C++ References, Const, Classes
CSE 333 Fall 2023

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Teaching Assistants:

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Relevant Course Information (1/2)

- Exercise 4 due Wednesday by 10pm
  - Hardest exercise (Rating: 5)
- Exercise 5 due Thursday by 10 pm
  - “Lighter” exercise in C++ (Rating: 1)

- Homework 2 due October 30 by 10pm
  - 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
Relevant Course Information (2/2)

- Midterm information via Ed post tomorrow
  - Covers scope, format, sample midterms (if applicable)
  - Poll for interest on brief review session
    - If sufficient interest session will be held Monday, October 23rd @ 8pm on Zoom.
Lecture Outline

- C++ References
- `const` in C++
- C++ Classes Intro
Pointers Reminder

- 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++

```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;
}
```

Note: Arrow points to next instruction.
Pointers Reminder

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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;
}
```

```c
x | 5
y | 10
z | 0x7fff...a4
```

Note: Arrow points to *next* instruction.
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  - These work the same in C and C++

```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;
}
```

Note: Arrow points to next instruction.
Pointers Reminder

- 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++

```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;
}
```

Note: Arrow points to *next* instruction.
Pointers Reminder

- **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++

```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;

    return EXIT_SUCCESS;
}
```

**Note:** Arrow points to next instruction.
Points Remark

- **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++

```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;
}
```

Note: Arrow points to `next` instruction.
References

- 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

```c
#include <iostream>

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;
}
```

Note: Arrow points to next instruction.
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```cpp
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;
}
```

Note: Arrow points to next instruction.
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```cpp
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
```

Note: Arrow points to *next* instruction.
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```cpp
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;
}
```

**Note**: Arrow points to next instruction.

```
A **reference** is an alias for another variable

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```c
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;
}
```

**Note**: Arrow points to *next* instruction.
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    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;
}
```

**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!

```cpp
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;
}
```

Note: Arrow points to next instruction.
Pass-By-Reference

- 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!

```cpp
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;
}
```

Note: Arrow points to next instruction.
Pass-By-Reference

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```cpp
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;
}
```

**Note:** Arrow points to next instruction.
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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;
}
```

Note: Arrow points to next instruction.
Pass-By-Reference

- 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!

```cpp
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;
}
```

Note: Arrow points to next instruction.
Pass-By-Reference

- C++ allows you to use real **pass-by-reference**
  - Client passes in an argument with normal syntax
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```cpp
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;
}
```

Note: Arrow points to next instruction.
What will happen when we try to compile and run this code?

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…

```
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;
}
```
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

```cpp
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
  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
  - const next to data type pointed to means you can’t use this pointer to change the thing being pointed to
  - Tip: read variable declaration from right-to-left
const and Pointers

- The syntax with pointers is confusing:

```c
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:

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

- 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

```cpp
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;
}
```

Make parameters const when you can!
What will happen when we try to compile and run this code?

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...

```c
void Foo(int* const x,
         int ref y, int z) {
    *x += 1; // allowed
    y *= 2; // allowed
    z -= 3; // allowed, but has no lasting effect
}

int main(int argc, char** argv) {
    const int a = 1;
    int b = 2, c = 3;
    //X Foo(&a, b, c);
    std::cout << "(" << a << "", " << b << "," << c << ")" << std::endl;
    return EXIT_SUCCESS;
}
```
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)
    - Or use `const` references (for complex struct/object instances)
  - Output parameters:
    - Use `const` pointers
      - Unchangeable pointers referencing changeable data
  - Ordering:
    - List input parameters first, then output parameters last

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

❖ 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, its 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**
  - This means that it cannot modify the object it was called on
    - The compiler will treat member variables as **const** inside the function at compile time
  - If a member function doesn’t modify the object, mark it **const**!
Class Definition (.h file)

```cpp
#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 that this function is not allowed to change the object on which it is called (the implicit "this" pointer).
- Function definitions.
- Compiler may choose to expand inline (like a macro) instead of an actual function call.
- Naming convention for class data members (Google C++ style guide).
#include <cmath>
#include "Point.h"

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

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);
}

void Point::SetLocation(const int x, const int y) {
  x_ = x;
  Y_ = y;
}
Class Usage (.cc file)

```cpp
#include <iostream>
#include <cstdlib>
#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 EXIT_SUCCESS;
}
```

usepoint.cc
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...