C++ Constructor Insanity

CSE 333 Autumn 2021

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Administrivia

- Exercise 8 due tonight @ 10pm
- Exercise 9 out Friday, not due until Wed (Oct. 27)
- Turn around for exercises will typically be longer going forward
- Homework 2 due next Thursday (Oct. 28)

Lecture Outline

- **Makefiles (briefly)**
- Constructors
- Copy Constructors
- ---
- Assignment
- Destructors

make

- `make` is a classic program for controlling what gets (re)compiled and how
  - Many other such programs exist (*e.g.*, `ant`, `maven`, IDE "projects")
- `make` has tons of fancy features, but only two basic ideas:
  1) Scripts for executing commands
  2) Dependencies for avoiding unnecessary work
- To avoid "just teaching `make` features" (boring and narrow), let's focus more on the concepts…

Building Software

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  - Creating programs from source code
  - Both programs that they write and other people write

- Programmers like to automate repetitive tasks
  - Repetitive: gcc -Wall -g -std=c17 -o widget foo.c bar.c baz.c

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    - Have an alias or bash script: 
    - Have a Makefile:  (you're ahead of us)

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- On larger projects, you can't or don't want to have one big (set of) command(s) that are all run every time you change anything. To do things "smarter," consider:

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  2) Source files could have multiple outputs (*e.g.*, `javadoc`). You may have to type out the source file name(s) multiple times
  3) You don't want to have to document the build logic when you distribute source code; make it relatively simple for others to build
  4) You don't want to recompile everything every time you change something (especially if you have 10^5-10^7 files of source code)

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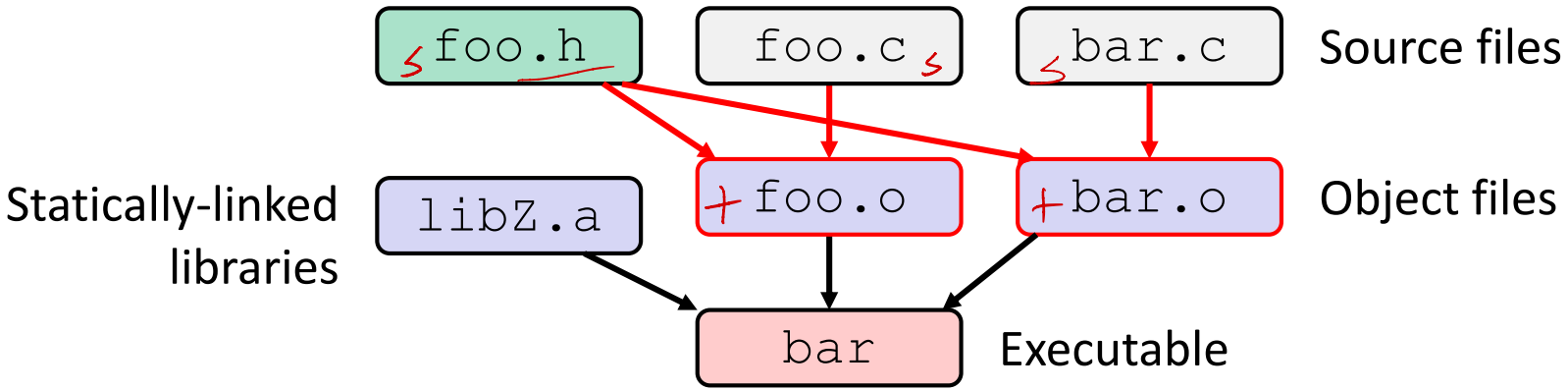
- A script can handle 1-3 (use a variable for filenames for 2), but 4 is trickier

Theory Applied to C

(s) source
(t) target



- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)

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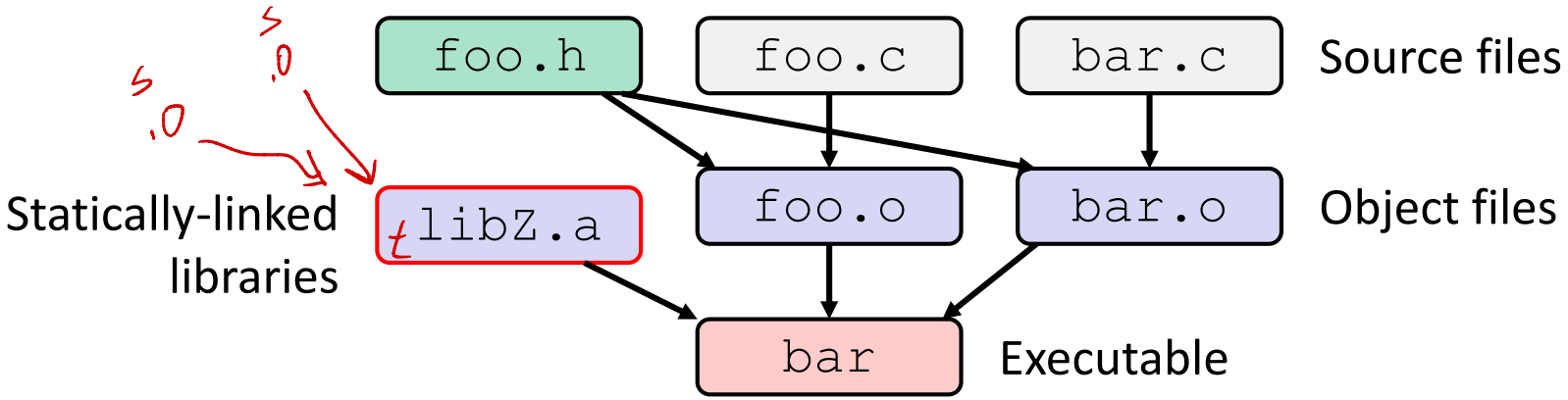

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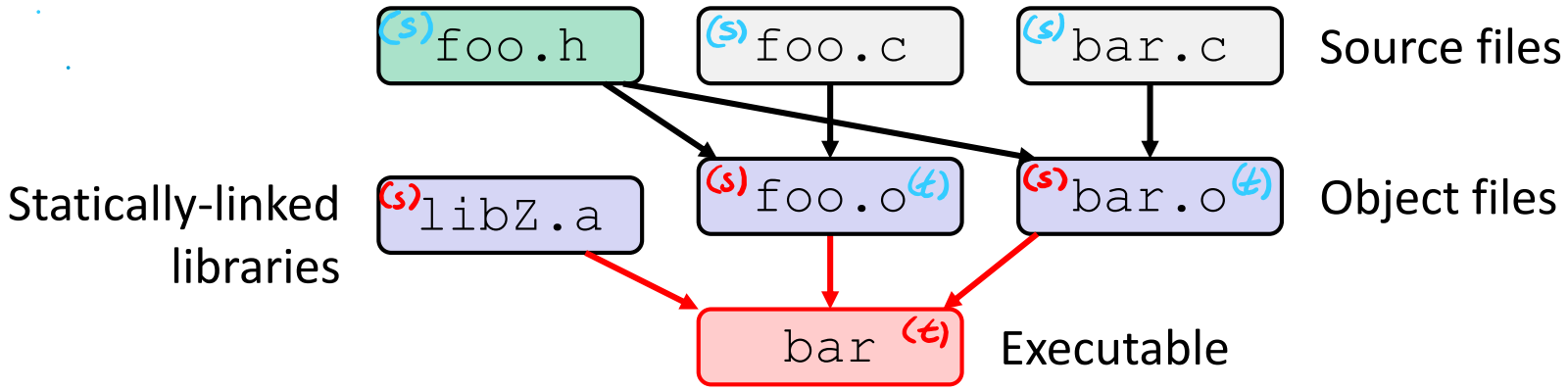
(t) = target



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- An archive (library, `.a`) depends on included `.o` files
- Creating an executable ("linking") depends on `.o` files and archives
  - Archives linked by `-L<path> -l<name>`
    (*e.g.*, `-L. -lfoo` to get `libfoo.a` from current directory)

Theory Applied to C

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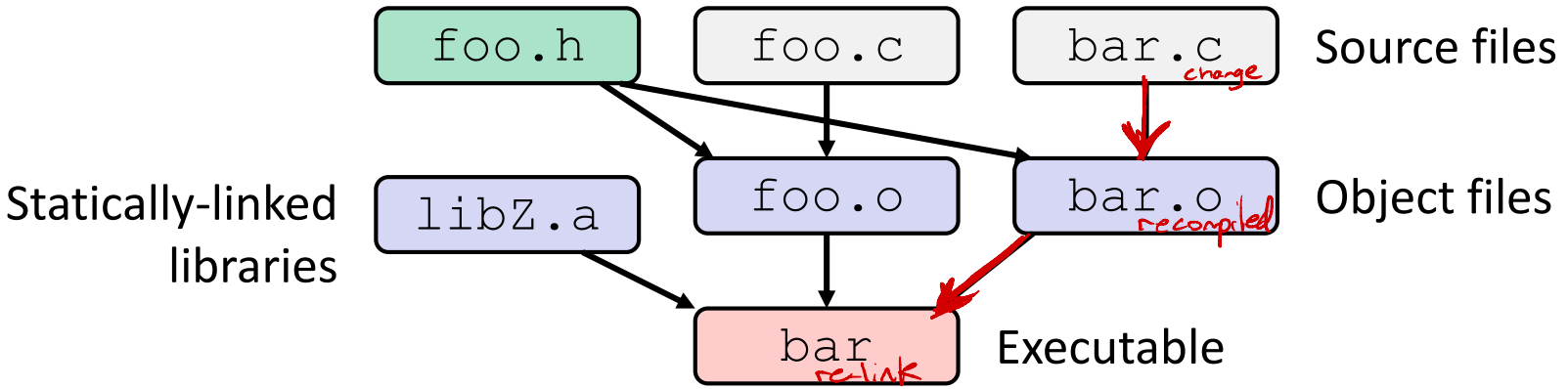
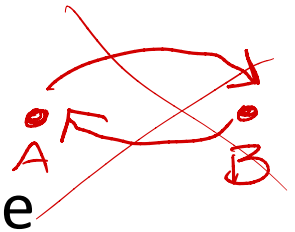


- If one `.c` file changes, just need to recreate one `.o` file, maybe a library, and re-link



- If a `.h` file changes, may need to rebuild more

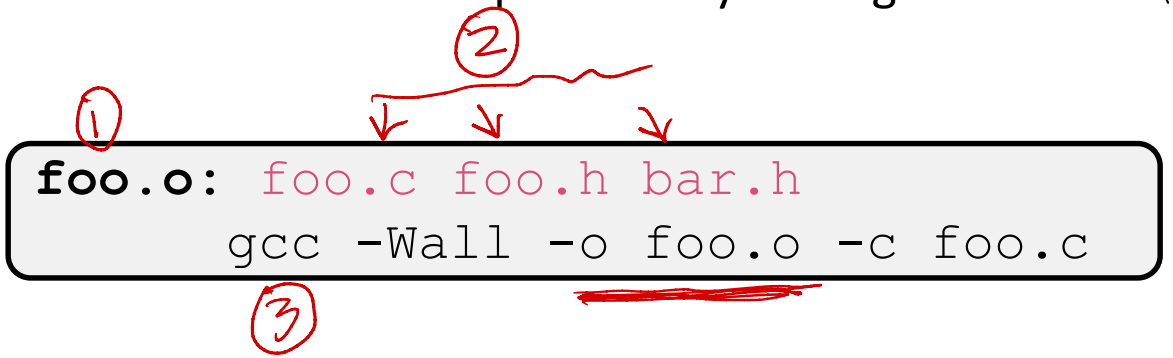
- Many more possibilities!

make Basics

- A makefile contains a bunch of triples:

  - Colon after target is *required*
  - Command lines must start with a **TAB**, NOT SPACES
  - Multiple commands for same target are executed *in order*
    - Can split commands over multiple lines by ending lines with '\'

- Example:



Using `make`

```
bash$ make -f <makefileName> target
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- Defaults: $ make
  - If no `-f` specified, use a file named `Makefile` in current dir
  - If no `target` specified, will use the first one in the file
  - Will interpret commands in your default shell
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  - Will interpret commands in your default shell
    - Set `SHELL` variable in makefile to ensure
- Target execution:
  - Check each source in the source list:
    - If the source is a target in the makefile, then process it recursively
    - If some source does not exist, then error
    - If any source is newer than the target (or target does not exist), run `command` (presumably to update the target)

"Phony" Targets

- A make target whose command does not create a file of the target's name (*i.e.*, a "recipe")
  - As long as target file doesn't exist, the command(s) will be executed because the target must be "remade"

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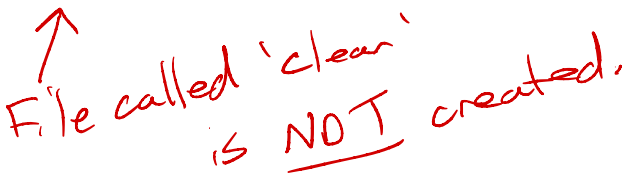

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- *e.g.*, target `all` is a convention to build all "final products" in the makefile
  - Lists all of the "final products" as sources

"all" Example

```
all: prog B.class someLib.a
      # notice no commands this time

prog: foo.o bar.o main.o
      gcc -o prog foo.o bar.o main.o

B.class: B.java
      javac B.java

someLib.a: foo.o baz.o
      ar r foo.o baz.o

foo.o: foo.c foo.h header1.h header2.h
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# similar targets for bar.o, main.o, baz.o, etc...
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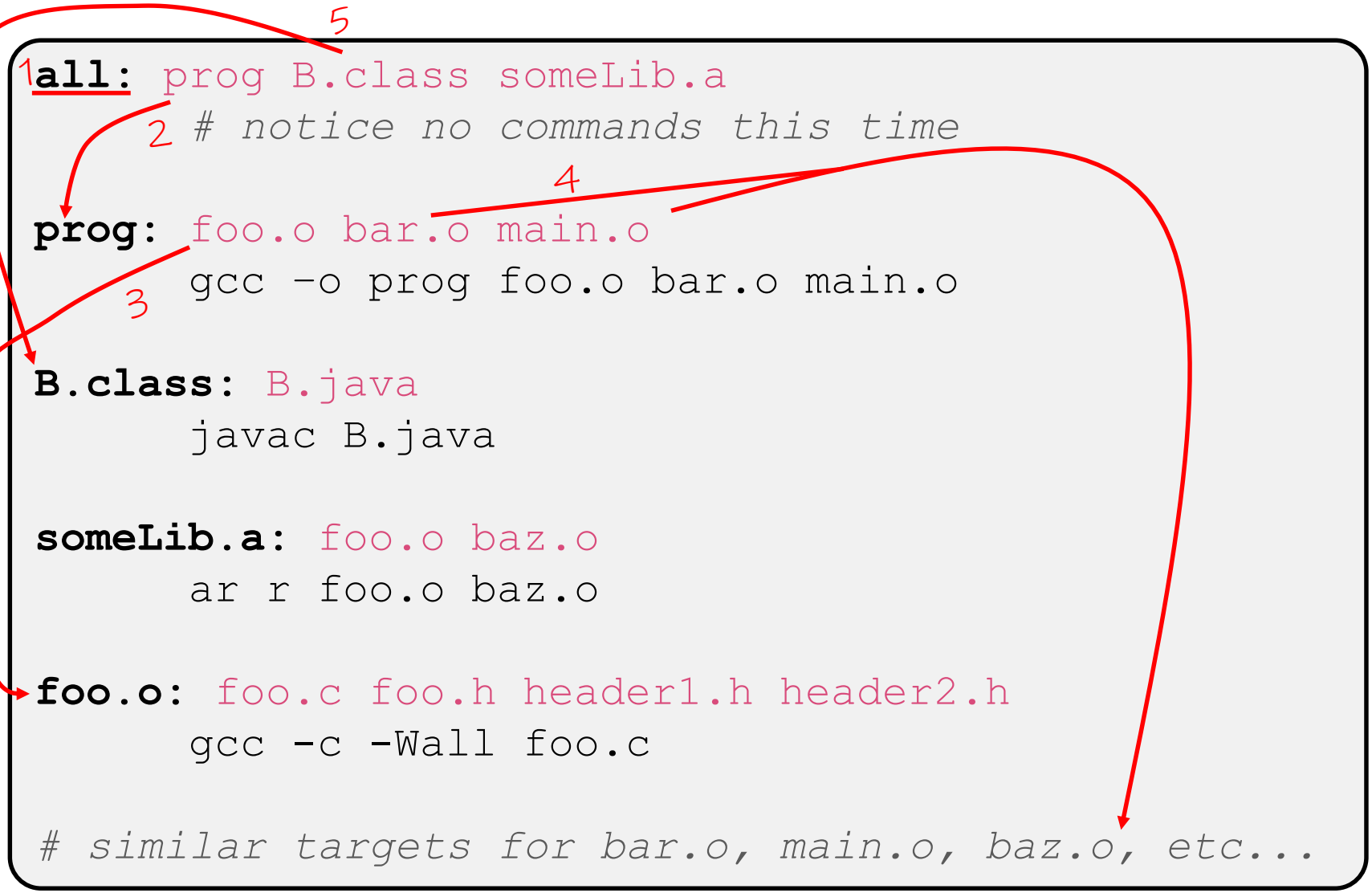
5
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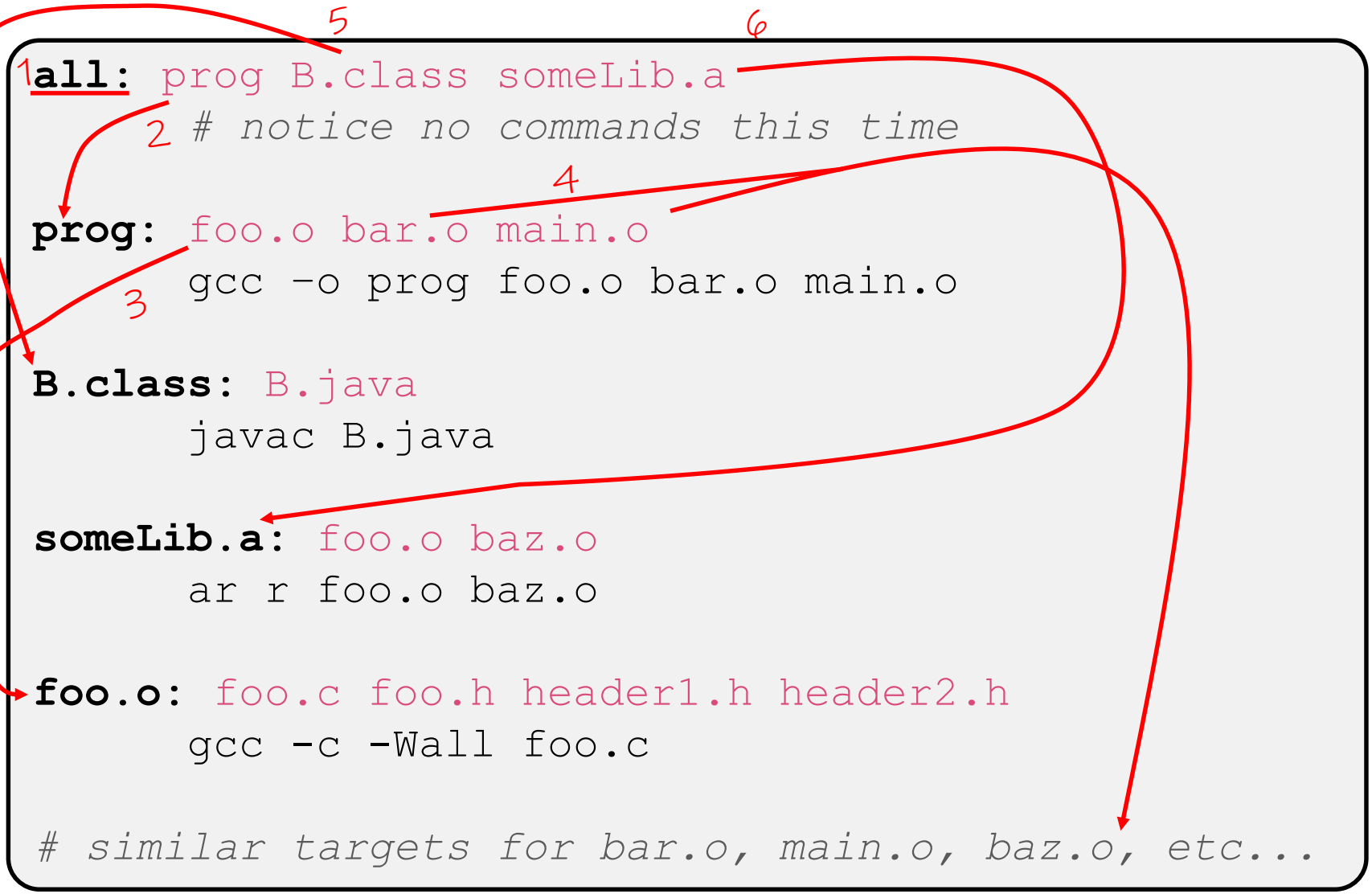
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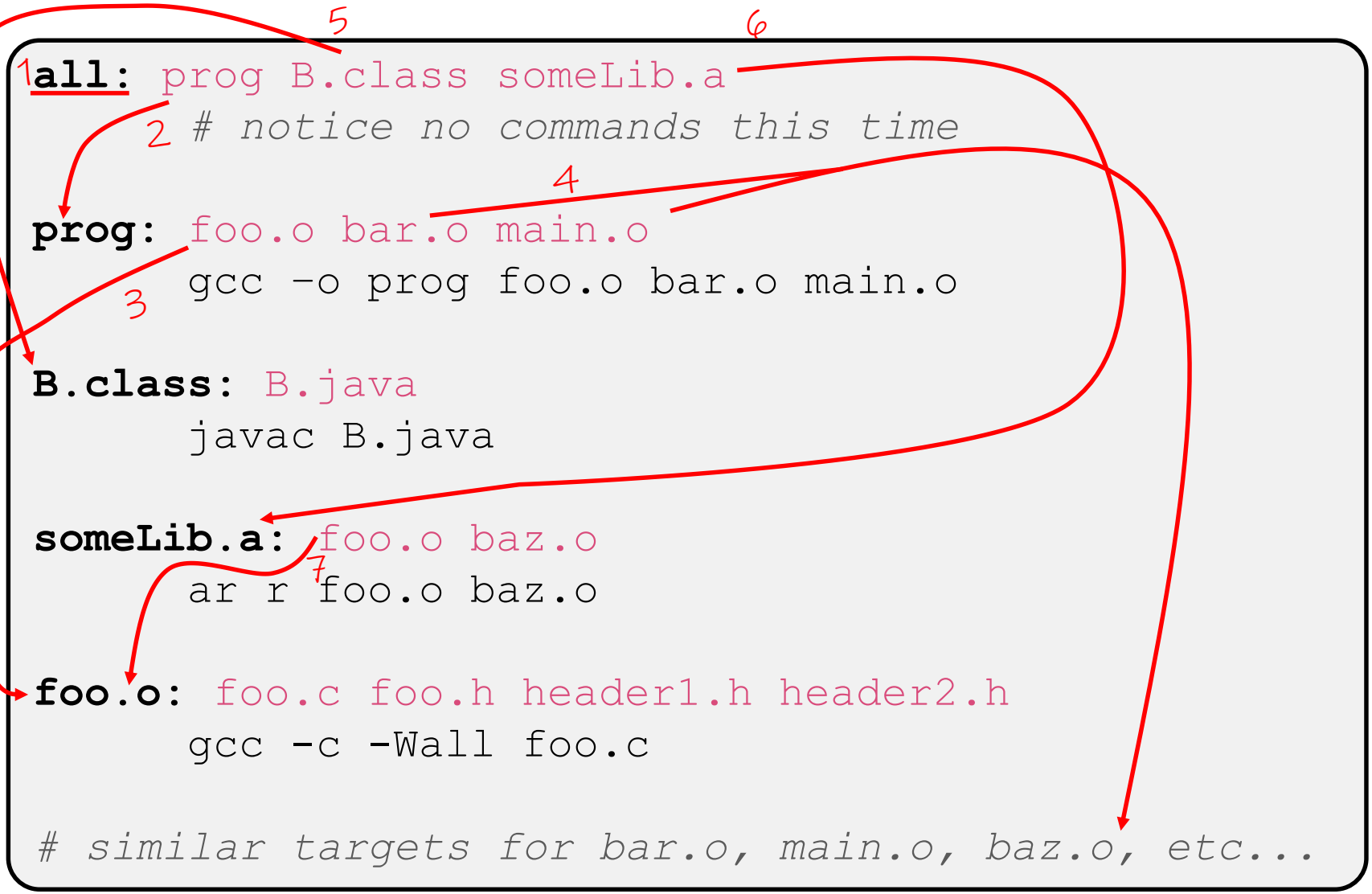
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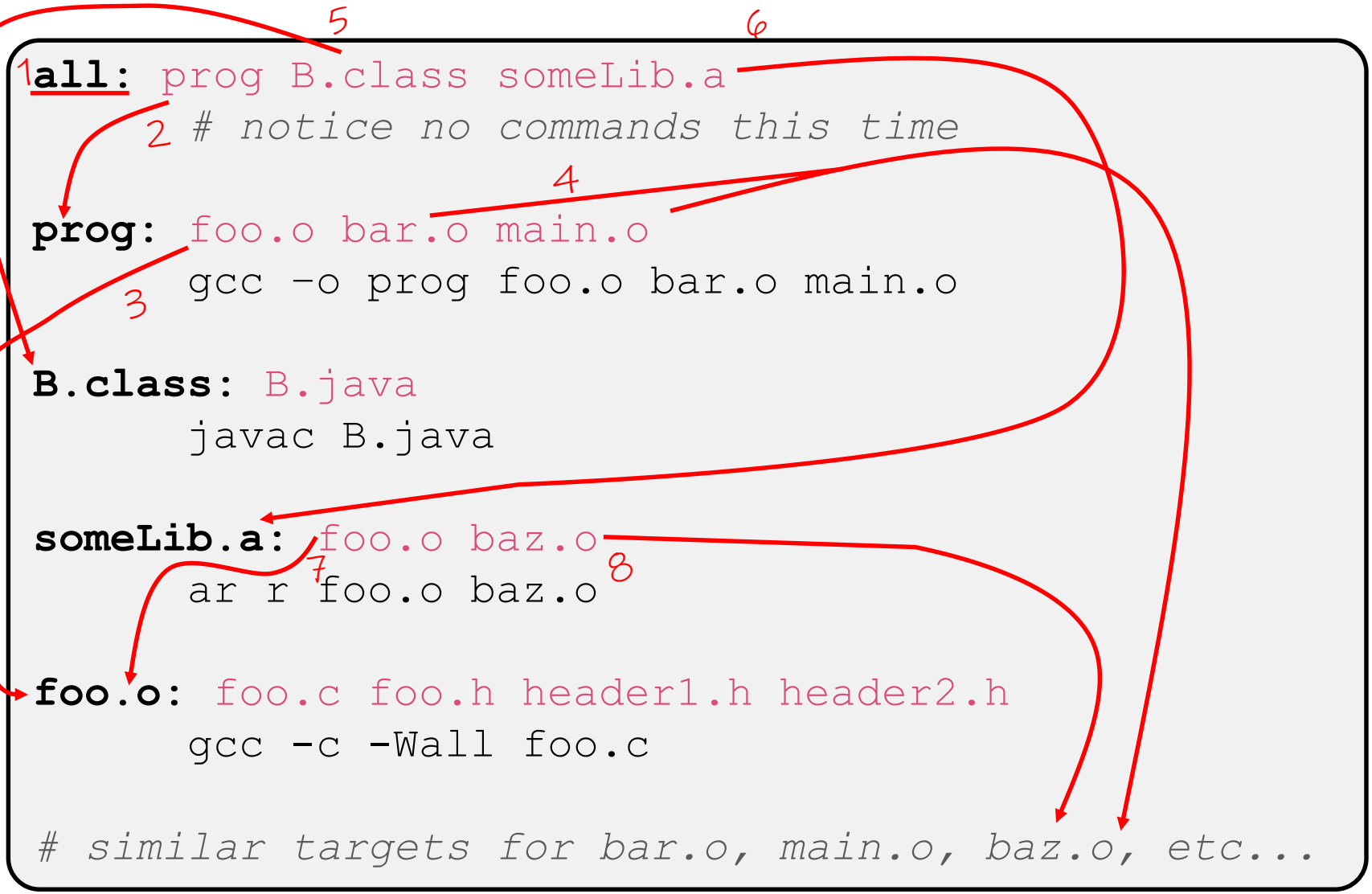
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Lecture Outline

- **Constructors**
- Copy Constructors
- Assignment
- Destructors

Memory Diagrams for Objects

- An **object** is an instance of a class that maintains its *state* independent from other objects
  - This state is the collection of its data members
  - Conceptually, an object acts like a collection of data fields (plus class metadata)
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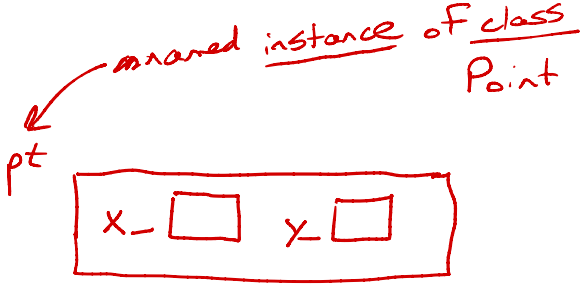
- Drawn out as variables within variables:

```
class Point {
 ...

 private:
  int x_;  // data member
  int y_;  // data member
};  // class Point
```



Constructors

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- Written with the class name as the method name:

```
Point(const int x, const int y);
```

  - C++ will automatically create a synthesized default constructor if you have *no* user-defined constructors
    - Takes no arguments and calls the default ctor on all non-"plain old data" (non-POD) member variables
    - Synthesized default ctor will fail if you have non-initialized const or reference data members

Synthesized Default Constructor Example

```
class SimplePoint {
 public:
  // no constructors declared!
  int get_x() const { return x_; }      // inline member function
  int get_y() const { return y_; }      // inline member function
  double Distance(const SimplePoint& p) const;
  void SetLocation(int x, int y);

 private:
  int x_;  // data member
  int y_;  // data member
};  // class SimplePoint
```

default behavior → primitive (think int): just allocate space

default behavior → objects: default constructor is called

SimplePoint.h

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
  SimplePoint x;  // invokes synthesized default constructor
  return EXIT_SUCCESS;
}
```

SimplePoint.cc

(main) x [x_ ? y_ ?]

Synthesized Default Constructor

- If you define *any* constructors, C++ assumes you have defined all the ones you intend to be available and will *not* add any others

```
#include "SimplePoint.h"

// defining a constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void foo() {
  SimplePoint x;          // compiler error:  if you define any
                          // ctors, C++ will NOT synthesize a
                          // default constructor for you.

  SimplePoint y(1, 2);    // works:  invokes the 2-int-arguments
                          // constructor
}
```

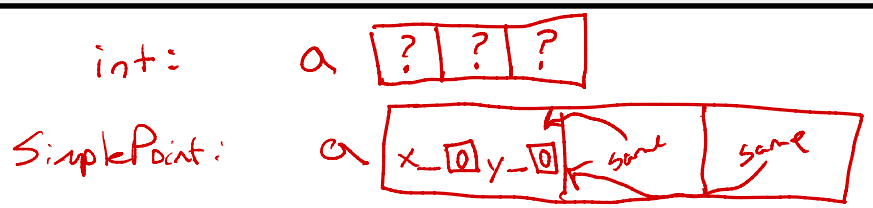
Multiple Constructors (overloading)

```
#include "SimplePoint.h"

// default constructor
SimplePoint::SimplePoint() {
  x_ = 0;
  y_ = 0;
}

// constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void foo() {
  SimplePoint x;       // invokes the default constructor
  SimplePoint y(1, 2); // invokes the 2-int-arguments ctor
  SimplePoint a[3];    // invokes the default ctor 3 times
}
```



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```
// constructor with an initialization list
Point::Point(const int x, const int y) : x_(x), y_(y) {
  std::cout << "Point constructed: (" << x_ << ",";
  std::cout << y_<< ")" << std::endl;
}
```

can be an expression
x+1

Initialization vs. Construction


```
class Point3D {
 public:
  // constructor with 3 int arguments
  Point3D(const int x, const int y, const int z) : y_(y), x_(x) {
    z_ = z;
  }

 private:
  int x_, y_, z_;  // data members
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- Data members in initializer list are initialized in the order they are defined in the class, not by the initialization list ordering (!)
  - Data members that don't appear in the initialization list are *default initialized/constructed* before body is executed

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- Initialization preferred to assignment to avoid extra steps
  - Real code should never mix the two styles

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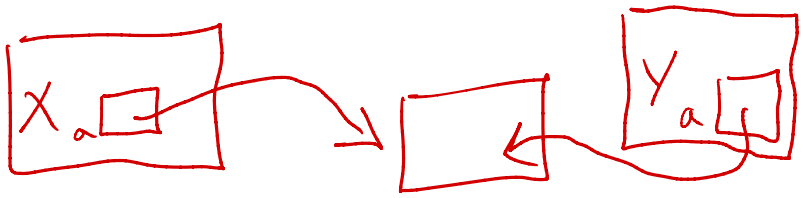
Copy Constructors



- C++ has the notion of a copy constructor (cctor)
  - Used to create a new object as a copy of an existing object

```
Point::Point(const int x, const int y) : x_(x), y_(y) { }

// copy constructor
Point::Point(const Point& copyme) {
  x_ = copyme.x_;
  y_ = copyme.y_;
}

void foo() {
  Point x(1, 2);  // invokes the 2-int-arguments constructor

  Point y(x);     // invokes the copy constructor
                  // could also be written as "Point y = x;"
}
```

ref to object of same class

alias binds to object

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}

void foo() {
  Point x(1, 2);  // invokes the 2-int-arguments constructor

  Point y(x);     // invokes the copy constructor
                  // could also be written as "Point y = x;"
}
```

  - Initializer lists can also be used in copy constructors (preferred)

Synthesized Copy Constructor

- If you don't define your own copy constructor, C++ will synthesize one for you
  - It will do a *shallow* copy of all of the fields (*i.e.*, member variables) of your class
  - Sometimes the right thing; sometimes the wrong thing

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
  SimplePoint x;
  SimplePoint y(x);  // invokes synthesized copy constructor
  ...
  return EXIT_SUCCESS;
}
```

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  - You *initialize* an object from another object of the same type:

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Point y(x);     // copy ctor
Point z = y;    // copy ctor
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  - You pass a non-reference object as a value parameter to a function:

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void foo(Point x) { ... }

Point y;        // default ctor
foo(y);         // copy ctor
```

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  - You *initialize* an object from another object of the same type:

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Point z = y;    // copy ctor
```

  - You pass a non-reference object as a value parameter to a function:

```
void foo(Point x) { ... }

Point y;        // default ctor
foo(y);         // copy ctor
```

  - You return a non-reference object value from a function:

```
Point foo() {
  Point y;      // default ctor
  return y;     // copy ctor
}
```

Compiler Optimization

- The compiler sometimes uses a "return by value optimization" or "move semantics" to eliminate unnecessary copies
  - Sometimes you might not see a constructor get invoked when you might expect it

```
Point foo() {
  Point y;          // default ctor
  return y;         // copy ctor? optimized?
}

int main(int argc, char** argv) {
  Point x(1, 2);    // two-ints-argument ctor
  Point y = x;      // copy ctor
  Point z = foo();  // copy ctor? optimized?
}
```