  - A filter "is a" sink and it "is a" source

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 2C

Assignment: make your code base be data flow networks with OOP



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)

Unix and Windows difference

- Unix:
  - "\n": goes to next line, and sets cursor to far left
- Windows:
  - "\n": goes to next line (cursor does not go to left)
  - "\m": sets cursor to far left

- Text files written in Windows often don't run well on Unix, and vice-versa
  - There are more differences than just newlines

vi: "set ff=unix" solves this