Basic Array Implementation
Exception Safety

CS 311 Data Structures and Algorithms
Lecture Slides
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Chris Hartman
Department of Computer Science
University of Alaska Fairbanks
cmhartman@alaska.edu
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Unit Overview
Handling Data & Sequences

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

Review
Where Are We? — The Big Problem

Our problem for much of the rest of the semester:

- Store: a collection of data items, all of the same type.
- Operations:
  - Access items [one item: retrieve/find, all items: traverse].
  - Add new item [insert].
  - Eliminate existing item [delete].
- All this needs to be efficient in both time and space.

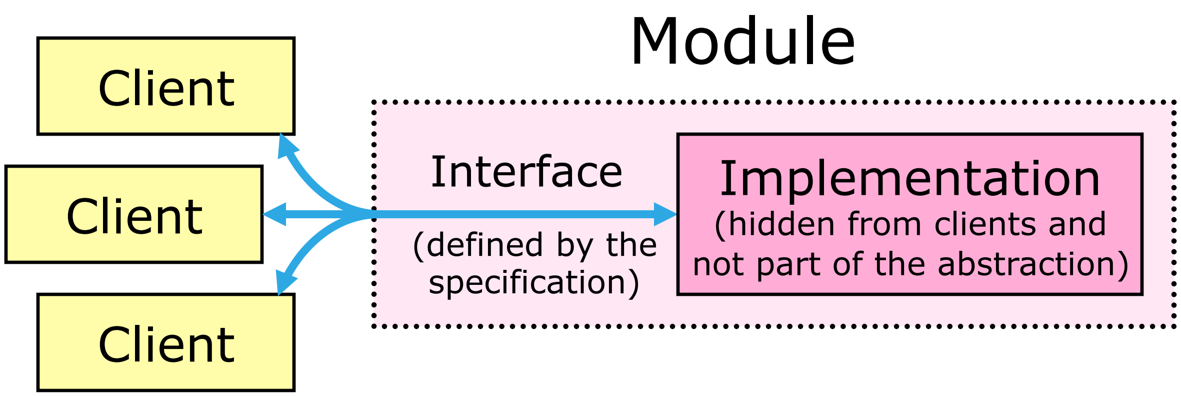
A solution to this problem is a **container**.

Generic containers: those in which client code can specify the type of data stored.

Review
Data Abstraction [1/4]

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**.

Review
Data Abstraction [2/4]

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**.

Review
Data Abstraction [3/4]

Abstract data type (ADT)

- A **collection of data**, along with a **set of operations** on that data.
- Independent of implementation and programming language.
- Examples: Sequence, SortedSequence.

Data structure

- A construct within a programming language that stores a collection of data.
- Examples: Array, Linked List.

Class

- A language feature in C++ and some other languages, intended to facilitate OOP.
- In C++ we *usually* implement a data structure using a class. However, we are not required to.
- Examples: **`std::vector<int>`**, **`std::list<double>`**.

Review
Data Abstraction [4/4]

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.

Review
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?

Review
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.

Review
Introduction to Sequences — ADT SortedSequence

SortedSequence: like Sequence, except that items are kept sorted.

Despite superficial similarity, a SortedSequence is fundamentally a different kind of thing from a Sequence.

- In practice, the ordering of a SortedSequence is often of little importance. Rather, are interested in items being **easy to find**.
- Sequence is a **position-oriented** ADT.
- SortedSequence is a **value-oriented** ADT.

SortedSequence can be used for:

- **Set** data.
- **Table** data.

Key-based look-up

We will get back to value-oriented ADTs later in the semester.

Review
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`**”.

Review
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`**

Basic Array Implementation
Introduction

In C++ we usually implement a data structure using a **class**.

- Operations are usually implemented using member functions.
- Some operations may need to be global functions, but they are still associated with the class, and are defined in the class's header and/or source files.
- Sometimes we need helper classes. These are probably not visible to client code.

The public interface is all that client code sees.

- Every operation should be implemented so that clients can use it.
- Make no functions available to client code that do not implement publicly available operations.
- In C++ this means that we give our class no public member functions that do not implement publicly available operations. We also do not declare global helper functions *in the header*.
- We can write any *private* functions we might need.
- We may wish to define public types, to help the client deal with the data.

Basic Array Implementation
General

Call our class "**`SmArray`**".

What type should a data item be?

What type should the size of a **`SmArray`** be?

How should we store the data?

How should we implement the iterators?

Have member types, as in STL containers: **`value_type`**, **`size_type`**, **`iterator`**, **`const_iterator`**.

Basic Array Implementation
General

Call our class "**`SmArray`**".

What type should a data item be?

- Use **`int`** for the value type (for now).
  - You will make it generic in Assignment 5.

What type should the size of a **`SmArray`** be?

- Use **`std::size_t`**.

How should we store the data?

- Use a dynamically allocated array of **`int`**s.
- Note: We could have used a separate RAII class, like **`IntArray`**.

How should we implement the iterators?

- Use pointers (**`int *`**, **`const int *`**).

Have member types, as in STL containers: **`value_type`**, **`size_type`**, **`iterator`**, **`const_iterator`**.

- This allows us to easily tell what a value is for.
- Also, we can easily change (say) the value type.

Basic Array Implementation Details

What data members should class **`SmArray`** have?

What class invariants should it have?

What should **`operator[]`** return? Should it be const or not?

What should **`begin`**, **`end`** return? Should they be const or not?

What about the Big Three? Can we use silently written functions?

Basic Array Implementation Details

What data members should class **SmArray** have?

- Size of the array: **size_type _size;**
- Pointer to the array: **value_type * _data;**

What class invariants should it have?

- Member "**_size**" should be nonnegative.
- Member "**_data**" should point to an **int** array, allocated with **new []**, owned by ***this**, holding **_size** **int**s.

What should **operator[]** return? Should it be const or not?

- We need two versions: non-const and const.
- The non-const version returns **value_type &**.
- The const version returns **const value_type &**.

What should **begin**, **end** return? Should they be const or not?

- As with **operator[]**, we need two versions.
- Non-const versions return **iterator**, const versions return **const_iterator**.

What about the Big Three? Can we use silently written functions?

- No. We are directly managing an owned resource.

Note: This design has a serious (but not obvious) problem, as we will see.

TO DO

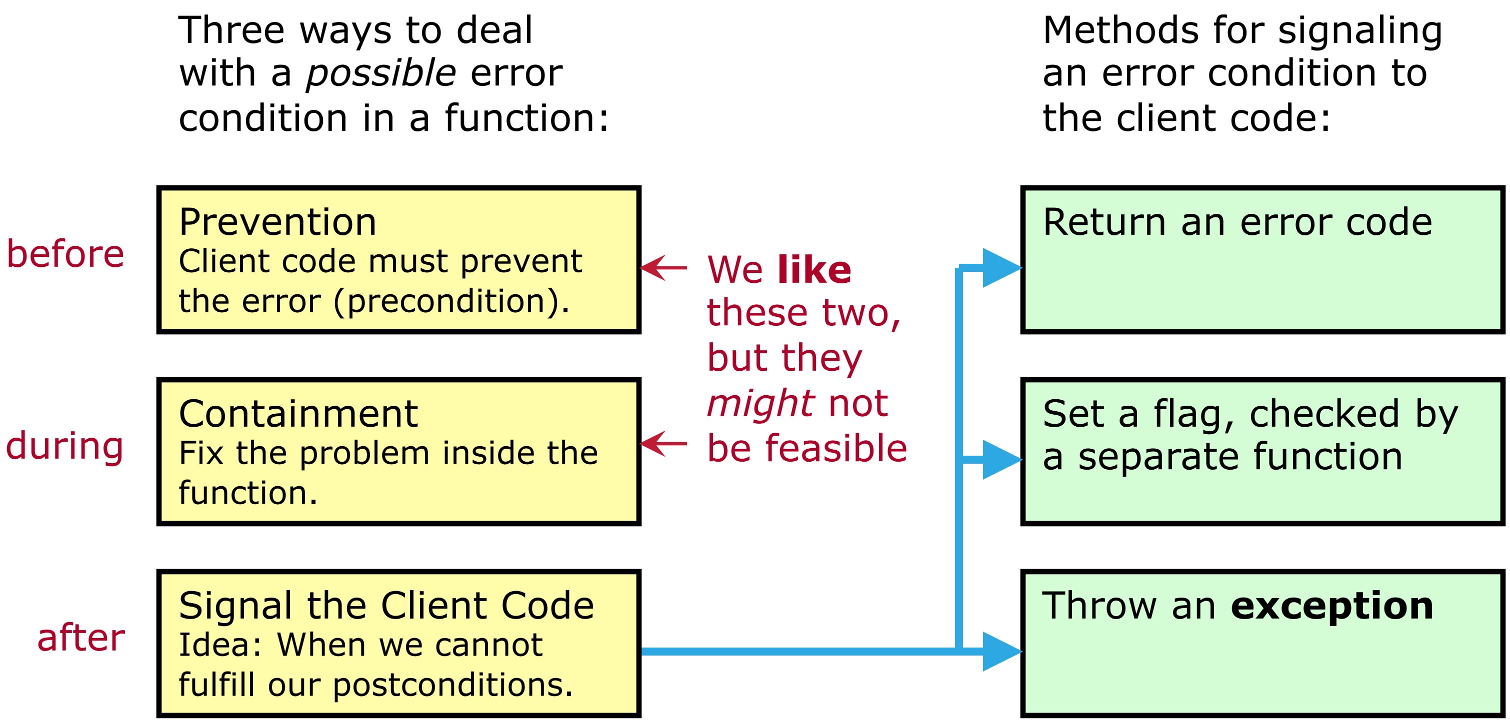
- Write *some* of class **`SmArray`**, as described.

Note: We will be writing and improving this class in various ways in the next few days. Your job in Assignment 5 will be to finish it, including turning it into a generic container class.

Exception Safety
Refresher — Error Handling

An **error condition** (or “error”) is a condition occurring during runtime that cannot be handled by the normal flow of execution.

- Not necessarily a bug or a user mistake.
- Example: Could not read file.



Exception Safety
Refresher — Introduction to Exceptions [1/4]

Exceptions are objects that are "**thrown**", generally to signal error conditions.

- We **catch** exceptions using a **`try`** … **`catch`** construction.
- "**`throw`**" backs out of blocks & functions, until a matching **`catch`** is found.
- An uncaught exception terminates the program.

```
Foo * makeAFoo() // throw(std::bad_alloc)
{ return new Foo(2, 3); }

void myFunc() // throw()
{
    Foo * p;
    try {
        p = makeAFoo();
    }
    catch (std::bad_alloc & e) {
        allocationSuccessful = false;
        cout << "Oops! Message: " << e.what() << endl;
    }
```

Catch by reference.

Exception Safety
Refresher — Introduction to Exceptions [2/4]

We can throw our own exceptions, using “**`throw`**”.

```
class Foo {
public:
    int & operator[](int index)  // May throw std::range_error
    {
        if (index < 0 || index >= arraySize)
            throw std::range_error("Foo: index out of range");
        return theArray[index];
    }
private:
    int * theArray;
    std::size_t arraySize;
};
```

We only do this when we must signal the client code that an error condition has occurred. (In data structures, this is rare.)

Exception Safety
Refresher — Introduction to Exceptions [3/4]

We can catch **all** exceptions, using "...".

- In this case, we do not get to look at the exception, since we do not know what type it is.

```
try {
    myFunc4(17);
}
catch (...) {
    fixThingsUp();
    throw;
}
```

- Inside any **`catch`** block, we can **re-throw the same exception** using **`throw`** with no parameters.

Exception Safety
Refresher — Introduction to Exceptions [4/4]

The following can throw in C++:

- "**`throw`**" throws.
- "**`new`**" may throw **`std::bad_alloc`** if it cannot allocate.
- A function that (1) calls a function that throws, and (2) does not catch the exception, will throw.
- Functions written by others may throw. See their doc's.

The following do *not* throw:

- Built-in operations on built-in types.
  - Including the built-in **`operator[]`**.
- Deallocation done by the built-in version of "**`delete`**".
  - Note: "**`delete`**" also calls destructors. These can throw.
- C++ Standard I/O Libraries (default behavior)

If a destructor is called between a throw and a catch, and that destructor throws, then the program terminates.

- Therefore, **destructors should not throw**.

Exception Safety
TO BE CONTINUED …

Exception Safety will be continued next time.