UNIVERSITY OF OREGON

CIS 330:

```
   __  __      _                        __   ______  ________
  / / / /___  (_)  __   ____ _____  ____/ /  / ____/ / / ____/__    __
 / / / / __ \/ / |/_/  / __ `/ __ \/ __  /  / /    _/_/ /  __/ /___/ /_
/ /_/ / / / / />  <   / /_/ / / / / /_/ /  / /___ _/_// /__/_  __/_  __/
\____/_/ /_/_/_/|_|   \__,_/_/ /_/\__,_/   \____//_/  \____//_/   /_/
```

Lecture 13: more class, C++ memory management

May 7th, 2018

Hank Childs, University of Oregon

Random Topics

Operator Precedence

Precedence	Operator	Description	Associativity
1	++ --	Suffix/postfix increment and decrement	Left-to-right
	()	Function call	
	[]	Array subscripting	
	.	Structure and union member access	
	->	Structure and union member access through pointer	
	(*type*){*list*}	Compound literal(C99)	
2	++ --	Prefix increment and decrement	Right-to-left
	+ -	Unary plus and minus	
	! ~	Logical NOT and bitwise NOT	
	(*type*)	Type cast	
	*	Indirection (dereference)	
	&	Address-of	
	sizeof	Size-of	
	_Alignof	Alignment requirement(C11)	
3	* / %	Multiplication, division, and remainder	Left-to-right
4	+ -	Addition and subtraction	
5	<< >>	Bitwise left shift and right shift	
6	< <=	For relational operators < and ≤ respectively	
	> >=	For relational operators > and ≥ respectively	
7	== !=	For relational = and ≠ respectively	
8	&	Bitwise AND	
9	^	Bitwise XOR (exclusive or)	
10	|	Bitwise OR (inclusive or)	
11	&&	Logical AND	
12	||	Logical OR	
13[note 1]	?:	Ternary conditional[note 2]	Right-to-Left
14	=	Simple assignment	
	+= -=	Assignment by sum and difference	
	*= /= %=	Assignment by product, quotient, and remainder	
	<<= >>=	Assignment by bitwise left shift and right shift	
	&= ^= |=	Assignment by bitwise AND, XOR, and OR	
15	,	Comma	Left-to-right

Source: http://en.cppreference.com/w/c/language/operator_precedence

Actions

performance of different fread options?

It seems like there are maybe three different ways to use fread:

option 1: fread(location, size_of_element, number_of_elements, file)

option 2: fread(location, size_of_element * number_of_elements, 1, file)

option 3: loop over i < number_of_elements: fread(location + i, size_of_element, 1, file)

You might want to use different options depending on the context, but supposing it didn't matter, I was wondering which would be the best?

I figured option 3 would be the slowest because of all the function calls. I wrote a little program and got running times: option 2 < option 1 << option 3

Does anyone know why option 2 is the fastest? If you're interested, the test program I wrote is at: http://ix.cs.uoregon.edu/~hampton2/330/fread_test/

This isn't the most important thing in the world ... just goofing around :)

DRAM vs NV-RAM

- DRAM: Dynamic Random Access Memory
  - stores data
  - each bit in separate capacitor within integrated circuit
  - loses charge over time and must be refreshed
  - → volatile memory
- NV-RAM: Non-Volatile Random Access Memory
  - stores data
  - information unaffected by power cycle
  - examples: Read-Only Memory (ROM), flash, hard drive, floppy drive, …

[Seagate Expansion 5TB Desktop External Hard Drive USB 3.0 (STEB5000100)](#)
by Seagate

$133.99 ~~$169.99~~ Prime
Get it by **Friday, Nov 20**

More Buying Choices
$133.99 new (68 offers)
$117.24 used (1 offer)

★★★★½ 1,394
Electronics Gift Guide See more
Trade-in eligible for an Amazon gift card
Electronics: See all 94 items

Crucial Ballistix Sport 16GB Kit (8GBx2) DDR3 1600 MT/s (PC3-12800) UDIMM Memory BLS2KIT8G3D1609DS1S00/ BLS2CP8G3D1609DS1S00
by Crucial

$74.99 ~~$159.99~~ Prime
Get it by **Thursday, Nov 19**

More Buying Choices
$69.95 new (73 offers)

★★★★★ 1,443
Product Description
... is a *16GB* kit consisting ... computers that take DDR3 UDIMM *memory* ...
Electronics: See all 454,298 items

Corsair Vengeance 16GB (2x8GB) DDR3 1600 MHz (PC3 12800) Desktop Memory (CMZ16GX3M2A1600C10)
by Corsair

$83.90 ~~$118.70~~ Prime
Get it by **Thursday, Nov 19**

More Buying Choices
$72.50 new (101 offers)
$74.99 used (3 offers)

★★★★½ 912
Product Features
XMP *Memory* Profile for simple, safe overclocking
Electronics: See all 454,298 items

Crucial 16GB Kit (8GBx2) DDR3/DDR3L-1600 MHz (PC3-12800) CL11 204-Pin SODIMM Memory for Mac CT2K8G3S160BM / CT2C8G3S160BM
by Crucial

$72.99 ~~$165.99~~ Prime
Get it by **Thursday, Nov 19**

More Buying Choices
$71.29 new (99 offers)
$62.00 used (8 offers)

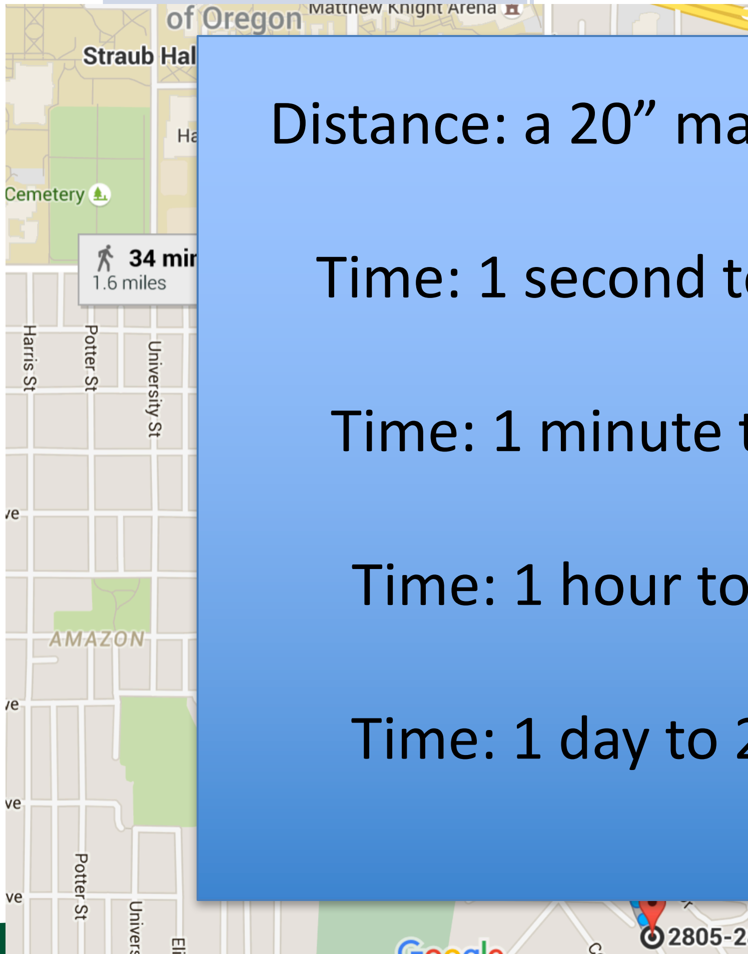
★★★★★ 3,247
Product Description
... CT2K8G3S160BM is a *16GB* kit consisting of (2) 8GB DDR3L (DDR3 low ...
Electronics: See all 454,298 items

Relationship to File Systems

- File Systems could be implemented in DRAM.
- However, almost exclusively on NV-RAM
  – Most often hard drives
- Therefore, properties and benefits of file systems are often associated with properties and benefits of NV-RAM.

DRAM vs NV-RAM properties

Property	DRAM	NV-RAM



Distance: a 20” map of Oregon is 1:100,000 scale

Time: 1 second to 27 hours is 1:100,000 scale

Time: 1 minute to 69 days is 1:100,000 scale

Time: 1 hour to 11 years is 1:100,000 scale

Time: 1 day to 273 years is 1:100,000 scale

Announcements

- Projects
  - 3B assigned Friday, due Wednesday
  - 3C posted Wednesday, due May 18
  - 3D posted Weds, also due May 18
    - 3D is not required to do 3E, etc.
    - So you can skip it, although you will lose points.

Announcements

- For Proj3, it is very important that you use my interface
  - Do not modify the files I tell you not to modify
  - If you do modify the files, it will be quite painful when I had you ~100 regression tests that assume the interface I have been providing

Project 3B

- Retrofit to use references
- Add useful routines for manipulating an image
  - Halve in size
  - Concatenate
  - Crop
  - Blend
- Assigned: May 2nd
- Due: Weds, May 9th

Review

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

```
C02LN00GFD58:330 hank$ cat 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$ g++ tallycounter.C
C02LN00GFD58:330 hank$ ./a.out
Count is 4
```

```
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

```
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());
}
```

```
#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();
    printf("Count is %d\n", tc.GetCount());
}
```

Note the typedef went away … not needed with C++.

(This is the flavor called “default constructor”)

```
C02LN00GFD58:330 hank$ cat tallycounterV4.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());
}
C02LN00GFD58:330 hank$ g++ tallycounterV4.C
C02LN00GFD58:330 hank$ ./a.out
Count is 14
```

Argument can be passed to constructor.
(This is the flavor called "parameterized constructor")

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

```
C02LN00GFD58:TC hank$ cat tallycounter.h
#ifndef TALLY_COUNTER_H
#define TALLY_COUNTER_H

struct TallyCounter
{
   int    count;

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

#endif
```

```
C02LN00GFD58:TC hank$ cat main.C

#include <stdio.h>

#incl

int m
{
    T
    t
    t
    t
    tc.
    printf("Count is %d\n", tc.GetCount());
}
```

```
C02LN00GFD58:TC hank$ cat Makefile
main: main.o tallycounter.o
        g++ -o main main.o tallycounter.o

.C.o: $<
        g++ -I. -c $<
```

```
C02LN00GFD58:TC hank$ cat tallycounter.C
#include <TallyCounter.h>

TallyCounter::TallyCounter(void)
{
    count = 0;
}

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

void
TallyCounter::Reset()
{
    count = 0;
}
    count++;
}
```

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"

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

      <------->

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

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.

```
struct TallyCounter
{
   int     count;

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

```
TallyCounter::TallyCounter(TallyCounter &c)
{
     count = c.count;
}
```

Constructor Types

```
struct TallyCounter
{
   int     count;

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

Default constructor

Parameterized constructor

Copy constructor

Conversion Constructor

```
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

```
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

New Stuff

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

public / private inheritance

- class A : [public|private] B
  - → class A : public B
  - → class A : private B
- So:
  - For public, base class's public members will be public
  - For private, base class's public members will be private
- Public common
  - I've never personally used anything else

public / private inheritance

- public inheritance → no restriction beyond what restrictions in base class
  - Example:
    - class A { private: int x; }; class B : public A {};
    - → B cannot access x
- private inheritance → *does* restrict beyond what restrictions in base class
  - Example 2:
    - class A { public: int x; }; class B : private A {};
    - → B again cannot access x

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

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.

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)

Public, private, protected

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

* = with public inheritance

protected example

```
128-223-223-73-wireless:CV hank$ cat protected.C
class A
{
  protected:
    int x;
};

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

int main()
{
    B b;
    b.x = 2;
    int y = b.foo();
}
128-223-223-73-wireless:CV hank$ g++ protected.C
protected.C:16:7: error: 'x' is a protected member of 'A'
    b.x = 2;
      ^
protected.C:4:9: note: declared protected here
    int x;
        ^
1 error generated.
```

proctected inheritance

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

- class A : protected B
  - .... can't find practical reasons to do this

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”
- Deallocate 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.

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

```
#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);
}
```

Calling base class constructor

Initializing data member

- 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);
}
```

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

What's the output?

The “is a” test

- Inhe … a” test

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

- 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

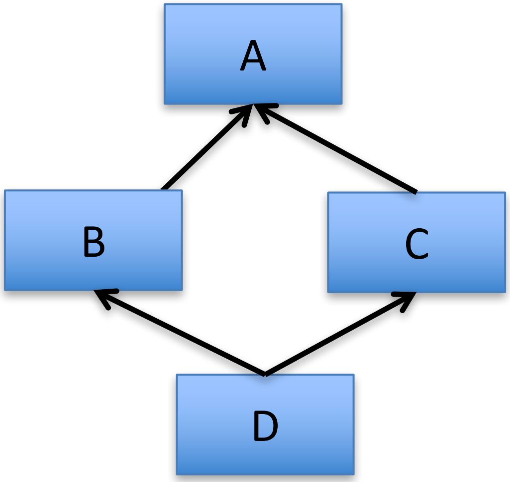
```
class Professor
{
    void Teach();
    void Grade();
    void Research();
};

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
{
};
```

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()
```

More on virtual functions upcoming

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

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)