

C++ References, Const, Classes

CSE 333 Autumn 2021

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Administrivia

- ❖ Exercise 8 due Wednesday @ 10 am
- ❖ Homework 2 due a week from Thursday (Oct. 28)
 - File system crawler, indexer, and search engine
 - Note: `libhw1.a` (yours or ours) and the `.h` files from hw1 need to be in right directory (`~yourgit/hw1/`)
 - Note: use Ctrl-D to exit `searchshell`, test on directory of small self-made files

Lecture Outline

- ❖ **C++ References**
- ❖ `const` in C++
- ❖ C++ Classes Intro

Pointers Reminder

Note: Arrow points to *next* instruction.

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify what it points to, but you can access/modify what it points to by *dereferencing*
 - These work the same in C and C++

```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int* z = &x;  
  
    *z += 1;  
    x += 1;  
  
    z = &y;  
    *z += 1;  
  
    return EXIT_SUCCESS;  
}
```



pointer.cc

Pointers Reminder

Note: Arrow points to *next* instruction.

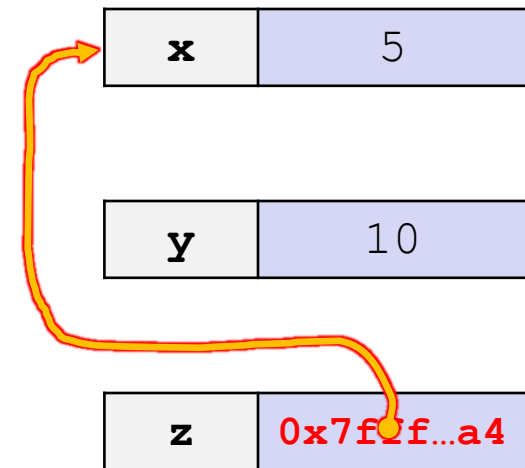
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```
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    int x = 5, y = 10;
    int* z = &x;

    *z += 1;
    x += 1;

    z = &y;
    *z += 1;

    return EXIT_SUCCESS;
}
```



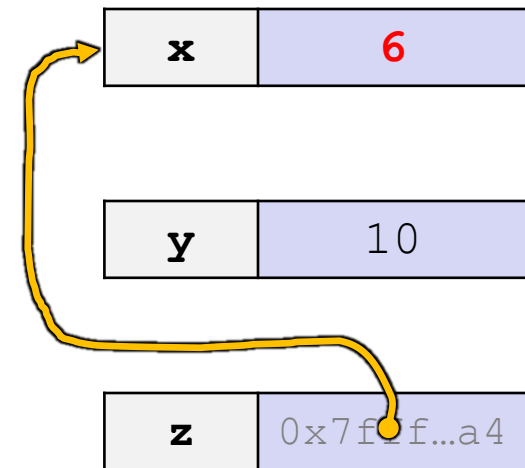
pointer.cc

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 - These work the same in C and C++

```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int* z = &x;  
  
    *z += 1; // sets x to 6  
    x += 1;  
  
    z = &y;  
    *z += 1;  
  
    return EXIT_SUCCESS;  
}
```



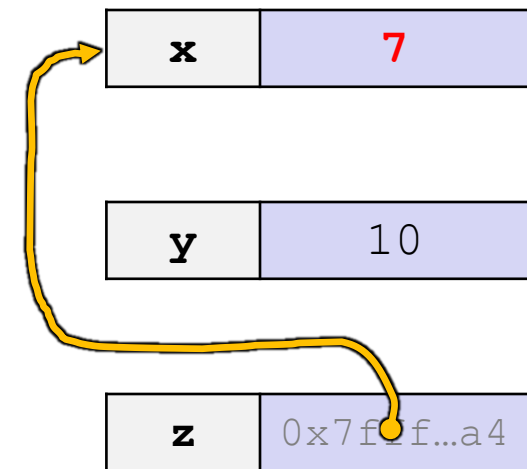
pointer.cc

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 - These work the same in C and C++

```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int* z = &x;  
  
    *z += 1; // sets x to 6  
    x += 1; // sets x (and *z) to 7  
  
    z = &y;  
    *z += 1;  
  
    return EXIT_SUCCESS;  
}
```



pointer.cc

Pointers Reminder

Note: Arrow points to *next* instruction.

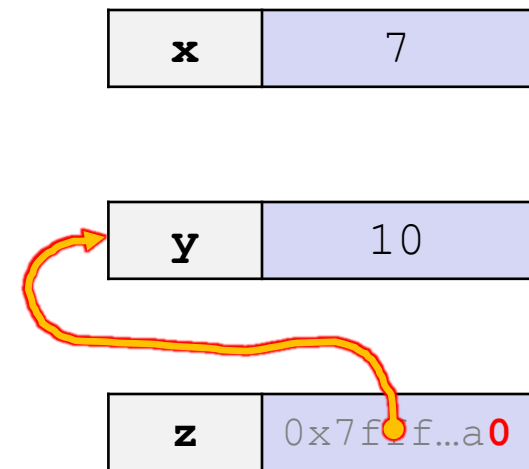
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```
int main(int argc, char** argv) {
    int x = 5, y = 10;
    int* z = &x;

    *z += 1; // sets x to 6
    x += 1; // sets x (and *z) to 7

    z = &y; // sets z to the address of y
    *z += 1;

    return EXIT_SUCCESS;
}
```



pointer.cc

Pointers Reminder

Note: Arrow points to *next* instruction.

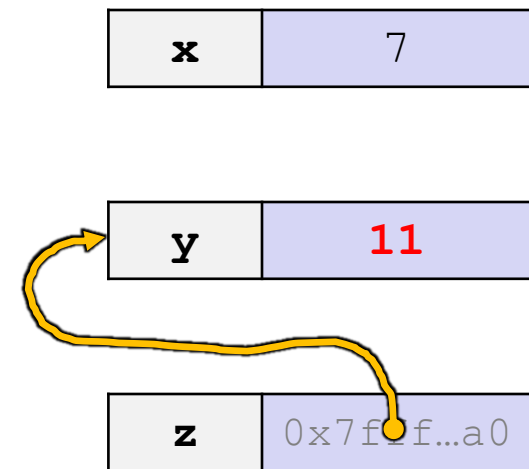
- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify what it points to, but you can access/modify what it points to by *dereferencing*
 - These work the same in C and C++

```
int main(int argc, char** argv) {
    int x = 5, y = 10;
    int* z = &x;

    *z += 1; // sets x to 6
    x += 1; // sets x (and *z) to 7

    z = &y; // sets z to the address of y
    *z += 1; // sets y (and *z) to 11

    return EXIT_SUCCESS;
}
```



pointer.cc

References

Note: Arrow points to *next* instruction.

- ❖ A **reference** is an alias for another variable
 - *Alias*: another name that is bound to the aliased variable
 - Mutating a reference *is* mutating the aliased variable
 - Introduced in C++ as part of the language

```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int& z = x;  
  
    z += 1;  
    x += 1;  
  
    z = y;  
    z += 1;  
  
    return EXIT_SUCCESS;  
}
```

When we use '&' in a type declaration, it is a reference.

&var still is "address of var"

x	5
----------	---

y	10
----------	----

reference.cc

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```
int main(int argc, char** argv) {
    int x = 5, y = 10;
    int& z = x; // binds the name "z" to x
    z += 1;
    x += 1;

    z = y;
    z += 1;

    return EXIT_SUCCESS;
}
```

x, z	5
-------------	---

y	10
----------	----

reference.cc

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```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int& z = x; // binds the name "z" to x  
  
    z += 1; // sets z (and x) to 6  
    x += 1;  
  
    z = y;  
    z += 1;  
  
    return EXIT_SUCCESS;  
}
```

x, z	6
-------------	----------

y	10
----------	----

reference.cc

References

Note: Arrow points to *next* instruction.

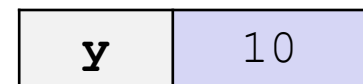
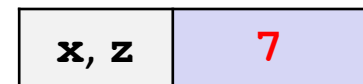
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```
int main(int argc, char** argv) {
    int x = 5, y = 10;
    int& z = x; // binds the name "z" to x

    z += 1; // sets z (and x) to 6
    x += 1; // sets x (and z) to 7

    → z = y; // Normal assignment
    z += 1;

    return EXIT_SUCCESS;
}
```



reference.cc

References

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```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int& z = x; // binds the name "z" to x  
  
    z += 1; // sets z (and x) to 6  
    x += 1; // sets x (and z) to 7  
  
    z = y; // sets z (and x) to the value of y  
    z += 1;  
  
    return EXIT_SUCCESS;  
}
```

x, z	10
-------------	-----------

y	10
----------	----

reference.cc

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```
int main(int argc, char** argv) {
    int x = 5, y = 10;
    int& z = x; // binds the name "z" to x

    z += 1; // sets z (and x) to 6
    x += 1; // sets x (and z) to 7

    z = y; // sets z (and x) to the value of y
    z += 1; // sets z (and x) to 11

    return EXIT_SUCCESS;
}
```

x, z	11
-------------	-----------

y	10
----------	----

reference.cc

Pass-By-Reference

Note: Arrow points to *next* instruction.

- ❖ C++ allows you to use real *pass-by-reference*
 - Client passes in an argument with normal syntax
 - Function uses reference parameters with normal syntax
 - Modifying a reference parameter modifies the caller's argument!

```
void swap(int& x, int& y) {  
    int tmp = x;  
    x = y;  
    y = tmp;  
}  
  
int main(int argc, char** argv) {  
    int a = 5, b = 10;  
    swap(a, b);  
    cout << "a: " << a << "; b: " << b << endl;  
    return EXIT_SUCCESS;  
}
```

Parameters are attached
To variables provided by caller

(main) a	5
-----------------	---

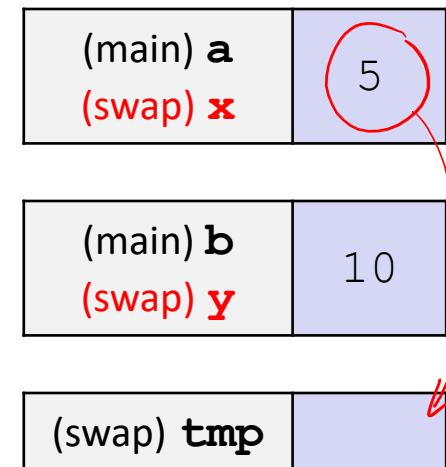
(main) b	10
-----------------	----

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→ int tmp = x;  
  x = y;  
  y = tmp;  
}  
  
int main(int argc, char** argv) {  
  int a = 5, b = 10;  
  
  swap(a, b);  
  cout << "a: " << a << "; b: " << b << endl;  
  return EXIT_SUCCESS;  
}
```

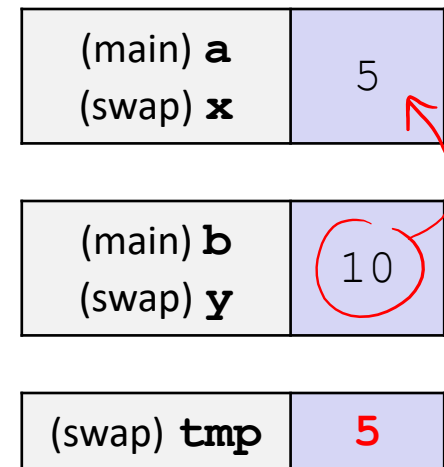


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void swap(int& x, int& y) {  
    int tmp = x;  
    x = y;  
    y = tmp;  
}  
  
int main(int argc, char** argv) {  
    int a = 5, b = 10;  
  
    swap(a, b);  
    cout << "a: " << a << "; b: " << b << endl;  
    return EXIT_SUCCESS;  
}
```



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void swap(int& x, int& y) {  
    int tmp = x;  
    x = y;  
    y = tmp;  
}  
  
int main(int argc, char** argv) {  
    int a = 5, b = 10;  
  
    swap(a, b);  
    cout << "a: " << a << "; b: " << b << endl;  
    return EXIT_SUCCESS;  
}
```

(main) a	10
(swap) x	10

(main) b	10
(swap) y	10


(swap) tmp	5
-------------------	---

Pass-By-Reference

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void swap(int& x, int& y) {  
    int tmp = x;  
    x = y;  
    y = tmp;  
}  
  
int main(int argc, char** argv) {  
    int a = 5, b = 10;  
  
    swap(a, b);  
    cout << "a: " << a << "; b: " << b << endl;  
    return EXIT_SUCCESS;  
}
```



(main) a	10
(swap) x	

(main) b	5
(swap) y	

(swap) tmp	5
-------------------	---

Pass-By-Reference

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 - Modifying a reference parameter modifies the caller's argument!

```
void swap(int& x, int& y) {  
    int tmp = x;  
    x = y;  
    y = tmp;  
}  
  
int main(int argc, char** argv) {  
    int a = 5, b = 10;  
  
    swap(a, b);  
    cout << "a: " << a << "; b: " << b << endl;  
    return EXIT_SUCCESS;  
}
```

(main) a	10
-----------------	----

(main) b	5
-----------------	---

 **Poll Everywhere**pollev.com/cse333

❖ What will happen when we run this?

- A. Output "(1,2,3)"
- B. Output "(3,2,3)"
- C. Compiler error about arguments to foo (in main)
- D. Compiler error about body of foo
- E. We're lost...

poll1.cc

```
void foo(int& x, int* y, int z) {  
    z = *y;  
    x += 2;  
    y = &x;  
}  
  
int main(int argc, char** argv) {  
    int a = 1;  
    int b = 2;  
    int& c = a;  
  
    foo(a, &b, c);  
    std::cout << "(" << a << ", " << b  
        << ", " << c << ")" << std::endl;  
  
    return EXIT_SUCCESS;  
}
```

Poll Everywhere

pollev.com/cse333

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    z = *y;
    x += 2;
    y = &x;
}

int main(int argc, char** argv) {
    int a = 1;
    int b = 2;
    int& c = a;

    →foo(a, &b, c);
    std::cout << "(" << a << ", " << b
              << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}
```

a, c	1
------	---

b	2
---	---

Poll Everywhere

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```
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→ z = *y;
  x += 2;
  y = &x;
}

int main(int argc, char** argv) {
  int a = 1;
  int b = 2;
  int& c = a;

  foo(a, &b, c);
  std::cout << "(" << a << ", " << b
    << ", " << c << ")" << std::endl;

  return EXIT_SUCCESS;
}
```

y	
---	--

z	1
---	---

(main) a, c (foo) x	1
------------------------	---

b	2
---	---

Poll Everywhere

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poll1.cc

```

void foo(int& x, int* y, int z) {
    z = *y;
    → x += 2;
    y = &x;
}

int main(int argc, char** argv) {
    int a = 1;
    int b = 2;
    int& c = a;

    foo(a, &b, c);
    std::cout << "(" << a << ", " << b
    << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}

```

y	
z	2

(main) a, c (foo) x	1
------------------------	---

b	2
---	---

Poll Everywhere

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poll1.cc

```

void foo(int& x, int* y, int z) {
    z = *y;
    x += 2;
    → y = &x;
}

int main(int argc, char** argv) {
    int a = 1;
    int b = 2;
    int& c = a;

    foo(a, &b, c);
    std::cout << "(" << a << ", " << b
              << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}

```

y	
---	--

z	2
---	---

(main) a, c (foo) x	3
------------------------	---

b	2
---	---

Poll Everywhere

pollev.com/cse333

❖ What will happen when we run this?

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poll1.cc

```

void foo(int& x, int* y, int z) {
    z = *y;
    x += 2;
    y = &x;
}

int main(int argc, char** argv) {
    int a = 1;
    int b = 2;
    int& c = a;

    foo(a, &b, c);
    std::cout << "(" << a << ", " << b
    << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}

```

The diagram illustrates the memory layout for the variables in the code. It consists of several boxes representing memory cells:

- A box with 'y' and an empty cell next to it.
- A box with 'z' and a cell containing '2'.
- A box with '(main) a, c' and '(foo) x' and a cell containing '3'.
- A box with 'b' and a cell containing '2'.

A red arrow points from the empty cell next to 'y' to the cell containing '3'.

Poll Everywhere

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- E. We're lost...

poll1.cc

```
void foo(int& x, int* y, int z) {
    z = *y;
    x += 2;
    y = &x;
}

int main(int argc, char** argv) {
    int a = 1;
    int b = 2;
    int& c = a;

    foo(a, &b, c);
    → std::cout << "(" << a << ", " << b
       << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}
```

a, c	3
------	---

b	2
---	---

Lecture Outline

- ❖ C++ References
- ❖ **const in C++**
- ❖ C++ Classes Intro

const

- ❖ `const`: this cannot be changed/mutated
 - Used *much* more in C++ than in C
 - ★ Signal of intent to compiler; meaningless at hardware level
 - Results in compile-time errors

```
void BrokenPrintSquare(const int& i) {  
    i = i*i; // compiler error here!  
    std::cout << i << std::endl;  
}  
  
int main(int argc, char** argv) {  
    int j = 2;  
    BrokenPrintSquare(j);  
    return EXIT_SUCCESS;  
}
```

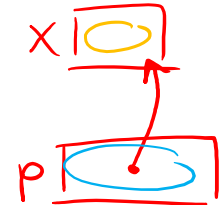
brokenpassbyrefconst.cc

const and Pointers

❖ Pointers can change data in two different contexts:

1) You can change the value of the pointer

```
int x;
int *p = &x;
```



2) You can change the thing the pointer points to
(via dereference)

❖ `const` can be used to prevent either/both of these behaviors!

■ `const` next to pointer name means you can't change the value of the pointer

```
int *const p;
```

■ `const` next to data type pointed to means you can't use this pointer to change the thing being pointed to

```
const int *p;
```

■ Tip: read variable declaration from *right-to-left*

const and Pointers

Voting (raise hand for yes):

 Compiles

yes

 Compiler error

no

❖ The syntax with pointers is confusing:

```
int main(int argc, char** argv) {
    int x = 5;           // int
    const int y = 6;    // (const int)
    ❌ y++;

    const int *z = &y; // pointer to a (const int)
    ❌ *z += 1;
    ✅ z++;

    int *const w = &x; // (const pointer) to a (variable int)
    ✅ *w += 1;
    ❌ w++;

    const int *const v = &x; // (const pointer) to a (const int)
    ❌ *v += 1;
    ❌ v++;

    return EXIT_SUCCESS;
}
```

const and Pointers

- ❖ The syntax with pointers is confusing:

```
int main(int argc, char** argv) {
    int x = 5;           // int
    const int y = 6;    // (const int)
    y++;                // compiler error

    const int *z = &y;  // pointer to a (const int)
    *z += 1;           // compiler error
    z++;               // ok

    int *const w = &x;  // (const pointer) to a (variable int)
    *w += 1;           // ok
    w++;               // compiler error

    const int *const v = &x; // (const pointer) to a (const int)
    *v += 1;           // compiler error
    v++;               // compiler error

    return EXIT_SUCCESS;
}
```



const Parameters

Make parameters const when you can

- ❖ A const parameter *cannot* be mutated inside the function
 - Therefore it does not matter if the argument can be mutated or not
- ❖ A non-const parameter *may* be mutated inside the function
 - Compiler won't let you pass in const parameters

```
void foo(const int* y) {
    std::cout << *y << std::endl;
}

void bar(int* y) {
    std::cout << *y << std::endl;
}

int main(int argc, char** argv) {
    const int a = 10;
    int b = 20;

    foo(&a);    // OK
    foo(&b);    // OK
    bar(&a);    // not OK - error
    bar(&b);    // OK

    return EXIT_SUCCESS;
}
```

 **Poll Everywhere**pollev.com/cse333

❖ What will happen when we try to compile and run?

poll2.cc

- A. Output "(2, 4, 0)"
- B. Output "(2, 4, 3)"
- C. Compiler error about arguments to foo (in main)
- D. Compiler error about body of foo
- E. We're lost...

```
void foo(int* const x,
         int& y, int z) {
    *x += 1;
    y *= 2;
    z -= 3;
}

int main(int argc, char** argv) {
    const int a = 1;
    int b = 2, c = 3;

    foo(&a, b, c);
    std::cout << "(" << a << ", " << b
              << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}
```

Poll Everywhere

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❖ What will happen when we try to compile and run?

*Can't modify the x, but can
modify *x (dereference) poll2.cc*

A. Output "(2, 4, 0)"

B. Output "(2, 4, 3)"

C. Compiler error
about arguments
to foo (in main)

D. Compiler error
about body of foo

E. We're lost...

```

void foo(int* const x,
Int ref → int& y, int z) {
    *x += 1;
    y *= 2;
    z -= 3;
}

int main(int argc, char** argv) {
    const int a = 1;
    int b = 2, c = 3;
    foo(&a, b, c);
    std::cout << "(" << a << ", " << b
    << ", " << c << ")" << std::endl;

    return EXIT_SUCCESS;
}

```

Allowed (pointing to `*x += 1;`)

Copy of int value (pointing to `int z`)

Allowed, but change doesn't persist out (pointing to `z -= 3;`)

Const mismatch (pointing to `foo(&a, b, c);`)



When to Use References?

- ❖ A stylistic choice, not mandated by the C++ language
- ❖ Google C++ style guide suggests:
 - Input parameters:
 - Either use values (for primitive types like `int` or small structs/objects) *↓ Avoid making unnecessary copies*
 - Or use `const` references (for complex struct/object instances)
 - Output parameters: *To make sure we don't change in function also allows const & non-const arguments*
 - Use `const` pointers
 - Unchangeable pointers referencing changeable data
 - Ordering:
 - List input parameters first, then output parameters last

```
void CalcArea(const int& width, const int& height,
              int* const area) {
    *area = width * height;
}
```

styleguide.cc

Lecture Outline

- ❖ C++ References
- ❖ `const` in C++
- ❖ **C++ Classes Intro**

Classes

❖ Class definition syntax (in a .h file):

```
class Name {  
    public:  
        // public member definitions & declarations go here  
  
    private:  
        // private member definitions & declarations go here  
}; // class Name
```

don't forget!

- Members can be functions (methods) or data (variables)

❖ Class member function definition syntax (in a .cc file):

```
retType Name::MethodName(type1 param1, ..., typeN paramN) {  
    // body statements  
}
```

- (1) *define* within the class definition or (2) *declare* within the class definition and then *define* elsewhere

Class Organization

- ❖ It's a little more complex than in C when modularizing with `struct` definition:
 - Class definition is part of interface and should go in `.h` file
 - Private members still must be included in definition (!)
 - Usually put member function definitions into companion `.cc` file with implementation details
 - Common exception: setter and getter methods
 - These files can also include **non-member functions** that use the class
- ❖ Unlike Java, you can name files anything you want
 - Typically `Name.cc` and `Name.h` for **class** `Name`

Const & Classes

- ❖ Like other data types, objects can be declared as const:
 - Once a const object has been constructed, it's member variables can't be changed.
 - Can only invoke member functions that are labeled const
- ❖ You can declare a member function of a class as const
 - If a member function doesn't modify the object, mark it const
 - Compiler will treat member variables as const inside the function, and check you don't manipulate the member variables at compile time

Class Definition (.h file)



Point.h

```

#ifndef POINT_H_
#define POINT_H_

class Point {
public:
    Point(const int x, const int y);           // constructor
    int get_x() const { return x_; }          // inline member function
    int get_y() const { return y_; }          // inline member function
    double Distance(const Point& p) const;    // member function
    void SetLocation(const int x, const int y); // member function

private:
    int x_; // data member
    int y_; // data member
}; // class Point

#endif // POINT_H_

```

const means the object we are calling on, can't be changed

Inline definition ok for simple getters/setters

Declarations

Google C++ naming conventions for data members

Class Member Definitions (.cc file)

Point.cc

```
#include <cmath>
#include "Point.h"
```

This code uses bad style for demonstration purposes

```
Point::Point(const int x, const int y) {
    x_ = x;
    this->y_ = y; // "this->" is optional unless name conflicts
}
```

Equivalent to `y_=y;`

"this" is a `Point* const`

Can't modify the "this" object inside the function

```
double Point::Distance(const Point& p) const {
    // We can access p's x_ and y_ variables either through the
    // get_x(), get_y() accessor functions or the x_, y_ private
    // member variables directly, since we're in a member
    // function of the same class.
```

```
    double distance = (x_ - p.get_x()) * (x_ - p.get_x());
    distance += (y_ - p.y_) * (y_ - p.y_);
    return sqrt(distance);
}
```

We have access to `x_`, could have used `x_` instead.

`const` won't affect caller, but good style

```
void Point::SetLocation(const int x, const int y) {
    x_ = x;
    y_ = y;
}
```

Can't be `const`. We have to mutate the `Point`

Class Usage (.cc file)

usepoint.cc

```
#include <iostream>
#include "Point.h"

using namespace std;

int main(int argc, char** argv) {
    Point p1(1, 2); // allocate a new Point on the Stack
    Point p2(4, 6); // allocate a new Point on the Stack

    cout << "p1 is: (" << p1.get_x() << ", ";
    cout << p1.get_y() << ")" << endl;

    cout << "p2 is: (" << p2.get_x() << ", ";
    cout << p2.get_y() << ")" << endl;

    cout << "dist : " << p1.Distance(p2) << endl;
    return 0;
}
```

Calls constructor to define an object on the stack. (no "new" keyword)

Dot notation to call function (like java)

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❖ What will happen when we try to compile and run?

poll3.cc

- A. Output "1"
- B. Output "351"
- C. Compiler error about violating const-ness of i (in main)
- D. Compiler error about one of the member functions
- E. We're lost...

```
class Integer {
public:
    Integer(int x) { x_ = x; }
    int GetValue() const { return x_; }
    void SetValue(int x) const { x_ = x; }
private:
    int x_;
};

int main(int argc, char** argv) {
    const Integer i(1);
    i.SetValue(i.GetValue() + 350);
    std::cout << i.GetValue() << std::endl;

    return EXIT_SUCCESS;
}
```

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❖ What will happen when we try to compile and run?

poll3.cc

- A. Output "1"
- B. Output "351"
- C. Compiler error about violating const-ness of i (in main)
- D. Compiler error about one of the member functions
- E. We're lost...

```
class Integer {
public:
    Integer(int x) { x_ = x; }
    int GetValue() const { return x_; }
    void SetValue(int x) const { x_ = x; }
private:
    int x_;
};

int main(int argc, char** argv) {
    const Integer i(1);
    i.SetValue(i.GetValue() + 350);
    std::cout << i.GetValue() << std::endl;

    return EXIT_SUCCESS;
}
```

 **Poll Everywhere**pollev.com/cse333

❖ What will happen when we try to compile and run?

poll3.cc

- A. Output "1"
- B. Output "351"
- C. Compiler error about violating const-ness of i (in main)
- D. Compiler error about one of the member functions
- E. We're lost...

```
class Integer {
public:
    Integer(int x) { x_ = x; }
    int GetValue() const { return x_; }
    void SetValue(int x) const { x_ = x; }
private:
    int x_;
};

int main(int argc, char** argv) {
    const Integer i(1);
    i.SetValue(i.GetValue() + 350);
    std::cout << i.GetValue() << std::endl;

    return EXIT_SUCCESS;
}
```

How to fix this?

Reading Assignment

- ❖ Before next time, *read* the sections in *C++ Primer* covering class constructors, copy constructors, assignment (`operator=`), and destructors
 - Ignore “move semantics” for now
 - The table of contents and index are your friends...

Extra Exercise #1

- ❖ Write a C++ program that:
 - Has a class representing a 3-dimensional point
 - Has the following methods:
 - Return the inner product of two 3D points
 - Return the distance between two 3D points
 - Accessors and mutators for the x , y , and z coordinates

Extra Exercise #2

- ❖ Write a C++ program that:
 - Has a class representing a 3-dimensional box
 - Use your Extra Exercise #1 class to store the coordinates of the vertices that define the box
 - Assume the box has right-angles only and its faces are parallel to the axes, so you only need 2 vertices to define it
 - Has the following methods:
 - Test if one box is inside another box
 - Return the volume of a box
 - Handles `<<`, `=`, and a copy constructor
 - Uses `const` in all the right places