# C++ References, Const, Classes
## CSE 333

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Zohar Le

Poll Everywhere

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Note: Arrow points to *next* instruction.

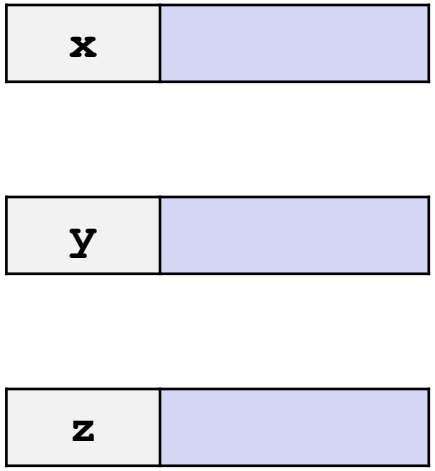
- Draw a box-and-arrow diagram illustrating the state of memory at line 5

```
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

# Administrivia

- Sections this week are HUGE!
  - POSIX I/O
  - C++ references and const (today!)
  - Possibly even C++ classes if we have time 😱😱😱
- Homework 2 due next Wednesday (4/14)
  - Note: `libhw1.a` (yours or ours) needs to be in correct directory (`hw1/`) for hw2 to build
  - Use Ctrl-D (eof) on a line by itself to exit `searchshell`; must free all allocated memory
  - Test on directory of small self-made files where you can predict the data structures and then check them
  - Valgrind takes a *long* time on the full test_tree. Try using enron docs only or other small test data directory for quick checks.
- What is an accommodation?
- Final exam details

# Administrivia

- What is an accommodation? To over-simplify:
  - Something that's costing you several hours a day
  - You didn't expect/plan for it, or is outside your control
  - Don't suffer in silence!

- Final exam details
  - Take-home exam on Gradescope
  - Due on Wednesday @ 4:20pm (the end of our normal exam time) and written to take ~2h of your time (excluding review)
  - Guaranteed to be released *no later than* Monday @ 4:20
  - Unlimited time, unlimited collaboration
    - … but not unlimited copying!

# Administrivia

- Final exam details … *and tips!*
  - Unlimited time, unlimited collaboration
    - … but not unlimited copying!
  - Interviews with former students show that this works well:
    - Open the exam as soon as it's released; note which topics are covered
    - Do a targeted review of those topics
    - Meet with a study group, solve the questions together
    - **DESTROY YOUR NOTES**
    - Re-solve the questions individually (should be fast, thanks to your individual + then group review), then submit to Gradescope
    - Enjoy your summer 😎

This is the part that's supposed to take 2h

# 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;

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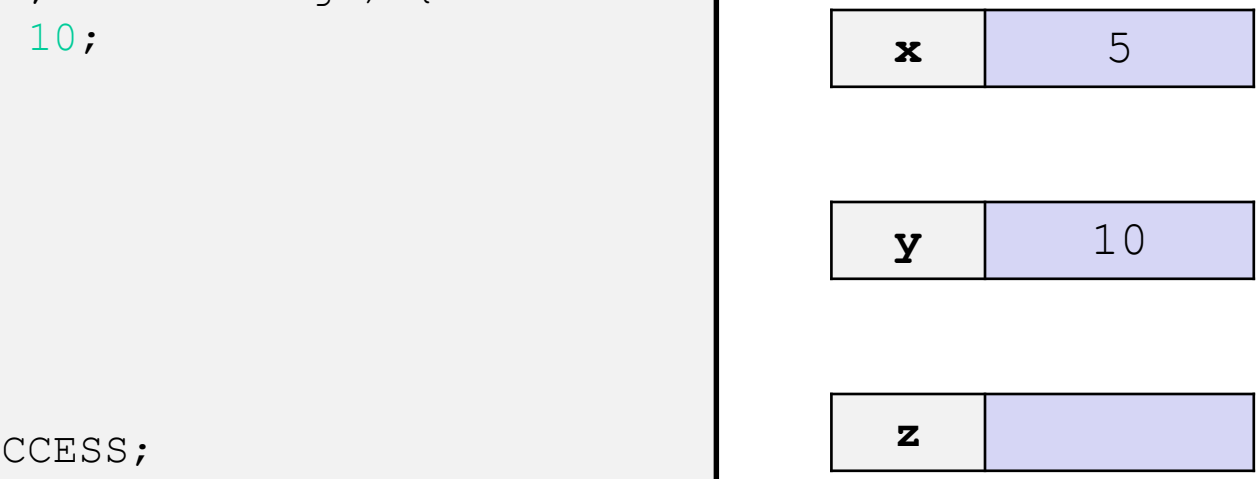
   x += 1;

   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```

pointer.cc



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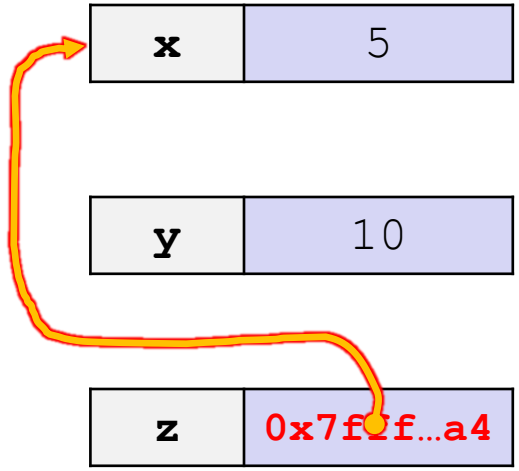


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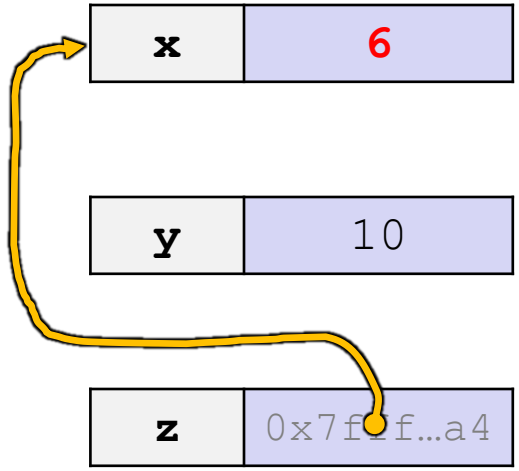
  int x = 5, y = 10;
  int* z = &x;

  *z += 1;   // sets x to 6
   x += 1;

   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```

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int main(int argc, char** argv) {
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}
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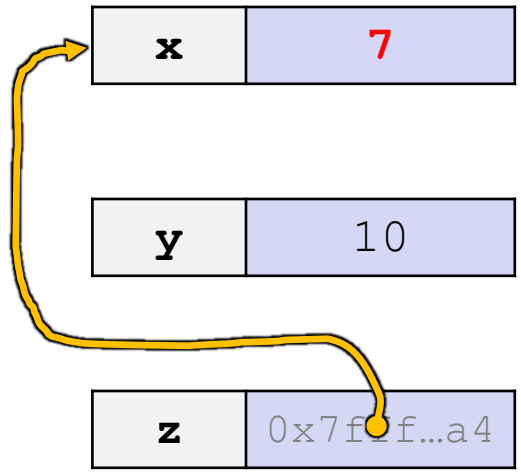


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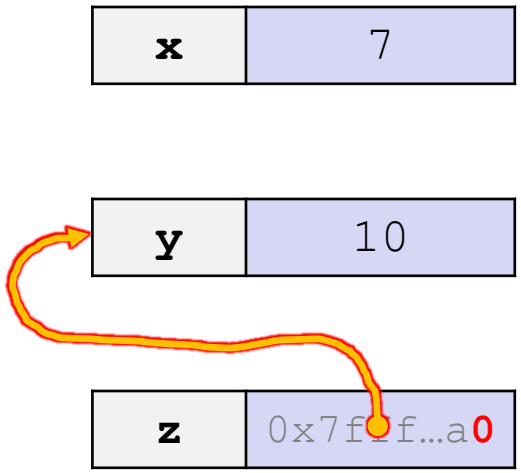
  *z += 1;

  return EXIT_SUCCESS;
}
```

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

   z = &y;   // sets z to the address of y
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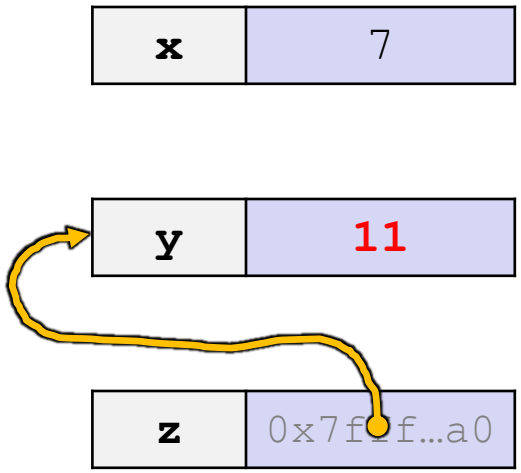
  return EXIT_SUCCESS;
}
```




pointer.cc

# 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

# Comparing our Examples

- A **reference** is an alias for another variable
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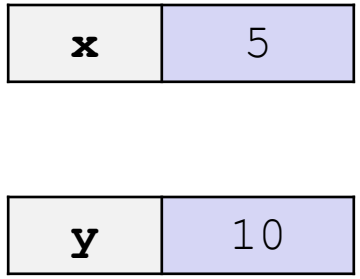
reference.cc



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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;
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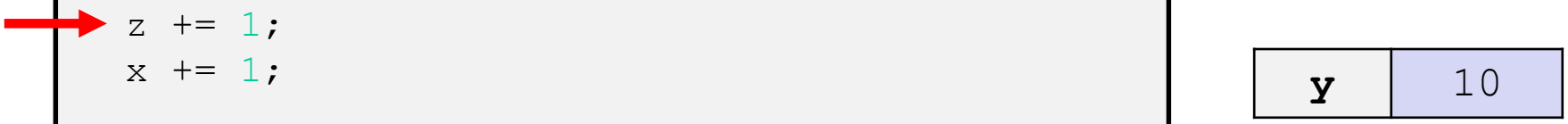
```

reference.cc



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  int x = 5, y = 10;
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  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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  x += 1;  // sets x (and z) to 7

  z  = y;
  z += 1;

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

| y | 10 |
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reference.cc

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  z += 1;

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}
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| x, z | 10 |
|---|---|

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|---|---|

reference.cc

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}
```

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

| y | 10 |
|---|---|

reference.cc

# Pass-By-Reference

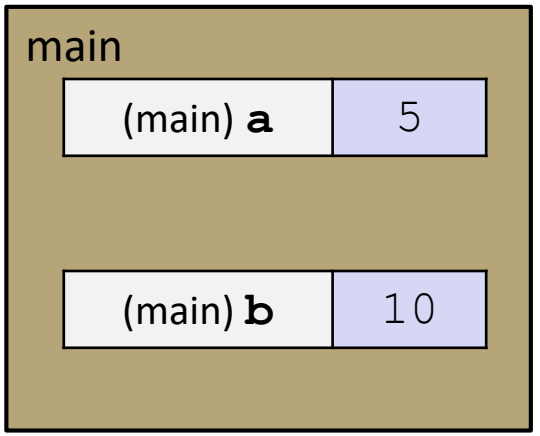
Note: Arrow points to *next* instruction.

- 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

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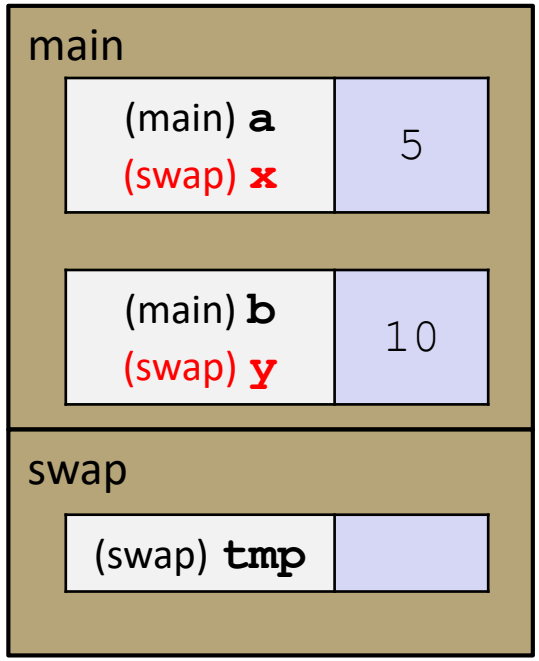


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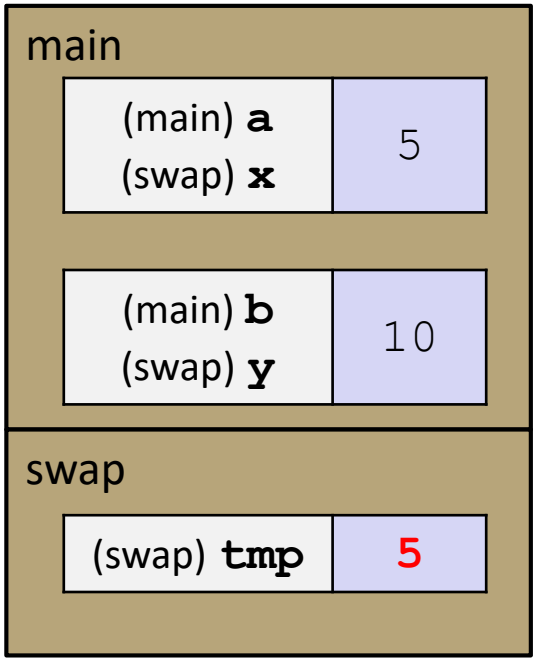


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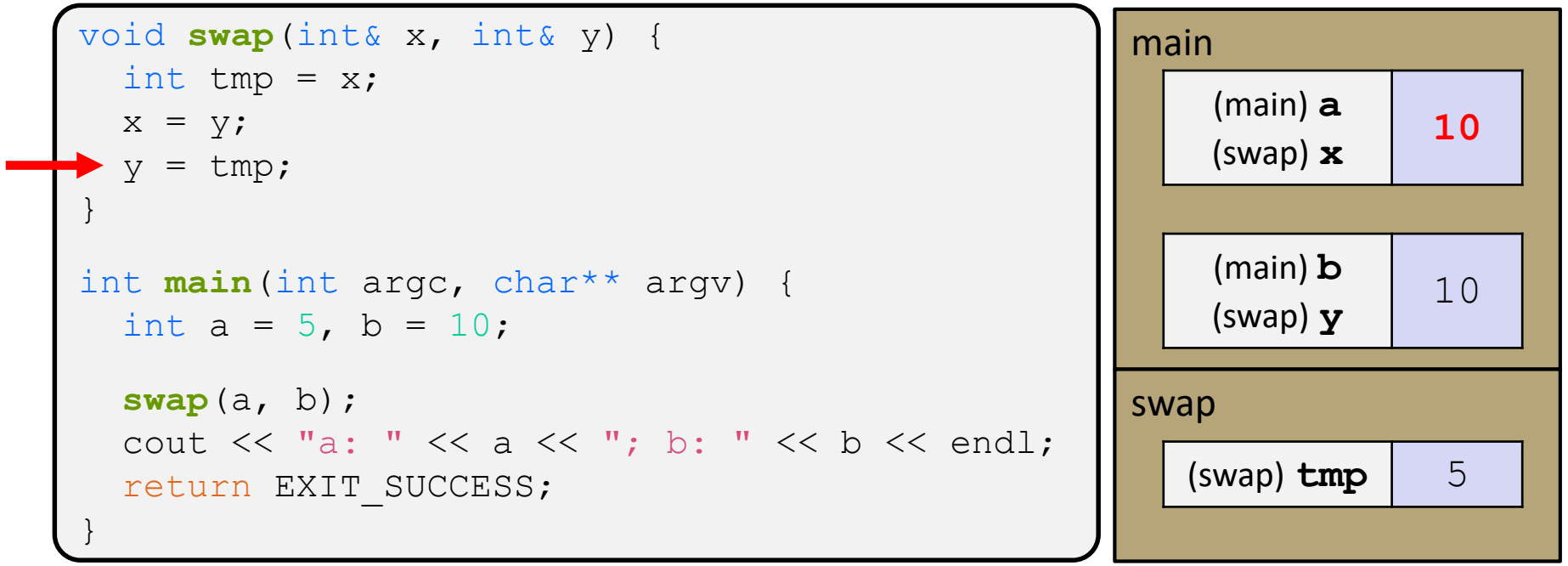


passbyreference.cc

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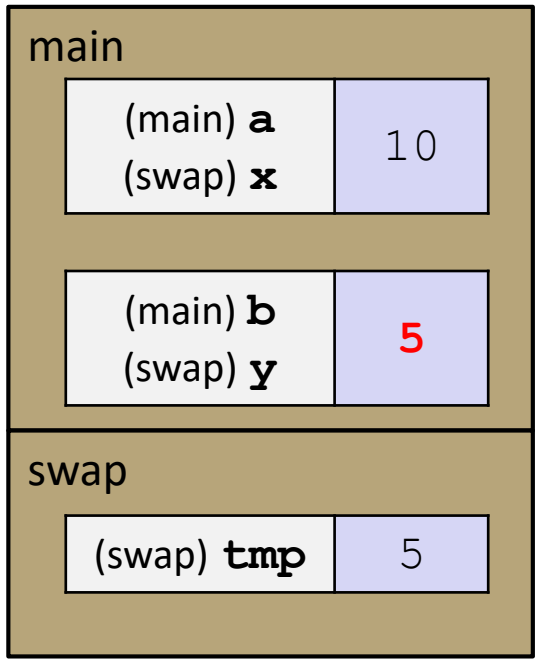


passbyreference.cc

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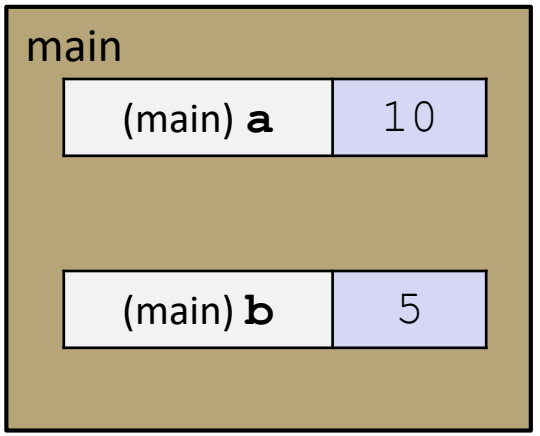



passbyreference.cc

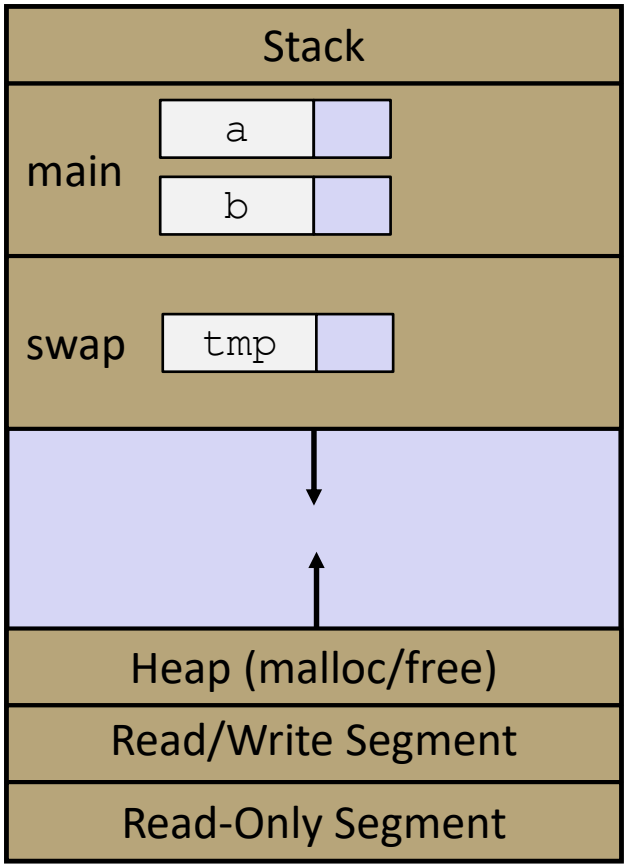
# Pass-By-Reference: Mental Model

- A **reference** is an alias for another variable
  - … so it's as if no additional space is allocated for it
  - Unlike a pointer, which **is** a variable and **does** require space

```
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);
return EXIT_SUCCESS;
}
```




passbyreference.cc

Poll Everywhere

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- At this point, which addresses are identical? In other words: which pairs of names are aliases?
  - `&a == &b`
  - `&a == &x`
  - `&y == &tmp`

```
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  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

# 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

- Since it's a variable, a pointer can modify a program's state by:
  1) Changing the value of the pointer (what it points to)
  2) Changing the thing the pointer points to (via dereference)



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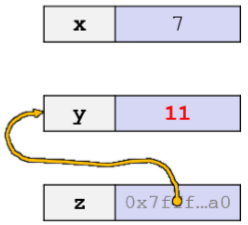
  - These work the same in C and C++

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

  return EXIT_SUCCESS;
}
```




pointer.cc

13

# `const` and Pointers

- Since it's a variable, a pointer can modify a program's state by:
  1) Changing the value of the pointer (what it points to)
  2) Changing 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:

```
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

- 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 *could* be mutated inside the function
  - It would be BAD if you could pass it a `const` var
  - Illegal regardless of whether *or not* the function actually tries to change the var

```
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/uwcse333

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

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…

```
#include <iostream>

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 0;
}
```

# Google Style Guide Convention

- Use `const` references or call-by-value for input values
  - Particularly for large values, use references (no copying)
- Use pointers for output parameters
- List input parameters first, then output parameters last

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

int main(int argc, char** argv) {
  int w = 10, h = 20, a;
  CalcArea(w, h, &a);
  return EXIT_SUCCESS;
}
```

ordinary int (not int&) probably better here, but shows how const ref can be used

styleguide.cc

# 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

# Lecture Outline

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

# Classes

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

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

 private:
  // private member delarations & definitions go here
};  // class Name
```

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

# Class Member Functions

- Class member functions can be:
  1. *defined* within the class definition
     - typically only used for trivial method definitions, like getters/setters

```
class Name {
  retType MethodName(type1 param1, …, typeN paramN) {
    // body statements
  }
};  // class Name
```

  2. *declared* within the class definition and then *defined* elsewhere

```
class Name {
  retType MethodName(type1 param1, …, typeN paramN);
};  // class Name
```

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

# Class Organization (.h/.cc)

- 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 (more about this later)

- Unlike Java, you can name files anything you want
  - But normally `Name.cc` and `Name.h` for `class Name`

# 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 (a different .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;
}
```

# Reading Assignment

- Before next time, you **must *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…
  - Should we start class with a "quiz" next time?
    - Topic: if we write C x = y; or C x(y); or x=y; or C x; , which is called: (i) constructor, (ii) copy constructor, (iii) assignment operator, …
  - Seriously – the next lecture will make a ***lot*** more sense if you've done some background reading ahead of time
    - Don't worry whether it all makes sense the first time you read it – it won't! The goal is to be aware of what the main issues are….

# 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