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About how long did Exercises 7 and 8 take you? (two polls)

- A. [0, 2) hours
- B. [2, 4) hours
- C. [4, 6) hours
- D. [6, 8) hours
- E. 8+ Hours
- F. I didn't submit / I prefer not to say

Systems Programming

C++ References, Const, Classes

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Relevant Course Information

- ❖ No exercise released with today's lecture
 - Ex 9 will be more difficult (Rating: 4)
 - Builds on concepts from both Wed and Fri's lecture
- ❖ Homework 2 due a week from Thursday (2/5)
 - [Partner declaration form](#) due tomorrow night
 - 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 (1/3)

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

Pointers Reminder (1/6)

Note: Arrow points to *next* instruction.

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify the variable 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;  
}
```

x	5
---	---

y	10
---	----

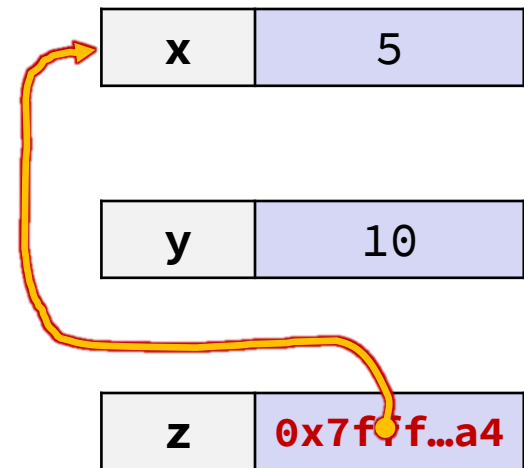
z	
---	--

pointer.cc

Pointers Reminder (2/6)

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify the variable 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;  
}
```

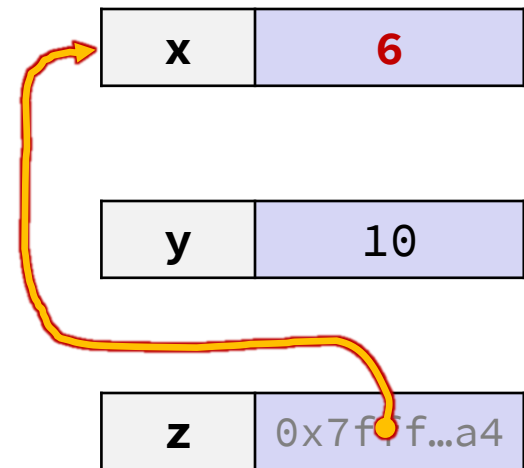


pointer.cc

Pointers Reminder (3/6)

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify the variable 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;  
  
    z = &y;  
    *z += 1;  
  
    return EXIT_SUCCESS;  
}
```

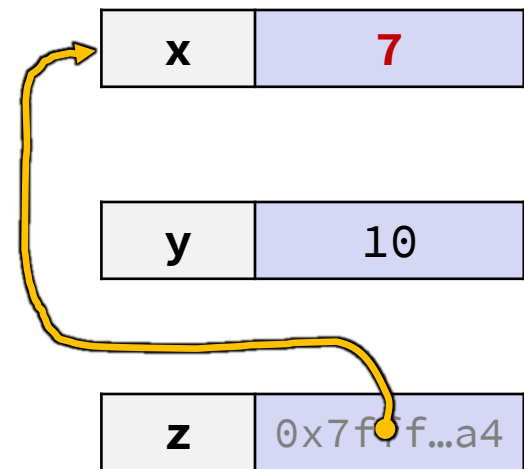


pointer.cc

Pointers Reminder (4/6)

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify the variable 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;  
    *z += 1;  
  
    return EXIT_SUCCESS;  
}
```

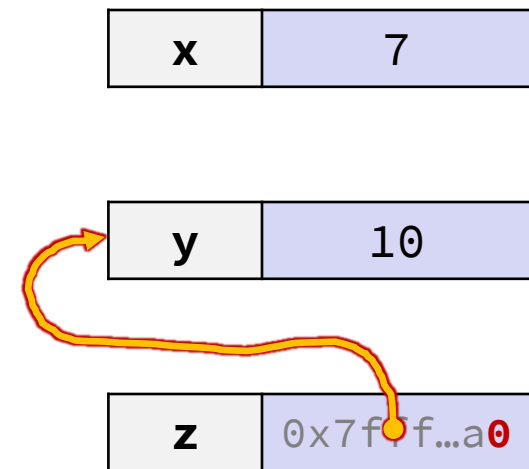


pointer.cc

Pointers Reminder (5/6)

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify the variable 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;  
  
    return EXIT_SUCCESS;  
}
```

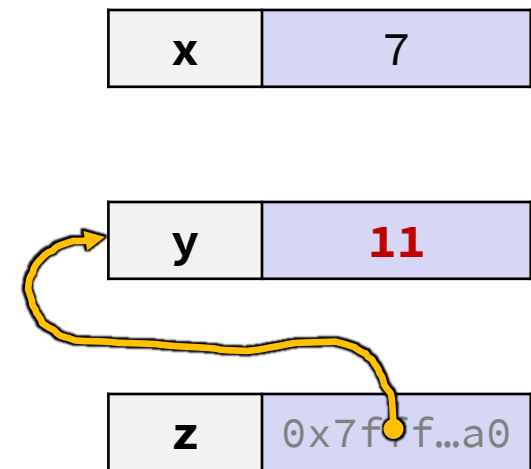


pointer.cc

Pointers Reminder (6/6)

- ❖ A **pointer** is a variable containing an address
 - Modifying the pointer *doesn't* modify the variable 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 (1/6)

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;  
}
```

x	5
---	---

y	10
---	----

reference.cc

References (2/6)

- ❖ 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; // binds the name "z" to x  
    z += 1;  
    x += 1;  
  
    z = y;  
    z += 1;  
  
    return EXIT_SUCCESS;  
}
```

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

y	10
---	----

reference.cc

References (3/6)

- ❖ 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; // 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 (4/6)

- ❖ 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; // binds the name "z" to x  
  
    z += 1; // sets z (and x) to 6  
    x += 1; // sets x (and z) to 7  
  
    → z = y;  
    z += 1;  
  
    return EXIT_SUCCESS;  
}
```

x, z	7
------	---

y	10
---	----

reference.cc

References (5/6)

- ❖ 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; // 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

References (6/6)

- ❖ 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; // 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 (1/6)

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;  
}
```

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

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

Pass-By-Reference (2/6)

- ❖ 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;  
}
```

(main) a (Swap) x	5
------------------------------------	---

(main) b (Swap) y	10
------------------------------------	----

(Swap) tmp	
-------------------	--

Pass-By-Reference (3/6)

- ❖ 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;  
}
```

(main) a	5
(Swap) x	

(main) b	10
(Swap) y	

(Swap) tmp	5
-------------------	---

Pass-By-Reference (4/6)

- ❖ 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;  
}
```

(main) a	10
(Swap) x	


(main) b	10
(Swap) y	

(Swap) tmp	5
-------------------	---

Pass-By-Reference (5/6)

- ❖ 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;  
}
```



(main) a	10
(Swap) x	

(main) b	5
(Swap) y	

(Swap) tmp	5
-------------------	---

Pass-By-Reference (6/6)

- ❖ 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;  
}
```

(main) **a**

10

(main) **b**

5

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What will happen when we try to compile and run this code?

poll1.cc

- 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 (2/3)

- ❖ 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
(i.e., address stored)
 - 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 Examples

❖ 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 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;
}
```

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What will happen when we try to compile and run this code?

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;
}
```



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

```
size_t StringBefore(const string& input, const string& search,
                    string* const result) {
    *result = input.substr(0, input.find(search));
    return input.find(search);
}
```

Lecture Outline (3/3)

- ❖ 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
```

- 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 **c**lass **N**ame

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)



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_
```

Class Member Definitions (.cc file)

Point.cc

```
#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)

usepoint.cc

```
#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;
}
```

Reading Assignment

- ❖ Before next time, *read* the sections in *C++ Primer* covering class constructors, copy constructors, assignment (operator=), and destructors
 - Free link for UW students to the [relevant section \(§13.1.1\)](#)
 - Click “Read now” and scroll down to “ Academic user?”
 - Ignore “move semantics” for now
 - The table of contents and index are your friends...