Where Are We?
Data Abstraction
Introduction to Sequences
Array Interface

CS 311 Data Structures and Algorithms

Lecture Slides

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Unit Overview
Algorithmic Efficiency & Sorting

Major Topics

- ✓ Introduction to Analysis of Algorithms
- ✓ Introduction to Sorting
- ✓ Comparison Sorts I
- ✓ More on Big-O
- ✓ The Limits of Sorting
- ✓ Divide-and-Conquer
- ✓ Comparison Sorts II
- ✓ Comparison Sorts III
- ✓ Radix Sort
- ✓ Sorting in the C++ STL

DONE

Where Are We?
From the First Day of Class: Course Overview — Goals

After taking this class, you should:

- Have experience writing and documenting high-quality code.
- Understand how to write robust code with proper error handling.
- Be able to perform basic analyses of algorithmic efficiency, including use of "big-O" notation.
- Be familiar with various standard algorithms, including those for searching and sorting.
- Understand what data abstraction is, and how it relates to software design.
- Be familiar with standard data structures, including their implementations and relevant trade-offs.

The rest of the semester

We will also discuss this in more detail

Where Are We?
From the First Day of Class: Course Overview — Topics

The following topics will be covered, *roughly* in order:

- Advanced C++
- Software Engineering Concepts
- Recursion
- Searching
- Algorithmic Efficiency
- Sorting

DONE

- **Data Abstraction**
- **Basic Abstract Data Types & Data Structures:**
  - **Smart Arrays & Strings**
  - **Linked Lists**
  - **Stacks & Queues**
  - **Trees (various types)**
  - **Priority Queues**
  - **Tables**

Goal: Practical generic containers

A **container** is a data structure holding multiple items, usually all the same type.

A **generic** container is one that can hold objects of client-specified type.

- Other, as time permits: graph algorithms, external methods.

Where Are We?
The Big Problem

For most of the rest of the semester, we will be addressing the following problem:

- We have a collection of data items, all of the same type, that we wish to store.
- We need to be able to access items [retrieve/find, traverse], add new items [insert] and eliminate items [delete].
- All this needs to be efficient in both time and space.

Solutions to this problem are called “**containers**”.

- There are many good ones.
- Which one we use depends on many factors, including what priority we place on the various requirements above.

We are particularly interested in **generic containers**: containers in which client code can specify the type of data to be stored.

Unit Overview
Handling Data & Sequences

We now begin a unit on handling data and implementing Sequence data.

Major Topics

- Data abstraction
- Introduction to Sequences
- Smart arrays
  - Array interface
  - Basic array implementation
  - Exception safety
  - Allocation & efficiency
  - Generic containers
- Linked Lists
  - Node-based structures
  - More on Linked Lists
- Sequences in the C++ STL
- Stacks
- Queues

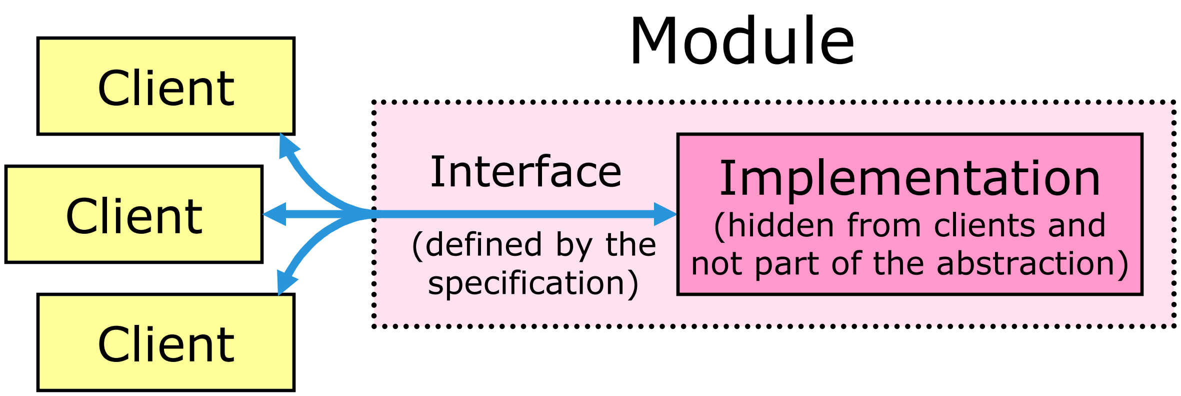
Some material is in chapters 3, 4, 6, and 7 in the text.

After this, we will look at trees.

Data Abstraction
Abstraction Again

Abstraction: Separate the purpose of a module from its implementation.

Recall: Function, class, or other unit of code. Generally smaller than a *package*.



We have been doing **functional abstraction**.

Now we look at **data abstraction**.

Data Abstraction
What is It?

In **data abstraction**, we separate the various aspects of dealing with data, from the implementation of the data:

- The conceptual form of the data.
- The **operations** available on the data.
- The method used to access the data.

Important concepts

- **Abstract data type** (ADT).
- **Interface**.

Data Abstraction
ADTs, Data Structures, Classes

Abstract data type (ADT):

- a **collection of data**, along with
- a **set of operations** on that data.

ADTs are independent of implementation, and even of programming language.

Data structure: a construct within a programming language that stores a collection of data.

C++ and some other programming languages include **classes**, which facilitate object-oriented programming.

- An important use of classes is the implementation of data structures, each of which is often conceptually based on some ADT.
- However, one can implement data structures without using classes.

Data Abstraction
ADT Example

Suppose we want to specify an ADT that holds exactly three pieces of information.

- We might call this ADT “Triple”.
- These are not assumed to be numeric or have any arithmetic properties at all. Rather, they are simply three pieces of data. Think of this as a list that always has size three.

What operations might such an ADT have?

- *The following were mentioned in class.*
  - *Data access (get/set).*
  - *Check equality.*
  - *Reorder.*
  - *Create.*
  - *Destroy.*
  - *Output.*

We *might* store the data for a Triple in an obvious data structure: three variables.

And we *might* implement all this using a class with three data members, and member functions implementing the various Triple operations.

Data Abstraction
Good Interfaces

When we implement a data structure, the idea of abstraction requires that we have a well defined **interface**.

Designing a good interface can be difficult. Here are some characteristics of a good interface.

An interface should be **complete**.

- All required operations should be *possible*.

We often strive for interfaces that are **minimal**.

- Avoid unnecessary functionality.

An interface should be **convenient**.

- Avoid making the interface a pain to use.

These two often pull in opposite directions.

We want to **facilitate efficiency**.

- Allow the data to be dealt with efficiently.

We often want our interface to be **generic**.

- Avoid restricting possible implementations and internal data types.

These two *can* pull in opposite directions.

Introduction to Sequences
What is a Sequence?

A **Sequence** is a collection of items that are in some order.

- We will restrict our attention to **finite** Sequences in which all items have the **same type**.
- It may help to think of an array here. However, there are other ways to store Sequences.

5	3	4	2	2	8	7	4	7	5	1	2

Questions

- What operations do we perform on Sequences?
- How can we implement a Sequence?
- How do we decide which implementation best fits any given circumstance?

Introduction to Sequences
ADT Sequence — Definition

ADT **Sequence**

- Data
  - An ordered sequence of values, all same type, indexed by 0, …, size-1.
- Operations
  - CreateEmpty
    - Creates empty Sequence (with size 0, i.e., no data).
  - CreateSized
    - Given a size, create a Sequence with that size.
  - Destroy
    - Destroys a Sequence.
  - Copy
    - Make a copy of a given Sequence.
  - LookUpByIndex
    - Given a valid index, returns Sequence item in modifiable form.
  - Size
    - Returns size of Sequence.
  - Empty
    - Returns whether the Sequence is empty, that is, has size zero.
  - Sort
    - Sort a Sequence, using some given comparison function.
  - Resize
    - Changes size of Sequence. Data for indices 0, …, min(old size, new size)–1 remains identical.
  - InsertByIter
    - Given an iterator (or pointer?) and an item, insert the item at the specified position.
  - RemoveByIter
    - Given an iterator, remove the item at that position.
  - InsertBeg
    - Given an item, insert it at the beginning.
  - RemoveBeg
    - Remove the first item.
  - InsertEnd
    - Like insertBeg, but at the end.
  - RemoveEnd
    - Like removeBeg, but at the end.
  - Splice
    - Move a contiguous subsequence from one Sequence to another.
  - Traverse
    - Performs some operation on every item in the Sequence, in order.
  - Swap
    - Exchange the values of two given Sequences.

Introduction to Sequences
ADT SortedSequence — Introduction

It is common to keep Sequence data sorted.

However, this changes the operations available.

- Operations that mess up the ordering are now disallowed.
- New operations, that make use of the ordering, become possible.

Therefore, we define another ADT, SortedSequence.

- Essentially, a SortedSequence is a Sequence in which the items are always kept sorted according to some comparison function.
- This is similar to Sorted List, in the text on pages 133–134.

Introduction to Sequences
ADT SortedSequence — Draft

ADT **SortedSequence** (draft)

- Data
  - An ordered list of values, all same type, indexed by 0, …, size-1, **in ascending order**.
- Operations
  - CreateEmpty
    - Creates empty SortedSequence (with size 0, i.e., no data).
  - CreateSized
    - Given a size, create a SortedSequence with that size.
  - Destroy
    - Destroys a SortedSequence.
  - Copy
    - Make a copy of a given SortedSequence.
  - LookUpByIndex
    - Given a valid index, returns SortedSequence item in modifiable form.
  - Size
    - Returns size of SortedSequence.
  - Empty
    - Returns whether the SortedSequence is empty, that is, has size zero.
  - Sort
    - Sort a SortedSequence, using some given comparison function.
- Resize
  - Changes size of SortedSequence. Data for indices 0, …, min(old size, new size)–1 remains identical.
- InsertByIter
  - Given an iterator (or pointer?) and an item, insert the item at the specified position.
- RemoveByIter
  - Given an iterator, remove the item at that position.
- InsertBeg
  - Given an item, insert it at the beginning.
- RemoveBeg
  - Remove the first item.
- InsertEnd
  - Like insertBeg, but at the end.
- RemoveEnd
  - Like removeBeg, but at the end.
- Splice
  - Move a contiguous subsequence from one Sequence to another.
- Traverse
  - Performs some operation on every item in the SortedSequence, in order.
- Swap
  - Exchange the values of two given SortedSequences.

Iffy …

Problems

Pointless or problematic

But if we get rid of the "problems", how can we add new items?

Introduction to Sequences
ADT SortedSequence — Improved

ADT **SortedSequence** (final)

- Data
  - An ordered list of values, all same type, indexed by 0, …, size-1, in ascending order, by some given comparison function.
- Operations
  - CreateEmpty
    - Creates empty SortedSequence (with size 0, that is, no data).
  - Destroy
    - Destroys a SortedSequence.
  - Copy
    - Make a copy of a given SortedSequence.
  - LookUpByIndex
    - Given a valid index, returns SortedSequence item in **non-modifiable** form.
  - Size
    - Returns size of SortedSequence.
  - Empty
    - Returns whether the SortedSequence is empty, that is, has size zero.

- **InsertByValue**
  - Given an item, insert it.
- **RemoveByValue**
  - Given a value, remove it.
- RemoveByIter
  - Given an iterator, remove item at that position.
- Traverse
  - Performs some operation on every item in the SortedSequence, in order.
- Swap
  - Exchange the values of two given SortedSequences.
- **Find**
  - Given value, find item(s) with equivalent value, if any exist.

ADT SortedSequence — What is it For?

In practice, the ordering of a SortedSequence is often of little importance. Rather, are interested in items being **easy to find**.

What can we do with this?

- First, we can store **Set data**. In a Set, we only care *whether* an item is in the container, not *where* it is.

Now suppose we have a SortedSequence whose items are pairs, and a comparison function that compares only the *first parts* of each pair. What is this good for?

(102, "John Smith")	(388, "Mary Jones")	(497, "Zyzzy Zyzz")	(562, "Ig Ogg")	(732, "Adam A.")

- **Key-based look-up**.
  - The first part of each pair is the **key**.
- “Arrays” (kind of), where the thing between the brackets does not have to be a nonnegative integer.
- That is, **Tables** (a.k.a. “dictionaries”, “associative arrays”, “maps”).

Introduction to Sequences
ADT SortedSequence — P.O. vs. V.O.

We conclude that, despite the similarities of Sequence and SortedSequence, there is a fundamental difference.

- Sequence handles an item according to its **position** (index) in the container.
- SortedSequence handles an item primarily according to its **value**.

Two Types of ADTs

- Sequence is a **position-oriented** ADT.
- SortedSequence is a **value-oriented** ADT.

SortedSequence is a bit inadequate as a value-oriented ADT.

- We often do not care about SortedSequence being a Sequence.
- Rather, we want to use it to store Set or Table data.
- Maybe we should break it away from its Sequence origins?

Important Questions (to be examined later)

- What do we really want from a value-oriented ADT?
- How does one implement these in efficient ways?

Array Interface Start

We wish to implement a Sequence using a “smart” array.

- It should know its size, be able to copy itself, etc.
  - Just like in Assignment 2.
- It should also be able to *change* its size.
  - Recall that the ADT has resize and various insert/remove operations.

Basic Ideas

- Use a C++ class. An object of the class implements a single Sequence.
- Many (most? all?) of the ADT Sequence operations should be implemented using class member functions.
- Use iterators, operators, ctors, and the dctor in the usual ways.
- *Every* function in the interface should exist in order to implement, or somehow make possible, an ADT operation.

Array Interface
By ADT Operation

Use iterators to handle positions, traversing.

ADT Operations

- CreateEmpty
  - Default ctor.
- CreateSized
  - Ctor given size.
- Destroy
  - Dctor.
- Copy
  - Copy ctor & copy assignment.
- LookUpByIndex
  - Bracket operator.
- Size
  - Member function "**`size`**".
- Empty
  - Member function "**`empty`**".
- Sort
  - Handle externally, using iterators. Use iterator-returning member functions "**`begin`**" and "**`end`**".
- Resize
  - Member function "**`resize`**".
- InsertByIter, InsertBeg, InsertEnd
  - Member function "**`insert`**" does InsertByIter.
  - Use in conjunction with iterator-returning functions to do InsertBeg, InsertEnd.
- RemoveByIter, RemoveBeg, RemoveEnd.
  - As above, using "**`remove`**".
- Splice
  - Call **`resize`**, then copy using **`op[]`**.
- Traverse
  - Use iterator-returning member functions "**`begin`**" and "**`end`**".
- Swap
  - Member function "**`swap`**".

Array Interface Summary

Ctors & Dctor

- Default ctor
- Ctor given size
- Copy ctor
- Dctor

Member Operators

- Copy assignment
- Bracket

Global Operators

- *None*

Associated Global Functions

- *None*

Named Public Member Functions

- **`size`**
- **`empty`**
- **`begin`**
- **`end`**
- **`resize`**
- **`insert`**
- **`remove`**
- **`swap`**

Array Interface Details

For most of the member functions in our class, it is pretty obvious what the function prototype should look like.

However, three of them are a little tricky:

- **`insert`**
  - Takes an iterator and an item.
  - Inserts the item just *before* the position referenced by the iterator.
  - Return value is an iterator to the inserted item.
- **`remove`**
  - Takes an iterator.
  - Removes the item referenced by the iterator.
  - Return value is an iterator to the item following the one removed.
- **`swap`**
  - Takes another Sequence, by reference.
  - Exchanges the values of this Sequence and the given one.
  - No return value.