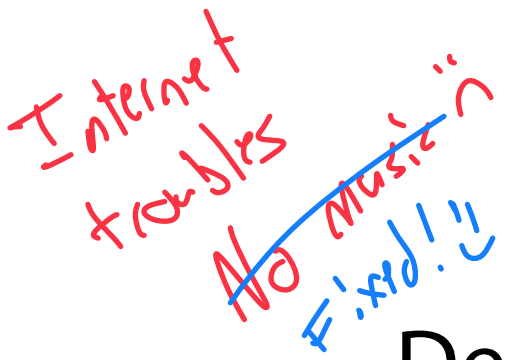
Data Structures

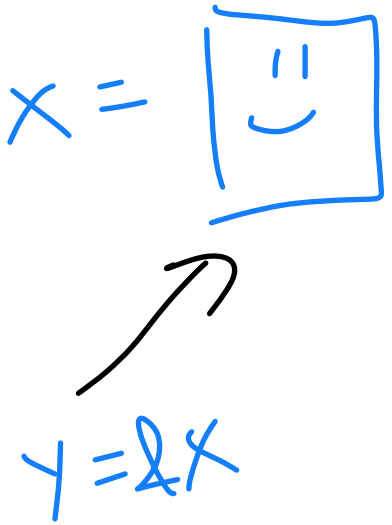
C++ Review

CS 225

Brad Solomon

August 27, 2025





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Scan for:

- Website
- Application
- Interest form

CS 199-225 Registration Issues

The department is aware of registration issues

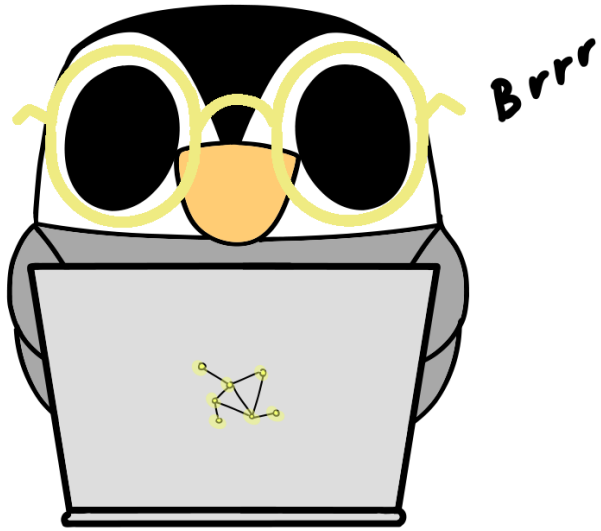
I will announce on Discord / class when this is fixed

(Optional) Open Lab This Week

This week's lab is open office hours

Focus is making sure your machine is setup for semester

Installation information available on website



Office Hours

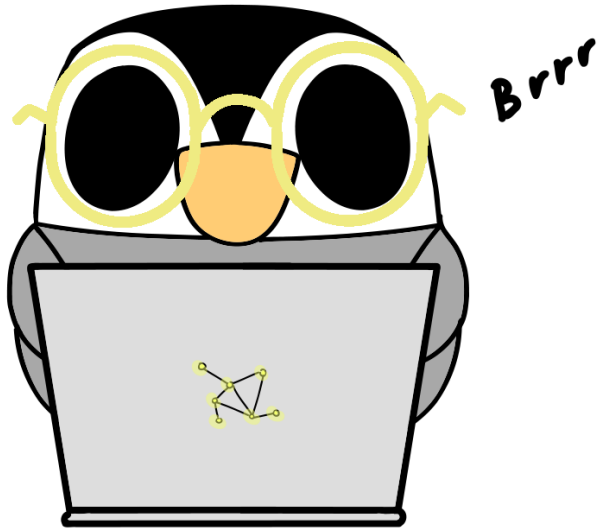
The office hour calendar will be populated next week

For now, please use Discord or Piazza or email

You can also stop by faculty office hours!

Thursday, 11 AM — 12 PM

Siebel 2233



Testing a 'Clicker' Set-up!

Have you signed up to take exam 0?

A) Yes! 80%

B) No!

Join Code: 225

You can participate by going to website:

https://clicker.cs.illinois.edu/

Exam 0 (9/3 — 9/5)

An introduction to CBTF exam environment / expectations

Quiz on foundational knowledge from all pre-reqs

Practice questions can be found on PL

Topics covered can be found on website

Registration is now open! :)

https://courses.engr.illinois.edu/cs225/fa2025/exams/

Learning Objectives

A brief high level review of C++

- Fundamentals of Objects / Classes
- Pointers
- Memory Management and Ownership

Brainstorm the List Abstract Data Types (ADT)

Encapsulation - Classes

Abstraction / organization separating:

Internal Implementation

- HOW
- Your job!

External Interface

- Doxygen
- what each function does

Brainstorming a 'Library' class

```
1  class Library {
2  public:
3
4
5
6
7
8
9
10
11
12
13 private:
14
15
16
17
18
19
20
21 };
```

Interface

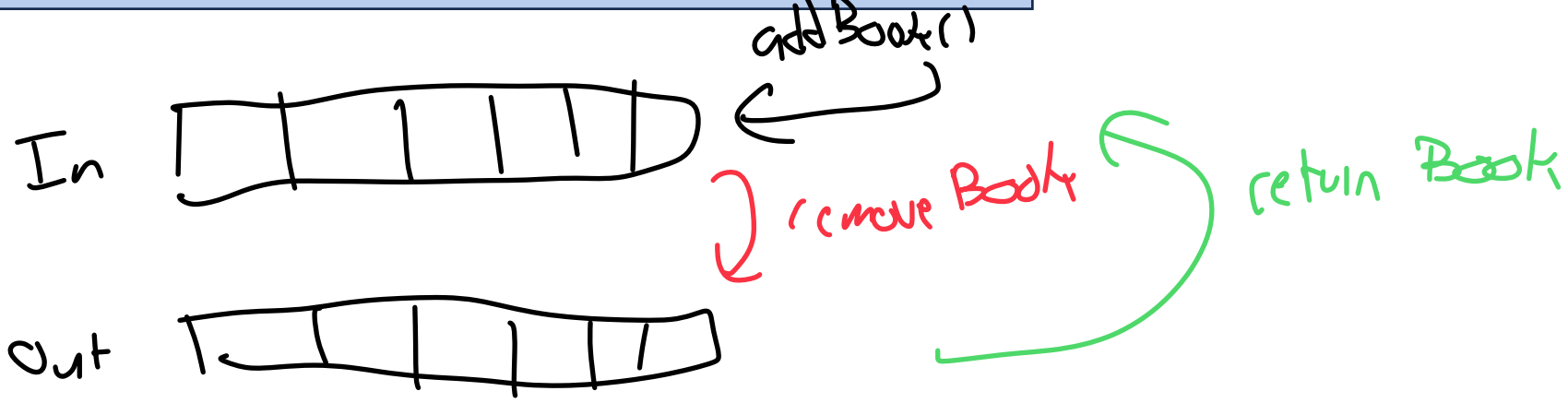
Function to search

By name → int

Memory Management — Ownership

Imagine I have a Library class (and hidden Book class):

```
 1 class Library{
 2 public:
 3     void addBook(Book * book);
 4     void removeBook(std::string title);
 5     void returnBook(Book * book);
 6
 7 private:
 8     std::vector<Book*> in;
 9     std::vector<Book*> out;
10 };
11
```



Memory Management — Ownership

Imagine I have a Library class:

```
1  class Library{
2  public:
3      void addBook(Book * book);
4      void removeBook(std::string title);
5      void returnBook(Book * book);
6
7  private:
8      std::vector<Book*> in;
9      std::vector<Book*> out;
10 };
11
```

Join Code: 225

Pretest: Does Library class 'own' the Books it is storing?

A) **Yes!** 22%

B) **No!** 70%

C) **Not sure** 8%

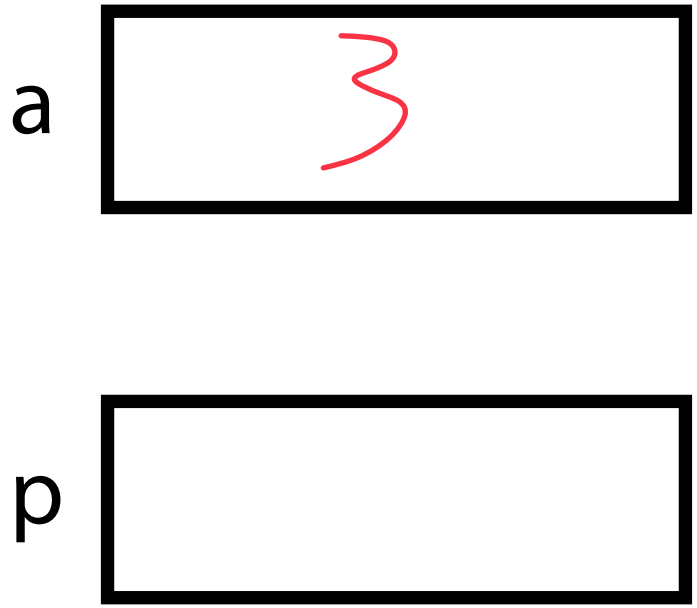
Pointers

Pointers store memory addresses

```
int a = 3;

int *p = &a;
```

address of



Pointers

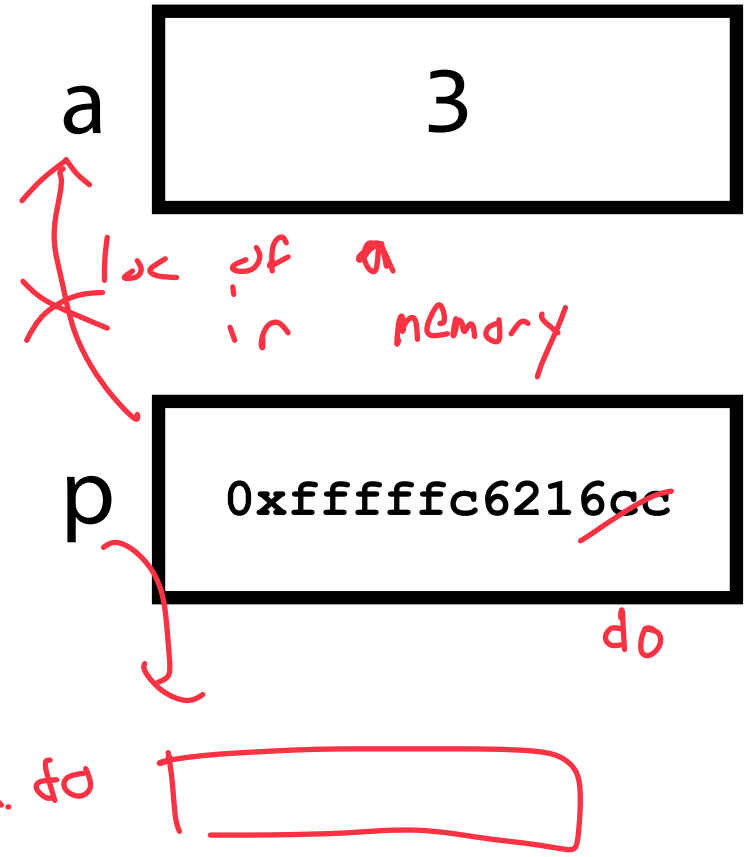
Pointers store memory addresses

```
int a = 3;

int *p = &a;

p++;
```

Does a change? Does p?



Pointers

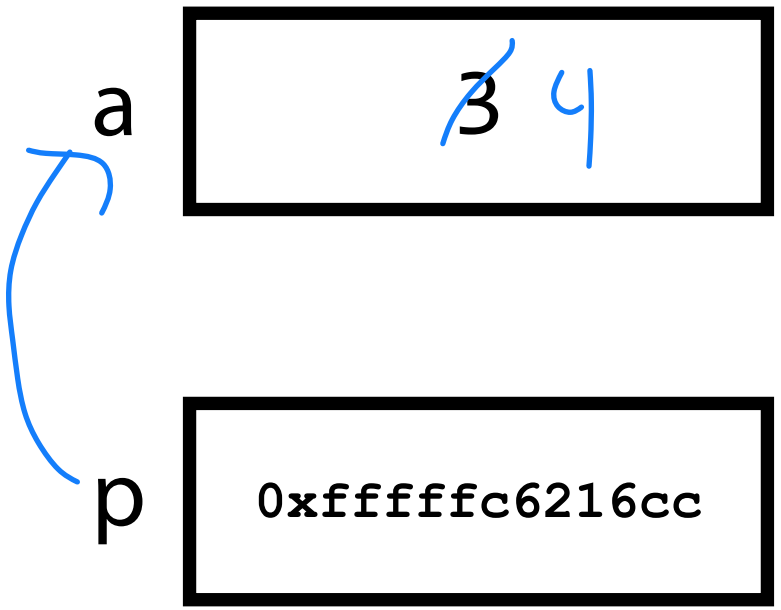
Pointers store memory addresses

```
int a = 3;

int *p = &a;

(*p)++;
```

dereference



Does a change? Does p?

Memory Management

Stack: Local variable storage

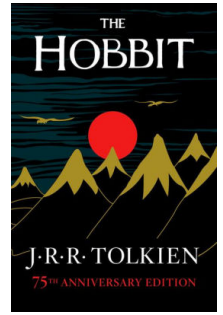
Ex: `int x = 5;`

Heap: Dynamic storage

Ex: `int* x = new int[5];`

↑ Must delete when done

Memory Management - Parameters



Pass by **Value:** A local copy of the original

Ex: addBook(Book book)

Pass by **Pointer to Value:** An address on the heap

Ex: addBook(Book* book)

Pass by **Reference:** An *alias* to an existing variable

Ex: addBook(Book& book)

Memory Management - Parameters

Which implementation do you prefer?

```
1  class Library {
2  public:
3      int numBooks;
4      std::string * titles;
5  };
6
7  // *** Function A ***
8  std::string getFirstBook(Library l){
9      return (l.numBooks > 0) ? l.titles[0] : "None";
10 }
11
12 // *** Function B ***
13 std::string getFirstBook(Library * l){
14     return(l->numBooks > 0) ? l->titles[0] : "None";
15 }
16
17 // *** Function C ***
18 std::string getFirstBook(Library & l){
19     return (l.numBooks > 0) ? l.titles[0] : "None";
20 }
21
22
23
24
```

10%

40%

50%

Memory Management

Local memory on the stack is managed by the computer

Heap memory allocated by **new** and freed by **delete**

Pass by value makes a copy of the object

Pass by pointer can be dereferenced to modify an object

Pass by reference modifies the object directly

Memory Management — Ownership

What does **ownership** mean in C++?

Defines who allocates/deallocates memory

Memory Management — Ownership

```
1  class Library{
2  public:
3      void addBook(Book * book);
4
5
6      void removeBook(std::string title);
7
8
9      void returnBook(Book * book);
10 private:
11
12     std::vector<Book*> in;
13
14
15     std::vector<Book*> out;
16
17
18 };
```

Does Library 'own' Books?

A) **Yes!** 17%.

B) **No!** 80%

C) **Not sure** 3%

Memory Management — Ownership

```
 1 class Library{
 2 public:
 3     void addBook(Book * book);
 4
 5
 6     void removeBook(std::string title);
 7
 8
 9     void returnBook(Book * book);
10 private:
11
12     std::vector<Book*> in;
13
14
15     std::vector<Book*> out;
16
17
18 };
```

Does Library 'own' Books?

A) **Yes!**

B) **No!**

C) **Not sure**

Are they destroyed when the Library destructor is called?

Books are somewhere else!

Memory Management — Ownership

```
1  class Library{
2  public:
3      void addBook(Book book);
4
5
6      void removeBook(std::string title);
7
8
9      void returnBook(Book book);
10 private:
11
12     std::vector<Book> in;
13
14
15     std::vector<Book> out;
16
17
18 };
```

Making a full copy

Vector of Book objects

Does Library 'own' Books?

A) **Yes!** 70%

B) **No!** 30%

C) **Not sure**

Memory Management — Ownership

```
1  class Library{
2  public:
3      void addBook(Book book);
4
5
6      void removeBook(std::string title);
7
8
9      void returnBook(Book book);
10 private:
11
12     std::vector<Book> in;
13
14
15     std::vector<Book> out;
16
17
18 };
```

Does Library 'own' Books?

A) **Yes!**

B) **No!**

C) **Not sure**

Are they destroyed when the Library destructor is called?

Library would delete vector which would delete Books

Memory Management — Ownership

```
1  class Library{
2  public:
3      void addBook(const Book& book);
4
5
6      void removeBook(std::string title);
7
8
9      void returnBook(const Book& book);
10 private:
11
12     std::vector<Book*> in;
13
14
15     std::vector<Book*> out;
16
17
18 };
```

Book * tmp = &book;

Does Library 'own' Books?

A) **Yes!** 33%

B) **No!** 66%

C) **Not sure**

Are they destroyed when the Library destructor is called?

Memory Management — Ownership

The owner of an object is responsible for its resource management (particularly allocation / deallocation)

A ‘litmus test’ of ownership — who handles destruction?

If we are storing pointers or references, not our problem!

Vector’s consolation prize — vector handles destruction

The Rule of Three

If it is necessary to **define any one** of these three functions in a class, it will be necessary to **define all three** of these functions:

1. Destructor — Called when we delete object

2. Copy Constructor — Make a new object as a copy of an existing one

3. Copy assignment operator — Assign value from existing X to Y

‘The Rule of Zero'

A corollary to Rule of Three

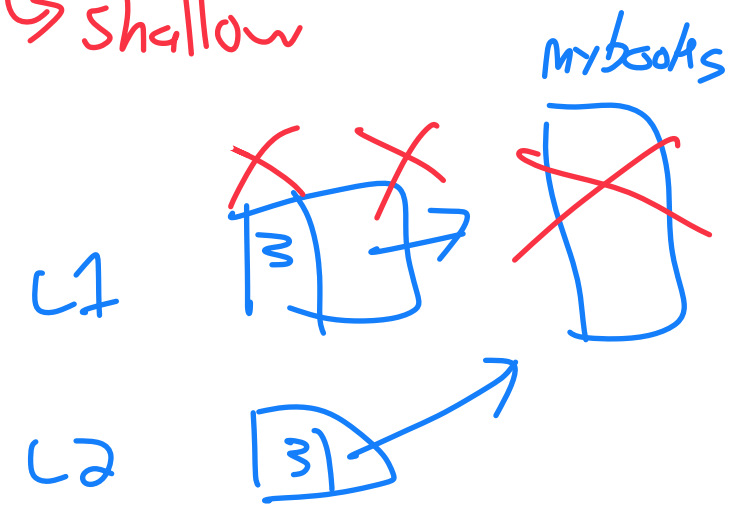
Classes that **declare** custom destructors, copy/move constructors or copy/move assignment operators should deal exclusively with ownership. Other classes **should not declare** custom destructors, copy/move constructors or copy/move assignment operators

— Scott Meyers

```
1  class Library {
2  public:
3      int numBooks;
4      std::string * titles;
5      ~Library();
6      Library( int num, std::string* list );
7  };
8
9  Library::~Library(){
10     delete titles;
11     titles = nullptr;
12 }
13
14 Library::Library(int num, std::string* list){
15     numBooks = inNum;
16     titles = new std::string[ inNum ];
17     std::copy(inList, inList + inNum, titles);
18 }
19
20 int main(){
21     std::string myBooks[3] = {"A", "B", "C"};
22     Library L1( 3, myBooks );
23     Library L2( L1 );
24     return 0;
25 }
```

automatically generate copy constructor

↳ shallow



```
1  class Library {
2  public:
3      int numBooks;
4      std::string * titles;
5      ~Library();
6      Library( int num, std::string* list );
7  };
8
9  Library::~Library(){
10     delete titles;
11     titles = nullptr;
12 }
13
14 Library::Library(int num, std::string* list){
15     numBooks = inNum;
16     titles = new std::string[ inNum ];
17     std::copy(inList, inList + inNum, titles);
18 }
19
20 int main(){
21     std::string myBooks[3] = {"A", "B", "C"};
22     Library L1( 3, myBooks );
23     Library L2( L1 );
24     return 0;
25 }
```

Whats wrong with this code?

A. Can't create L2 Library obj

B. Don't delete either Library

C. The second object being deleted crashes

Templates

A way to write generic code whose type is determined during completion

Stopped here for the day

Templates

A way to write generic code whose type is determined during completion

1. Templates are a recipe for code using generic types

Templates

A way to write generic code whose type is determined during completion

1. Templates are a recipe for code using generic types

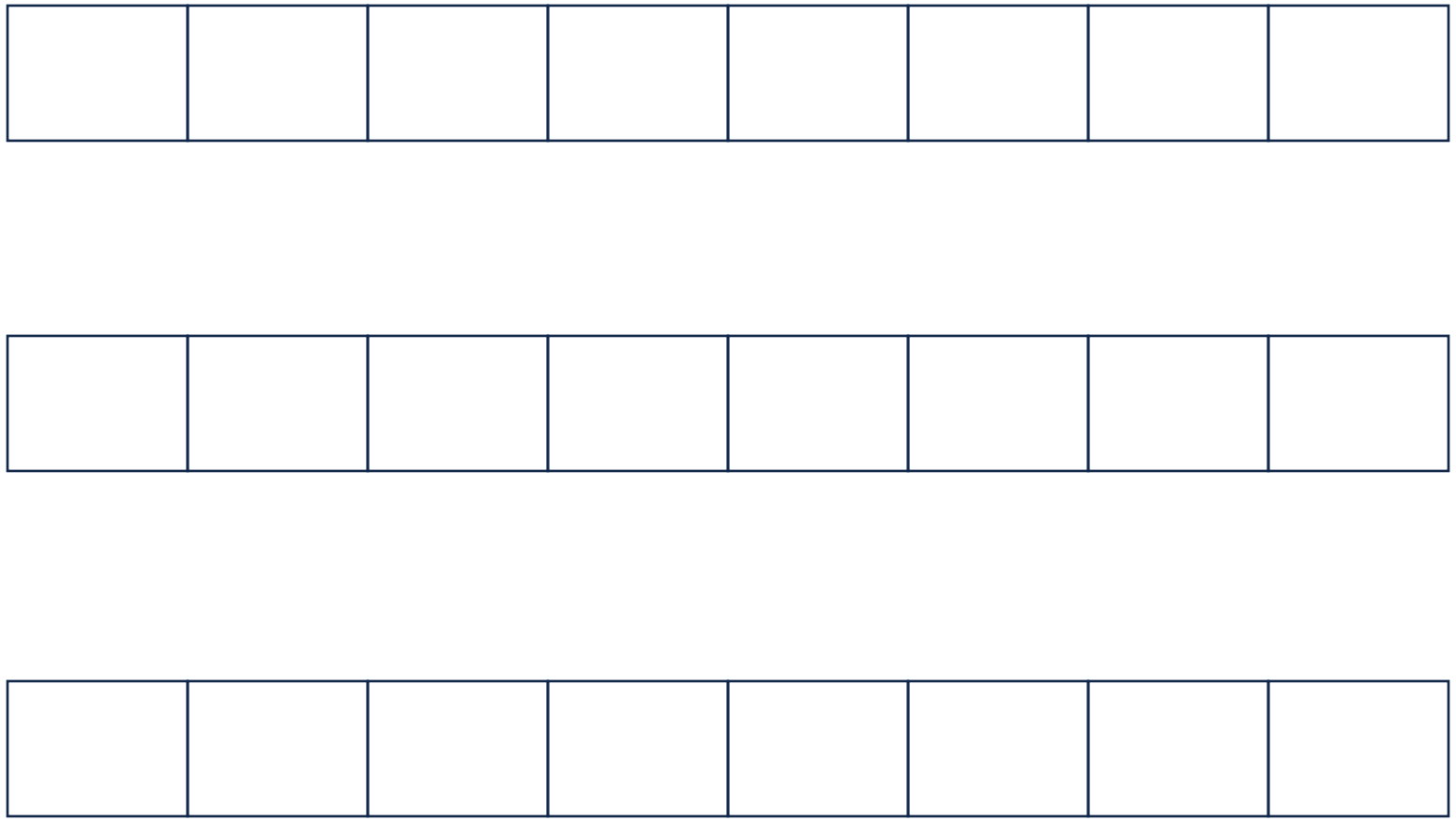
2. The compiler uses templates to generate C++ code **when needed**

```
template <typename T>
T sum(T a, T b){
...
}
```

template1.cpp

```
1  template <typename T>
2  T max(T a, T b) {
3    T result;
4    result = (a > b) ? a : b;
5    return result;
6  }
7
```

Templates are very useful!



List Abstract Data Type

What is the expected **interface** for a list?