# Poll Everywhere

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## Which concept did you find the most difficult in the context of HW1?

A. Pointers
B. Output parameters
C. Dynamic memory allocation
D. Structs
E. GDB
F. Style considerations
G. Prefer not to say

# C++ References, Const, Classes

## CSE 333 Spring 2023

**Instructor:** Chris Thachuk

**Teaching Assistants:**

| | |
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# Relevant Course Information

- Exercise 4 due next Thursday @ 11 am
  - Hardest exercise (Rating: 5)
- Exercise 5 due next Friday @ 11 am
  - "Lighter" exercise in C++ (Rating: 1)

- Homework 2 due April 27
  - 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

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++

```
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

| | |
|---|---|
| **x** | 5 |
| **y** | 10 |
| **z** | |

# Pointers Reminder

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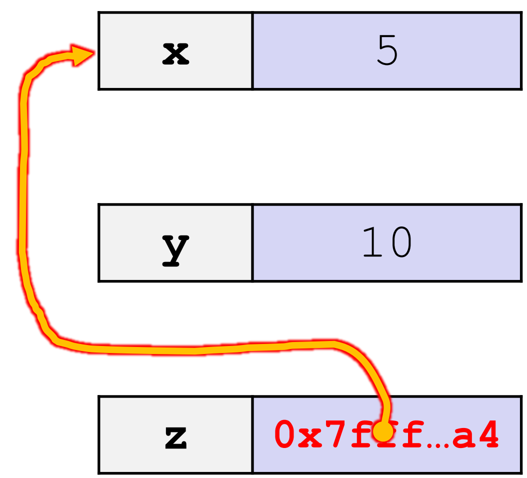
```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int* z = &x;

  *z += 1;
   x += 1;

   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```




pointer.cc

Note: Arrow points to *next* instruction.

# Pointers Reminder

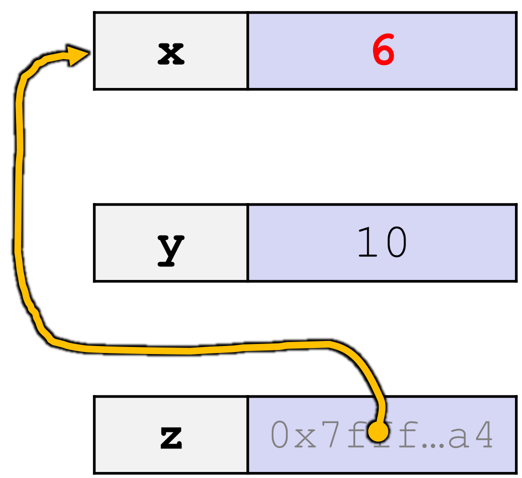
- A **pointer** is a variable containing an address
  - Modifying the pointer *doesn't* modify what it points to, but you can access/modify what it points to by *dereferencing*
  - These work the same in C and C++

```
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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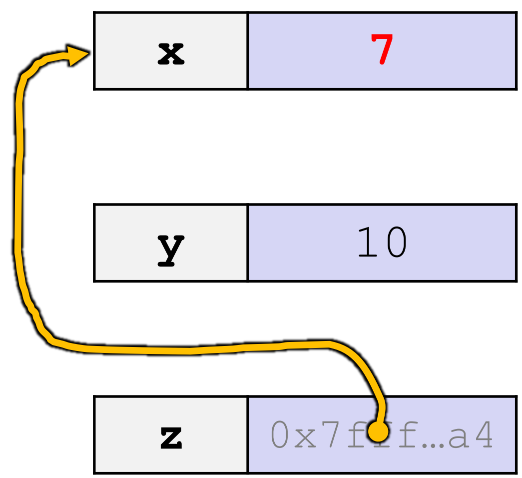
  - These work the same in C and C++

```
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

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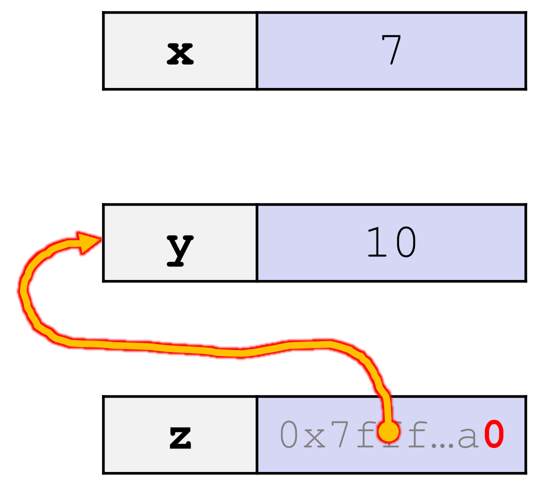
```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int* z = &x;

  *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

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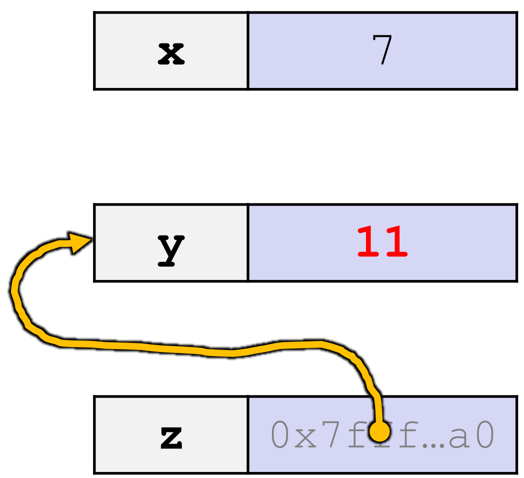
```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int* z = &x;

  *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;   // sets y (and *z) to 11

  return EXIT_SUCCESS;
}
```




pointer.cc

# References

Note: Arrow points to *next* instruction.

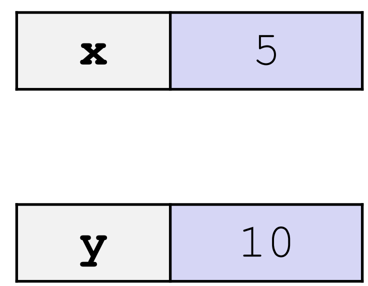
- A **reference** is an alias for another variable
  - *Alias*: another name that is bound to the aliased variable
    - Mutating a reference ***is*** mutating the aliased variable
  - Introduced in C++ as part of the language

```
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;
}
```




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

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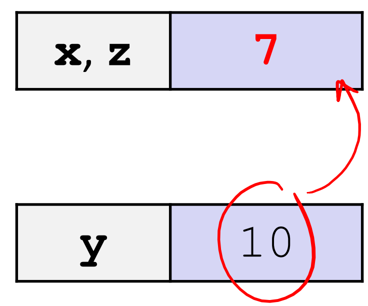
```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int& z = x;  // binds the name "z" to x

  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

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  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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```
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  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;
}
```

aliases that are bound to arguments

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

passbyreference.cc

# Pass-By-Reference

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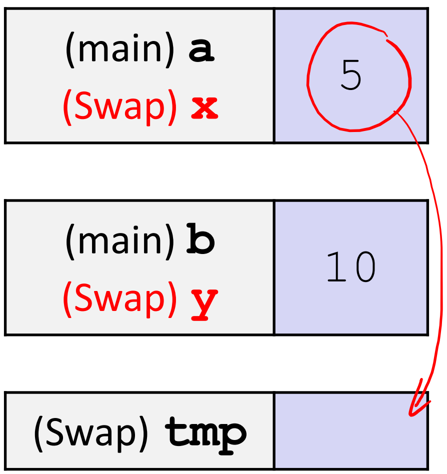
```
void Swap(int& x, int& y) {
  int tmp = x;
  x = y;
  y = tmp;
}

int main(int argc, char** argv) {
  int a = 5, b = 10;

  Swap(a, b);
  cout << "a: " << a << "; b: " << b << endl;
  return EXIT_SUCCESS;
}
```




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**<br>(Swap) **x** | 5 |
| (main) **b**<br>(Swap) **y** | 10 |
| (Swap) **tmp** | **5** |

passbyreference.cc

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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;
}
```

| | |
|---|---|
| (main) **a**<br>(Swap) **x** | **10** |
| (main) **b**<br>(Swap) **y** | 10 |
| (Swap) **tmp** | 5 |

passbyreference.cc

# Pass-By-Reference

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  - 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

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  - 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

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

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. 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...

# 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

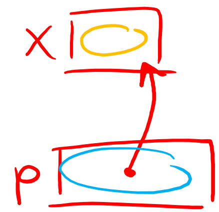
```
void BrokenPrintSquare(const int& i) {
  i = i*i;  // compiler error here!
  std::cout << i << std::endl;
}

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

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




- `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++;

  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;
}
```

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;

  Foo(&a);    // OK
  Foo(&b);    // OK
  Bar(&a);    // not OK - error
  Bar(&b);    // OK

  return EXIT_SUCCESS;
}
```

doesn't actually modify value of y!

# Poll Everywhere

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## 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...

poll2.cc

can't change x, but can change the thing it points to

```
void Foo(int* const x,
         int& 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;

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

  return EXIT_SUCCESS;
}
```

int ref

local copy of int

# 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)

avoid making copy of argument

don't change in function body; allows both const & non-const arguments

  - Output parameters:
    - Use `const` pointers
      - Unchangeable pointers referencing changeable data
  - Ordering:
    - List input parameters first, then output parameters last

output parameter unnecessary for this example, but used for illustration

```
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, 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_
```

this const means that this function is not allowed to change the object on which it is called (the implicit "this" pointer)

function definitions

declarations

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)

# Class Member Definitions (.cc file)

Point.cc

BAD STYLE
used here on purpose

```
#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;
}
```

equivalent to y_ = y;

"this" is a (Point * const)

makes "this" a (const Point * const)

equivalent to p.x_

can't be const because we are mutating "this"

# 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;
}
```

calls defined constructor

"dot notation" used for member functions

# 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…