Poll Everywhere

pollev.com/cse333

About how long did Exercise 4 take you?

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

C++ References, Const, Classes

CSE 333 Summer 2023

Instructor: Timmy Yang

Teaching Assistants:

Jennifer Xu Leanna Nguyen Pedro Amarante

Sara Deutscher Tanmay Shah

Relevant Course Information (1/2)

- Exercise 5 due Wednesday @ 1 pm
  - "Lighter" exercise in C++ (Rating: 1)

- Homework 2 due a week from Thursday (7/20)
  - Partner sign up due Thursday night (see Ed post #116)
  - 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)

- Quiz 1 released today @ 2pm (7/10)
  - Will be administered on Gradescope, closes Wednesday (7/12) @ 11:59pm
    - Quiz should take 45-30 min to complete (i.e., meant to be short).
  - Please keep all Quiz questions on Ed private
    - If anything is frequently asked, we'll make a separate announcement.
  - Questions about the Quiz in Office Hours can only be clarification questions.
    - TAs may ask you to post on the Ed board instead of answering directly.
  - Academic Conduct Policy applies to all Quizzes as well
    - Please don't copy other's work, do not use Chat-GPT
    - https://courses.cs.washington.edu/courses/cse333/23su/quizzes/

Lecture Outline

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

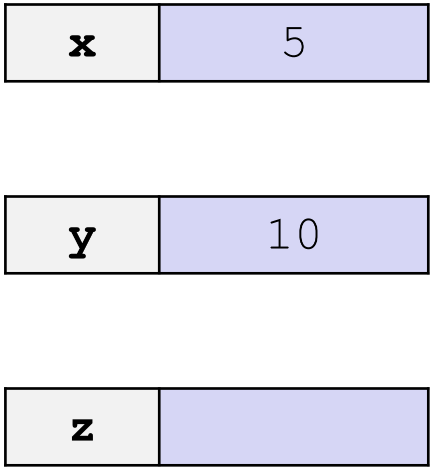
Pointers Reminder

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



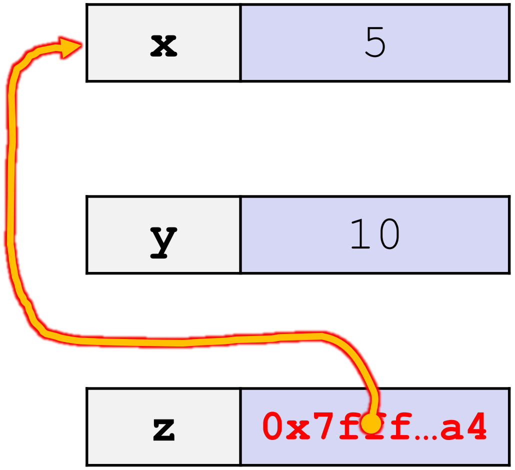
Pointers Reminder

Note: Arrow points to *next* instruction.

- 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



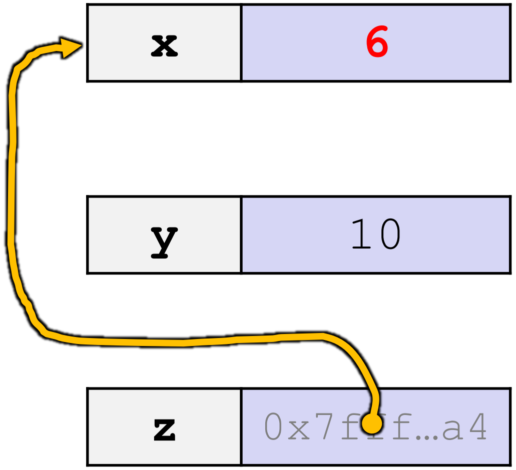
Pointers Reminder

Note: Arrow points to *next* instruction.

- 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;

   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```

pointer.cc

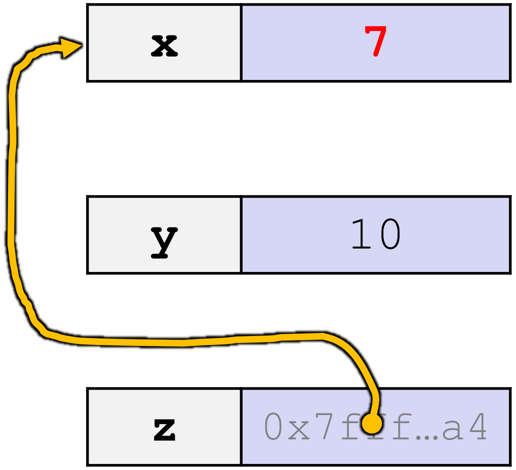


Pointers Reminder

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;
  *z += 1;

  return EXIT_SUCCESS;
}
```



pointer.cc

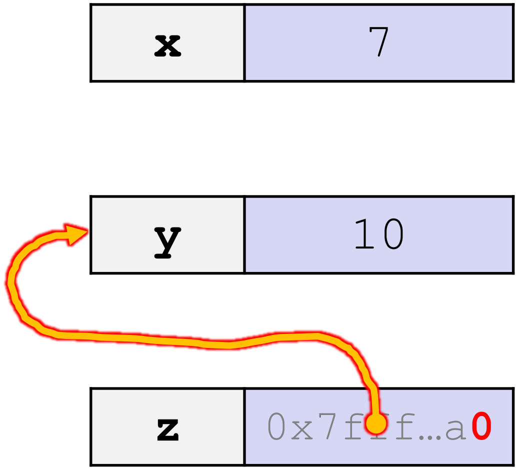
Pointers Reminder

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;

  return EXIT_SUCCESS;
}
```

pointer.cc

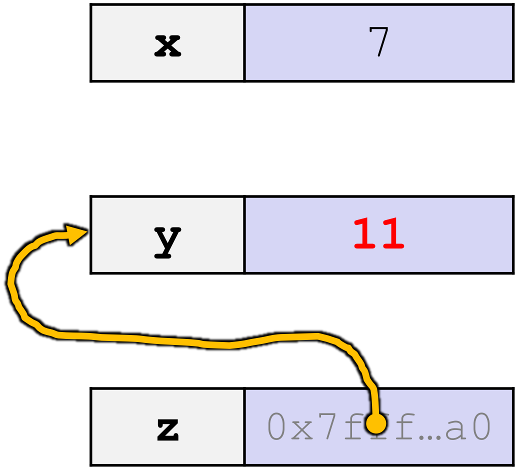


Pointers Reminder

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;
}
```



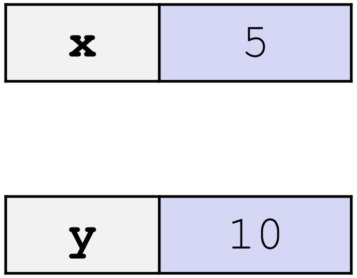
pointer.cc

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

```
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;
}
```



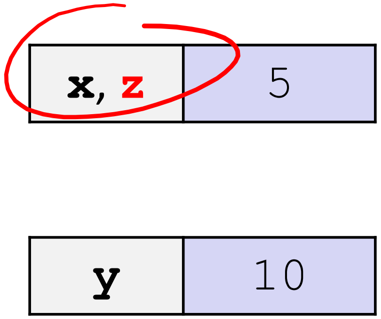
reference.cc

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;   // 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

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;  // 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

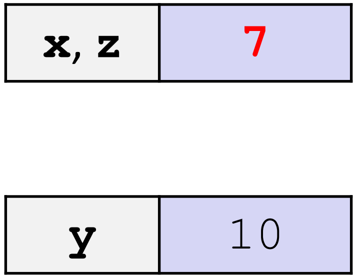
reference.cc

References

Note: Arrow points to *next* instruction.

- 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

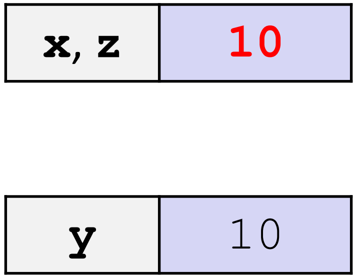
reference.cc

References

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;  // 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;
}
```



reference.cc

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

```
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

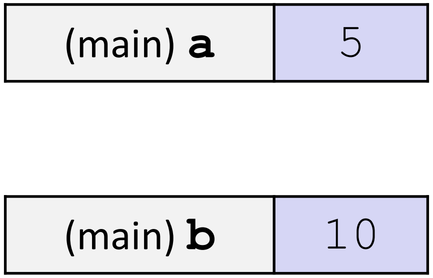
reference.cc

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;
}
```



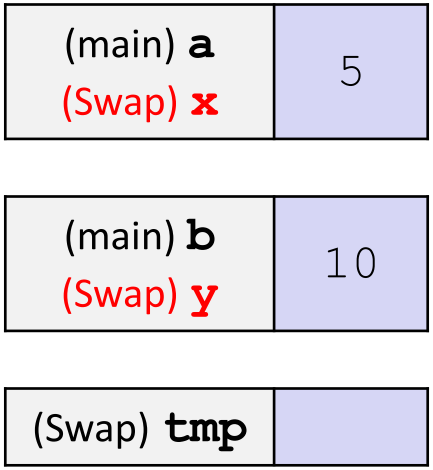
passbyreference.cc

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;
}
```



(main) **a** (Swap) **x** 5

(main) **b** (Swap) **y** 10

(Swap) **tmp**

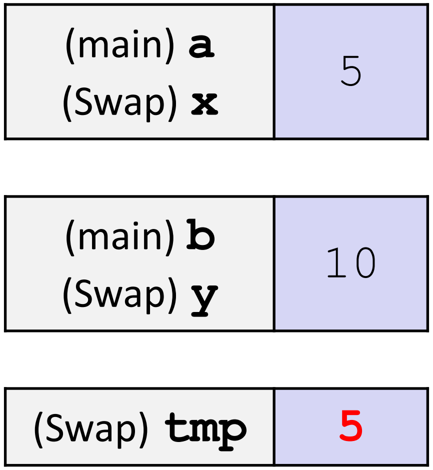
passbyreference.cc

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;
}
```



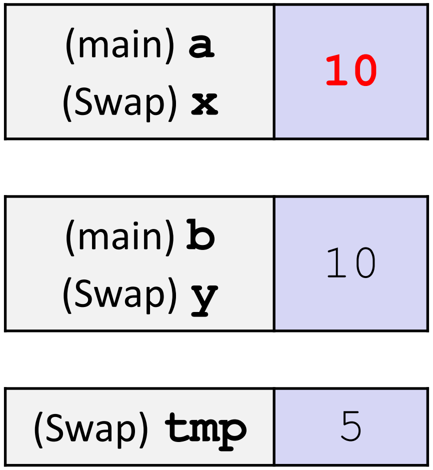
passbyreference.cc

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;
}
```



(main) **a** (Swap) **x**	**10**
(main) **b** (Swap) **y**	10
(Swap) **tmp**	5

passbyreference.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;
}
```

(main) **a** (Swap) **x**	10
(main) **b** (Swap) **y**	**5**
(Swap) **tmp**	5

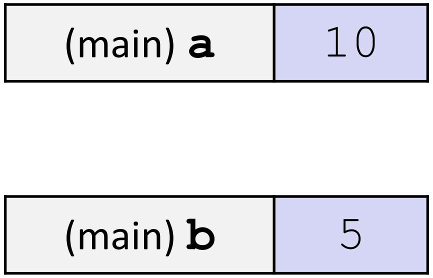
passbyreference.cc

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;
}
```



(main) **a**	10
(main) **b**	5

passbyreference.cc

Poll Everywhere

pollev.com/cse333

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

A. Output "(1,2,3)"

[✓ B.] Output "(3,2,3)"

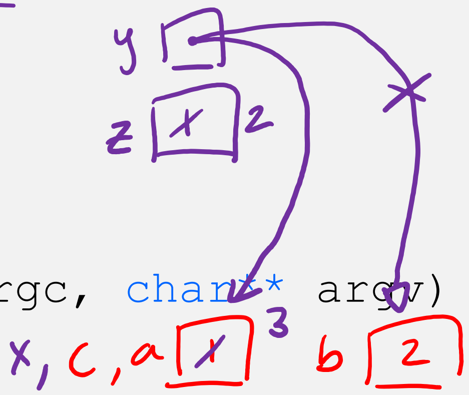
C. Compiler error about arguments to Foo (in main)

D. Compiler error about body of Foo

E. We're lost…

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;
}
```



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

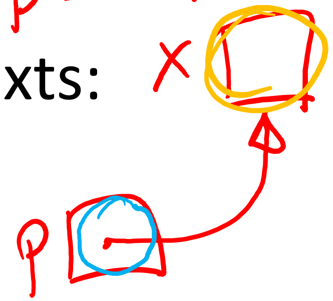
```
void BrokenPrintSquare(const int& i) {
  i = i*i;  // compiler error here!
  std::cout << i << std::endl;
}

int main(int argc, char** argv) {
  int j = 2;
  BrokenPrintSquare(j);
  return EXIT_SUCCESS;
}
```

brokenpassbyrefconst.cc

`const` and Pointers

int x;

int* p = &x;



- Pointers can change data in two different contexts:
  1) You can change the value of the pointer (the address)
  2) You can change the thing the pointer points to (via dereference) e.g. *p = 7;

- `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; X ✓
  - `const` next to data type pointed to means you can't use this pointer to change the thing being pointed to const int* p; ✓ X
  - Tip: read variable declaration from *right-to-left*

`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;                       // error
  z++;                           // ok

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

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

  return EXIT_SUCCESS;
}
```

constmadness.cc

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;
}
```

constmadness.cc

const Parameters

STYLE TIP

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;
      const int *
  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 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;
  const int*
  Foo(&a, b, c);
  std::cout << "(" << a << "," << b
   << "," << c << ")" << std::endl;

  return EXIT_SUCCESS;
}
```

a $\boxed{1}$ b $\boxed{2}$

c $\boxed{3}$

When to Use References?

STYLE TIP

- 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

```
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
```

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

Don't forget!

- 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 if 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)

STYLE TIP

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_
```

not modifying object

underscore after field name common convention

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
}
```

BAD STYLE

Doing things multiple ways is bad style but good for learning

"this" is a pointer to the object

```
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);
}
```

can use getter or directly access fields

```
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
  - Ignore "move semantics" for now
  - The table of contents and index are your friends…