C++ References, Const

CSE 333 Autumn 2019

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About how long did Exercise 7 take?

A. 0-1 Hours
B. 1-2 Hours
C. 2-3 Hours
D. 3-4 Hours
E. 4+ Hours
F. I prefer not to say

Administrivia

- Exercise 8 released today, due Friday
  - First C++ exercise!
  - Some parallels to ex0; compare between C/C++

- #include <stdlib.h> or <cstdlib> for EXIT_SUCCESS

Lecture Outline

- **Intro to C++, continued**
- C++ References
- `const` in C++

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

- C++'s standard library has a `std::string` class
  - Include the `string` header to use it
    - Seems to be automatically included in `iostream` on CSE Linux environment (C++11) – but include it explicitly anyway if you use it
  - http://www.cplusplus.com/reference/string/

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

- The `using` keyword introduces a namespace (or part of) into the current region
  - `using namespace std;` imports all names from `std::`
  - `using std::cout;` imports *only* `std::cout` (used as `cout`)

Let's Refine It a Bit


```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

- Here we are instantiating a `std::string` object *on the stack* (an ordinary local variable)
  - Passing the C string `"Hello, World!"` to its constructor method
  - `hello` is deallocated (and its destructor invoked) when `main` returns: RAII!

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

Google style guide says no

using std::cout
using std::endl

- The C++ string library also overloads the << operator
  - Defines a function (*not* an object method) that is invoked when the LHS is `ostream` and the RHS is `std::string`
    - http://www.cplusplus.com/reference/string/string/operator<</

String Concatenation

concat.cc

```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello");
  hello = hello + ", World!";
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

- The string class overloads the "+" operator
  - Creates and returns a new string that is the concatenation of the LHS and RHS

String Assignment

concat.cc

```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello");
  hello = hello + ", World!";
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

- The string class overloads the "=" operator
  - Copies the RHS and replaces the string's contents with it

String Manipulation

concat.cc

```
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
  string hello("Hello");
  hello = hello + ", World!";
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

- This statement is complex!
  - First "+" creates a string that is the concatenation of `hello`'s current contents and `", World!"`
  - Then "=" creates a copy of the concatenation to store in `hello`
  - Without the syntactic sugar:
    - `hello.operator=(hello.operator+(", World!"));`

Stream Manipulators

manip.cc

```
#include <iostream>
#include <cstdlib>
#include <iomanip>

using namespace std;

int main(int argc, char **argv) {
  cout << "Hi! " << setw(4) << 5 << " " << 5 << endl;
  cout << hex << 16 << " " << 13 << endl;
  cout << dec << 16 << " " << 13 << endl;
  return EXIT_SUCCESS;
}
```

- `iomanip` defines a set of stream manipulator functions
  - Pass them to a stream to affect formatting
    - http://www.cplusplus.com/reference/iomanip/
    - http://www.cplusplus.com/reference/ios/

Stream Manipulators

manip.cc

```
#include <iostream>
#include <cstdlib>
#include <iomanip>

using namespace std;

int main(int argc, char **argv) {
  cout << "Hi! " << setw(4) << 5 << " " << 5 << endl;
  cout << hex << 16 << " " << 13 << endl;
  cout << dec << 16 << " " << 13 << endl;
  return EXIT_SUCCESS;
}
```

- `setw(x)` sets the width of the *next* field to `x`
  - Only affects the next thing sent to the output stream (*i.e.* it is not persistent)

Stream Manipulators

manip.cc

```
#include <iostream>
#include <cstdlib>
#include <iomanip>

using namespace std;

int main(int argc, char **argv) {
  cout << "Hi! " << setw(4) << 5 << " " << 5 << endl;
  cout << hex << 16 << " " << 13 << endl;
  cout << dec << 16 << " " << 13 << endl;
  return EXIT_SUCCESS;
}
```

- `hex`, `dec`, and `oct` set the numerical base for printing *integers* output to the stream
  - In effect until stream is set to another base (*i.e.* it is persistent)

C and C++

helloworld3.cc

```
#include <cstdio>
#include <cstdlib>

int main(int argc, char **argv) {
  printf("Hello from C!\n");
  return EXIT_SUCCESS;
}
```

- C is (roughly) a subset of C++
  - You can still use `printf` … but considered bad style
  - Can mix C and C++ idioms if needed to work with existing code, but avoid mixing if you can
    - Use C++(11)

Reading

echonum.cc

```
#include <iostream>
#include <cstdlib>

using namespace std;

int main(int argc, char **argv) {
  int num;
  cout << "Type a number: ";
  cin >> num;
  cout << "You typed: " << num << endl;
  return EXIT_SUCCESS;
}
```

- `std::cin` is an object instance of class `istream`
  - Supports the >> operator for "extraction"
    - Can be used in conditionals – (`std::cin>>num`) is `true` if successful
  - Has a `getline()` method and methods to detect and clear errors

Lecture Outline

- Intro to C++, continued
- **C++ References**
- `const` in C++

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++

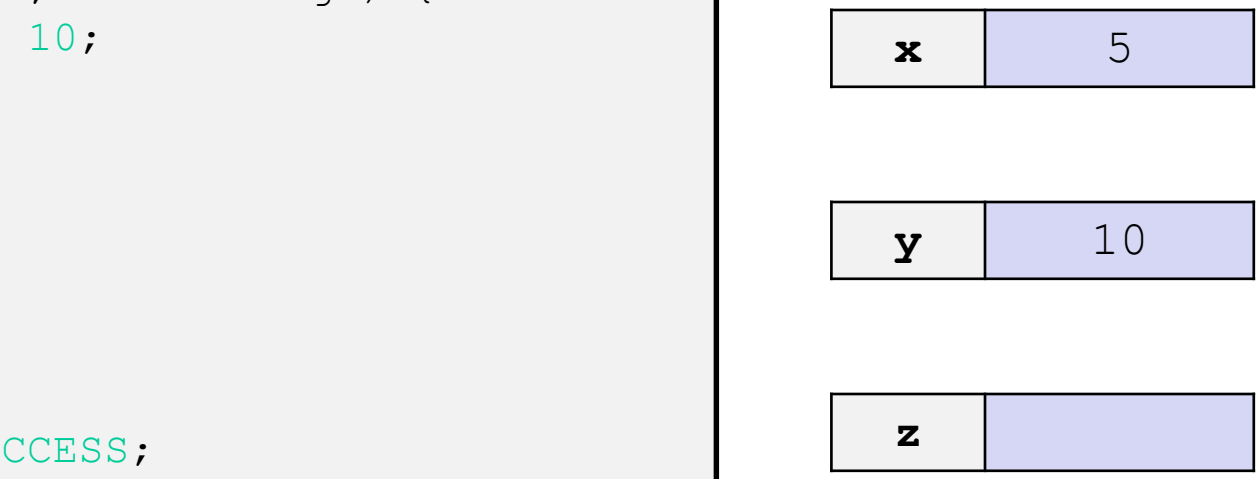
```
int main(int argc, char **argv) {
  int x = 5, y = 10;
  int *z = &x;

  *z += 1;
   x += 1;

   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```

pointer.cc



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   x += 1;

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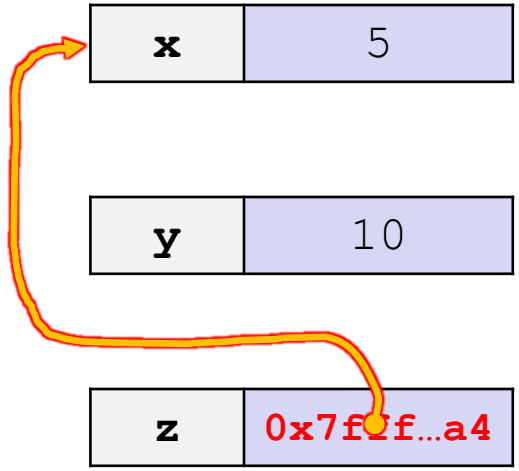
  *z += 1;

  return EXIT_SUCCESS;
}
```



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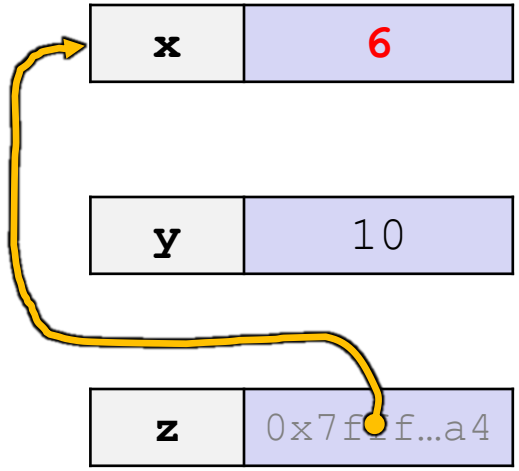
  - These work the same in C and C++

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

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

   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```



pointer.cc

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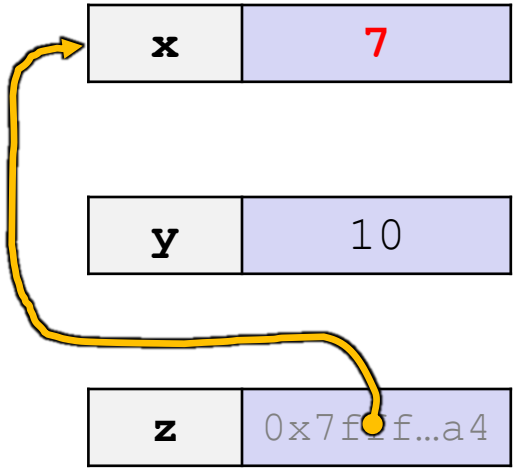
  - These work the same in C and C++

```
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 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;
}
```

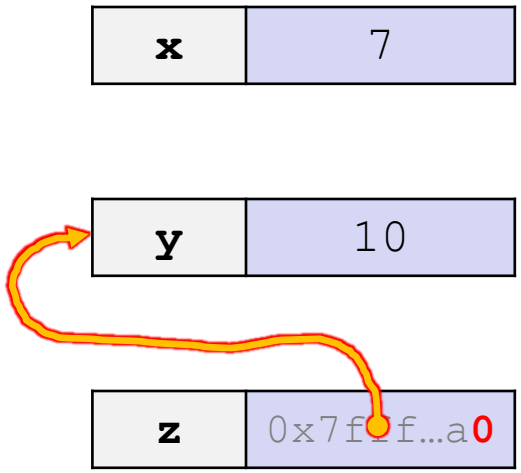

pointer.cc

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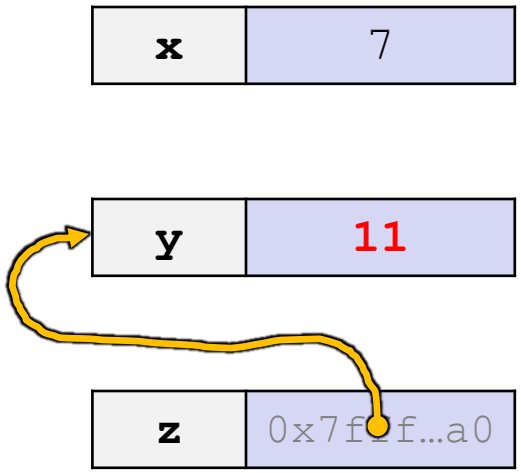
  - These work the same in C and C++

```
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!

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

Cannot have an "unitialized" alias; cannot re-alias either!
int &z; ← illegal

```
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

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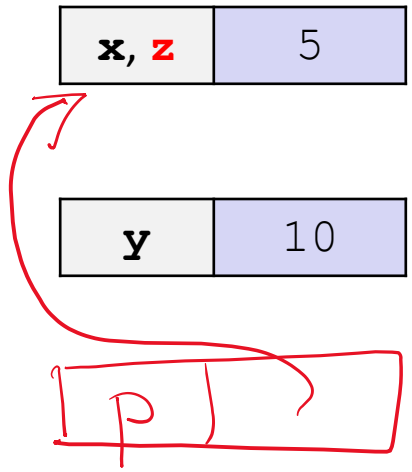
```
int main(int argc, char **argv) {
  int x = 5, y = 10;
  int &z = x;  // binds the name "z" to x
  int *p = &x
  z += 1;
  x += 1;

  z  = y;
  z += 1;

  return EXIT_SUCCESS;
}
```



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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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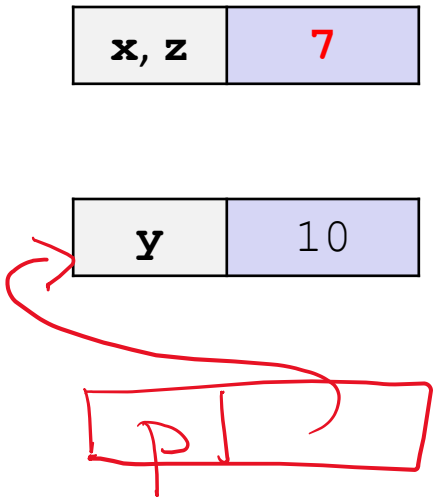
```
int main(int argc, char **argv) {
  int x = 5, y = 10;
  int &z = x;  // binds the name "z" to x
  int *p = &x
  z += 1;  // sets z (and x) to 6
  x += 1;  // sets x (and z) to 7

  z  = y;   p = &y
  z += 1;

  return EXIT_SUCCESS;
}
```



Pointer assignment: changes which pointee
reference assignment: NORMAL ASSIGNMENT SEMANTICS!

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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

References!

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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
           // y=z would set y 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 argument with normal "copy" syntax
  - Function uses reference parameters with normal syntax
  - … but modifying it 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

passbyreference.cc

Pass-By-Reference

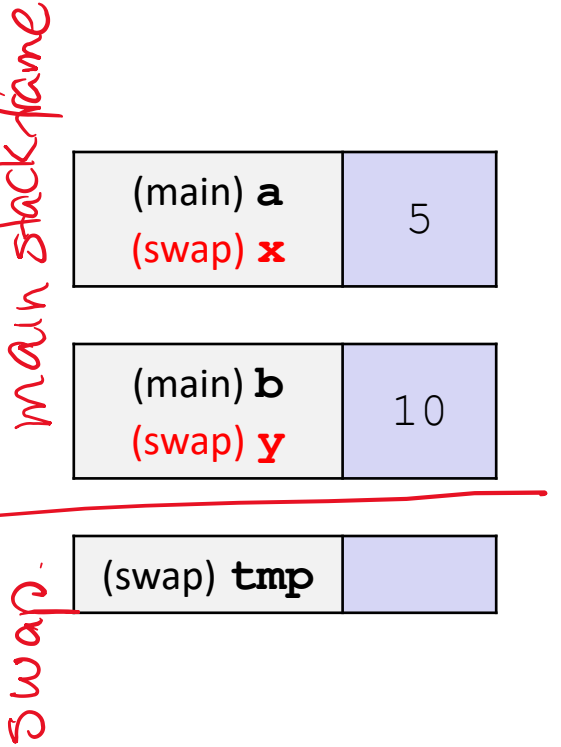
Note: Arrow points to *next* instruction.

- 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;
}
```



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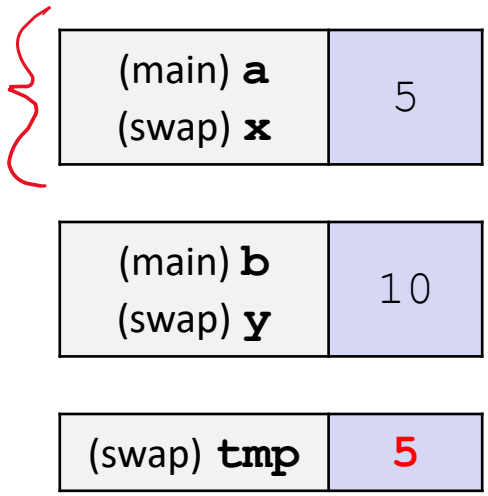
    - Modifying a reference parameter modifies the caller's argument!

```
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;
}
```

&a == &x (address of a and address of x are the same)



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(b,a) binds x→b & y→a
  swap(a, b); // binds x→a & y→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

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

Lecture Outline

- Intro to C++, continued
- C++ References
- **`const` in C++**

const

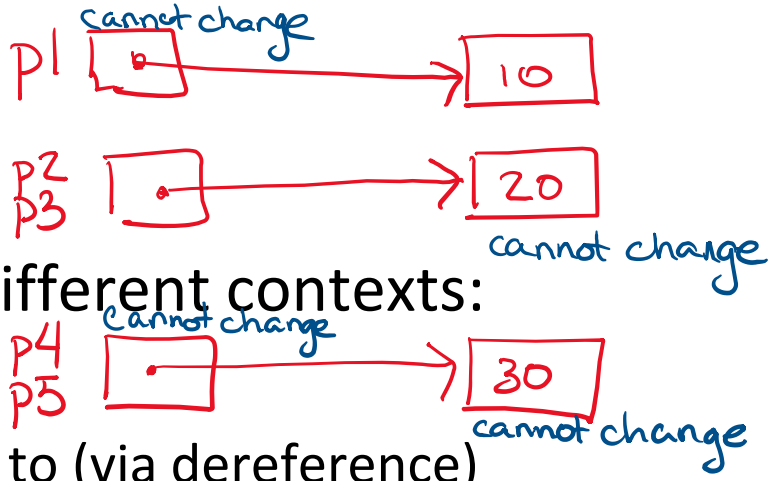
- `const`: this cannot be changed/mutated
  - Used *much* more in C++ than in C
  - Signal of intent to compiler; meaningless at hardware level
    - Results in compile-time errors

```
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) Change the value of the pointer
  2) 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 = can't change the value of the pointer
  - `const` next to data type = can't use this pointer to change the thing being pointed to
  - Tip: `const` binds *leftward* (and "bounces off" if leftmost)

int *const p1

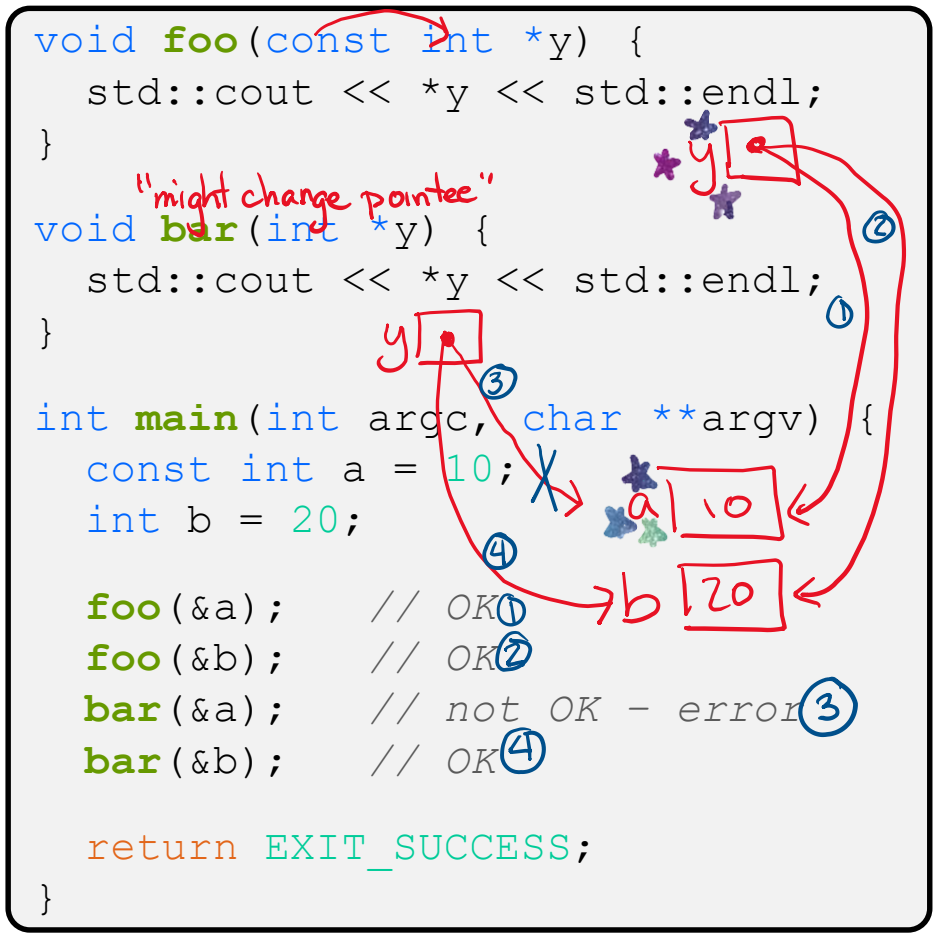
int const *p2
const int *p3
} equivalent

"const ALL the things!"

const int *const p4
int const *const p5
} equivalent

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
  - It would be BAD if you passed it a `const` variable



Poll Everywhere

pollev.com/cse333

- 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. I'm not sure…

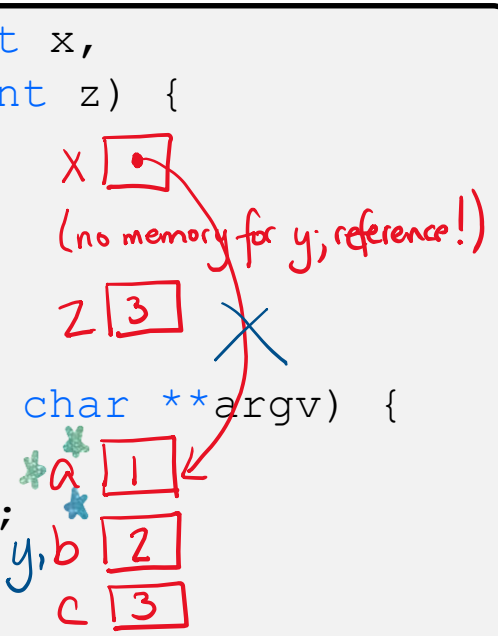
poll.cc

```
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 have two options:
    - Pass by copy for primitive types, like `int` or small structs/objects
    - `const` references for complex structs/objects
  - Output parameters:
    - `const` pointers (unchangeable pointers referencing changeable data)
  - Input parameters first, then output parameters

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

styleguide.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…
  - Should we start class with a quiz next time?

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