Ve 280

Programming and Introductory Data Structures

Abstract Data Types

Announcement

- No lecture on June 20 (next Tuesday)
  - Already have had a make-up

Outline

- Introduction to Abstract Data Types
- Class in C++: A Trivial Example
- More Details on Class
- Another Class Example: a Mutable Set of Integers

Types

- The role of a type:
  - The set of values that can be represented by items of the type
  - The set of operations that can be performed on items of the type.

- Example
  - C++ string values:

    operations:

Struct Types

- Struct types have the following feature:
  - **Every detail** of the type is known to all users of that type.
  - This is sometimes called the **concrete implementation**.

- Example: the `struct Grades` talked before.

```
struct Grades {
   char name[9];
   int  midterm;
   int  final;
};
```

Struct Types

```
struct Grades {
  char name[9];
  int  midterm;
  int  final;
};
```

- Every function knows the details of exactly how `Grades` are represented.
- A change to the `Grades` definition (for example, change C-string for `name` to a C++-String) requires that we **make changes throughout the program** and recompile everything using this struct.

Abstract Data Types

Introduction

- Contrast the property of struct types with that of the functions
  - A function written by others shows **what** the function does, but not **how** it does it
- For function, if we find a faster way to implement, we can just replace the old implementation with the new one
  - No other components of the program calling the function need to change

Abstract Data Types

Introduction

- To solve the problem for struct type, we'll define **abstract data types**, or **ADTs**.
- An ADT provides an **abstract description** of **values** and **operations**.
- The definition of an ADT must combine **both** some notion of **what** values that type represents, and **what** operations on values it supports.
  - However, we can leave off the details of **how**.
- Example: mobile phone
  - Type: a portable telephone that can make and receive calls
  - Operations: turn on/off, make/receive call, text message

We don't know details!

Abstract Data Types

Introduction

- Abstract data types provide the following two advantages:

1. Information hiding: we don't need to know the details of how the **object** is **represented**, nor do we need to know how the **operations on those objects** are **implemented**.
2. Encapsulation: the objects and their operations are defined in the same place; the ADT combines both data and operation in one entity.

Abstract Data Types

Example

- `list_t`:
  - Information Hiding: In the `list_t` data type, you never knew the precise implementation of the `list_t` structure (except by looking in `recursive.cpp`).
  - Encapsulation: The definitions of the operations on lists (`list_print`, `list_make`, etc.) were found in the same header file as the type definition of `list_t`.

Abstract Data Types

Benefits

- Abstract data types have several benefits like we had with functional abstraction:
  - ADTs are **local**: the implementation of other components of the program does not depend on the **implementation** of ADT.
    - To realize other components, you only need to focus **locally**.
  - ADTs are **substitutable**: you can change the implementation and no users of that type can tell.

Abstract Data Types

Introduction

- Someone still needs to know/access the details of how the type is implemented.
  - I.e., how the values are represented and how the operations are implemented
  - This is referred to as the "**concrete representation**" or just the "**representation**"

- Question: Who can access the representation?
- Answer: **only** the operations defined for that type should have access to the representation.
  - Everyone else may access/modify this state only **through** operations.

Abstract Data Types

On to Classes

- C++ "class" provides a mechanism to give **true** encapsulation.

- The basic idea behind a class is to provide **a single entity** that both defines:
  - The **value** of an object.
  - The **operations** available on that object. These operations are sometimes also called **member functions** or **methods**.

Outline

- Introduction to Abstract Data Types
- Class in C++: A Trivial Example
- More Details on Class
- Another Class Example: a Mutable Set of Integers

Abstract Data Types

Classes – A trivial example

```
class anInt {
    // OVERVIEW: a trivial class to get/set a
    //           single integer value
    int    v;
public:
    int    get_value();
           // EFFECTS: returns the current
           //          value
    void   set_value(int newValue);
           // MODIFIES: this
           // EFFECTS: sets the current value
           // equal to newValue
};
```

Abstract Data Types

Classes – A trivial example

```
class anInt {
    // OVERVIEW: a trivial class to get/set a
    //           single integer value
    int      v;
  public:
    int      get_value();
             // EFFECTS: returns the current
             //          value
    void     set_value(int newValue);
             // RME: Omitted for space
};
```

- There are a few things to notice about this definition:
  - There is a single OVERVIEW specification that describes the class as a whole.

Abstract Data Types

Classes – A trivial example

```
class anInt {
    // OVERVIEW: Omitted for space
    int     v;
  public:
    int     get_value();
        // EFFECTS: returns the current value
    void    set_value(int newValue);
        // RME: Omitted for space
};
```

- There are a few things to notice about this definition:
  - The declaration includes both data elements (`int v`) and member functions/methods (`get_value` and `set_value`).

Abstract Data Types

Classes – A trivial example

```
class anInt {
    // OVERVIEW: Omitted for space
    int    v;
  public:
    int    get_value();
           // EFFECTS: returns the current
           //          value
    void   set_value(int newValue);
           // MODIFIES: this
           // EFFECTS: sets the current value
           // equal to arg
};
```

- There are a few things to notice about this definition:
  - Each function that is declared must have a corresponding specification.

Abstract Data Types

Classes – A trivial example

```
class anInt {
    // OVERVIEW: Omitted for space
    int    v;
  public:
    int    get_value();
          // EFFECTS: returns the current value
    void   set_value(int newValue);
           // MODIFIES: this
           // EFFECTS: sets the current value
           // equal to arg
};
```

- There are a few things to notice about this definition:
  - `set_value` says it MODIFIES `this`. This is the generic name for "**this object**".

Outline

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Abstract Data Types

Classes – More Details

- By default, every member of a class is **`private`**.
  - Members = data members + function members
- A private member is visible only to **other members** of this class.
  - `int v` was a private member in the class `anInt`.
  - "Private" hides the implementation of the type from the user.

Abstract Data Types

Classes – More Details

- However, if everything were private, the class wouldn't be particularly useful!
- So, the **`public`** keyword is used to signify that some members are **visible** to anyone who sees the class declaration, not just visible to other members of this class.
  - Everything **after** the **`public`** keyword is **visible** to others.

Abstract Data Types

Classes – A trivial example

```
class anInt {
    // OVERVIEW: a trivial class to get/set a
    //           single integer value
    int    v;
  public:
    int    get_value();
           // EFFECTS: returns the current
           //          value
    void   set_value(int newValue);
           // MODIFIES: this
           // EFFECTS: sets the current value
           // equal to arg
};
```

Abstract Data Types

Classes – A trivial example

This declaration, as it is, is incomplete. We have not yet defined the bodies of the member functions.

```
class anInt {
    // OVERVIEW: a trivial class to get/set a
    //           single integer value
    int    v;
  public:
    int    get_value();
           // EFFECTS: returns the current
           //          value
    void   set_value(int newValue);
           // MODIFIES: this
           // EFFECTS: sets the current value
           // equal to arg
};
```

Abstract Data Types

Classes – Defining member functions

```
class anInt {
    // OVERVIEW: a trivial class to get/set a
    //           single integer value
```

Note: You can actually define the functions within the class definition, but this "exposes" information, which is best left hidden!

```
int anInt::get_value() {
  return v;
}
void anInt::set_value(int newValue) {
  v = newValue;
}
```

The definitions of member functions are usually put in the .cpp file

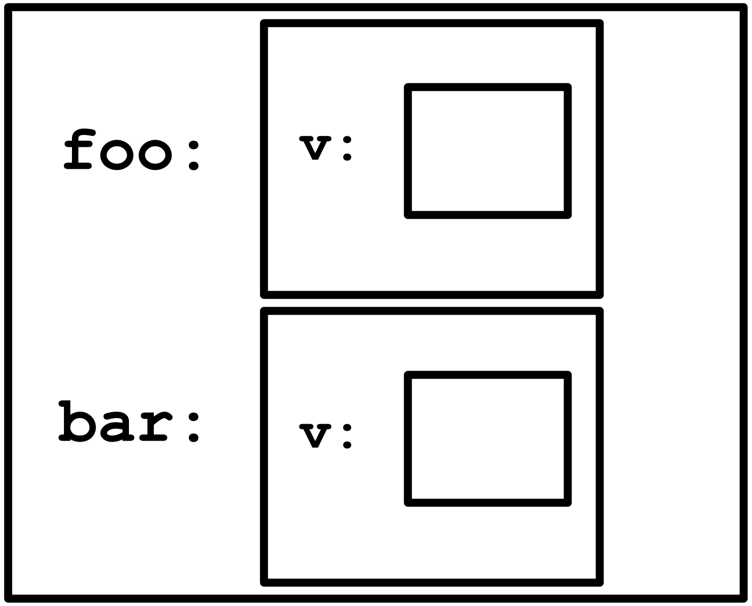
Abstract Data Types

Classes – Declaring class objects

- We can declare **objects** of type `anInt` as you would expect:

```
anInt     foo;
anInt     bar;
```

- This produces an environment with two objects:



These values are still undefined (i.e. there is no initial value). We'll see several ways to set an initial value for data members later.

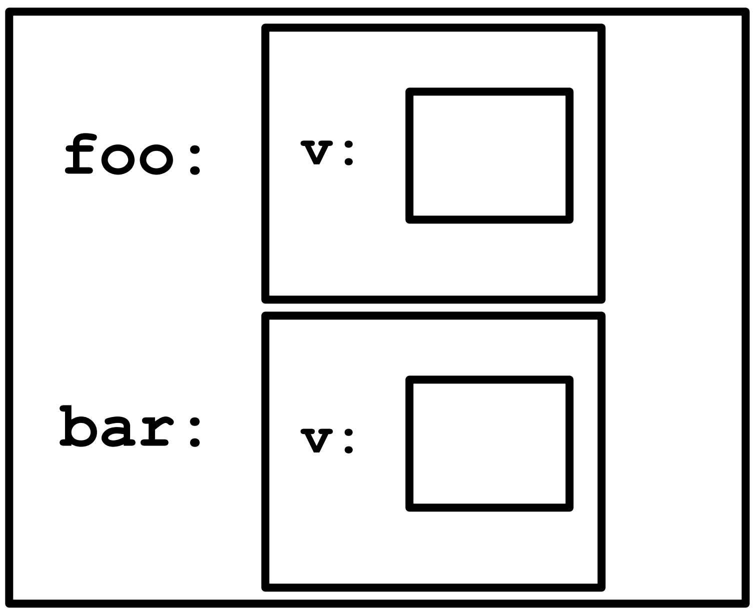
Abstract Data Types

Classes – Establishing data member values

- We can call the set_value member function to establish a value:

```
foo.set_value(1);
```

This calls foo's set_value() method.



Abstract Data Types

Classes – Establishing data member values

- There is one very important difference between <u>normal</u> function calls and **member** function calls:
  - The **other** members of the object are **also visible** to the function members!
  - For example, `v` is visible to the function `set_value()`

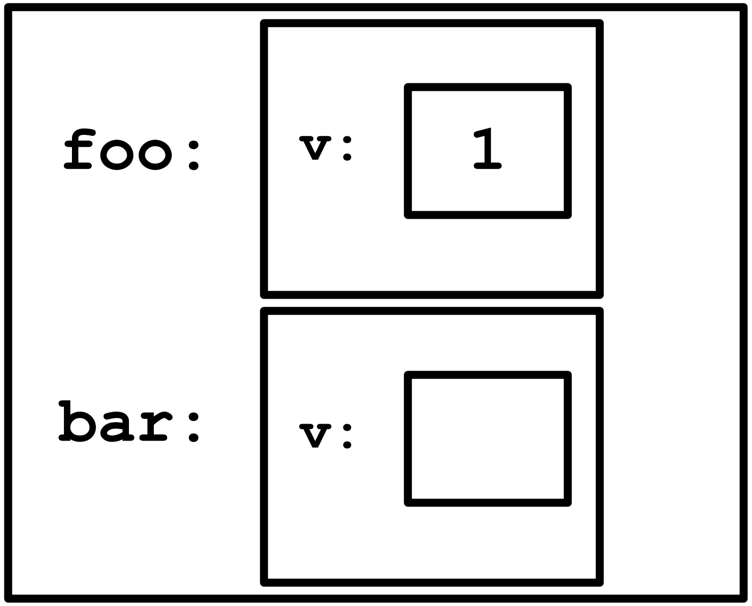
```
void anInt::set_value(int newValue) {
  v = newValue;
}
```

Abstract Data Types

Classes – Establishing data member values

- So, set value changes **`foo`**'s `v`:

```
foo.set_value(1);
```



Abstract Data Types

Classes – Accessing data member values

- We can't access v directly:

```
cout << foo.v; // Compile-time error
```

  because `v` is **private**!

- However, we can use the get_value() method to do so for us:

```
cout << foo.get_value(); // OK.
```

  because `get_value()` is **public**!

- Finally, class objects can be passed just like anything else.
- Like everything else (except arrays), they are passed by value.

Abstract Data Types

Class Example: Classes

- What is the result of the following?

```
void add_one(anInt i) {
  i.set_value(i.get_value()+1);
}
int main() {
  anInt foo;
  foo.set_value(0);
  add_one(foo);
  cout << foo.get_value() << endl;
  return 0;
}
```

Abstract Data Types

Classes – Passing by reference

- To pass a class object by reference, you use either a pointer argument or a reference argument, i.e.:

```
void add_one(anInt *ip) {
  ip->set_value(ip->get_value() + 1);
}
```

- This version would change the class object passed to it!

Outline

- Introduction to Abstract Data Types
- Class in C++: A Trivial Example
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- Another Class Example: a Mutable Set of Integers

Abstract Data Types

Using Classes

- Suppose we wanted to build an abstraction that held a **mutable** set of integers.

- This is a **set** in the mathematical sense:
  - A collection of zero or more integers, with **no duplicates**.

- The set is "mutable" because we can insert values into and remove objects from the set.

Abstract Data Types

Using Classes

- Suppose we wanted to build an abstraction that held a **mutable** set of integers.

- There are four **operations** on this set that we will define:
  1. Insert a value into the set.
  2. Remove a value from the set.
  3. Query to see if a value is in the set.
  4. Count the number of elements in the set.

Abstract Data Types

Using Classes

- Here is an **incomplete** definition of a class implementing such an ADT:

```
class IntSet {
    // OVERVIEW: a mutable set of integers

  public:
    void insert(int v);
      // MODIFIES: this
      // EFFECTS: this = this + {v}
    void remove(int v);
      // MODIFIES: this
      // EFFECTS: this = this - {v}
    bool query(int v);
      // EFFECTS: returns true if v is in this,
      //          false otherwise
    int  size();
      // EFFECTS: returns |this|.
};
```

Abstract Data Types

Using Classes

```
class IntSet { // omitted OVERVIEW for space
  public:
    void insert(int v); // omitted RME for space
    void remove(int v); // omitted RME for space
    bool query(int v); // omitted RME for space
    int  size(); // omitted RME for space
};
```

- The class is incomplete because we haven't chosen a **representation** for sets.
- Choosing a representation involves two things:
  - Deciding what **concrete** data elements will be used to **represent the values** of the set.
  - Providing an **implementation** for each **method**.

Abstract Data Types

Using Classes

```
class IntSet { // omitted OVERVIEW for space
  public:
    void insert(int v); // omitted RME for space
    void remove(int v); // omitted RME for space
    bool query(int v); // omitted RME for space
    int  size(); // omitted RME for space
};
```

- Despite not having a representation for a set, the (incomplete) definition above is all that a **customer** of the `IntSet` abstraction needs to know since it has:
  - The general overview of the ADT.
  - The specification of each method.

Abstract Data Types

Using Classes

- Start with a representation for the set itself:
  - Use an array.
  - Represent a set of size N as an **unordered** array of integers with no duplicates, stored in the first N slots of the array.
  - `int numElts`: maintains the number of elements currently in the array.

rep invariant

- These last two statements are called **representation invariants** or **rep invariants** (more on this later).
- This invariant is a rule that the representation must obey both **immediately before** and **immediately after** any method's execution.

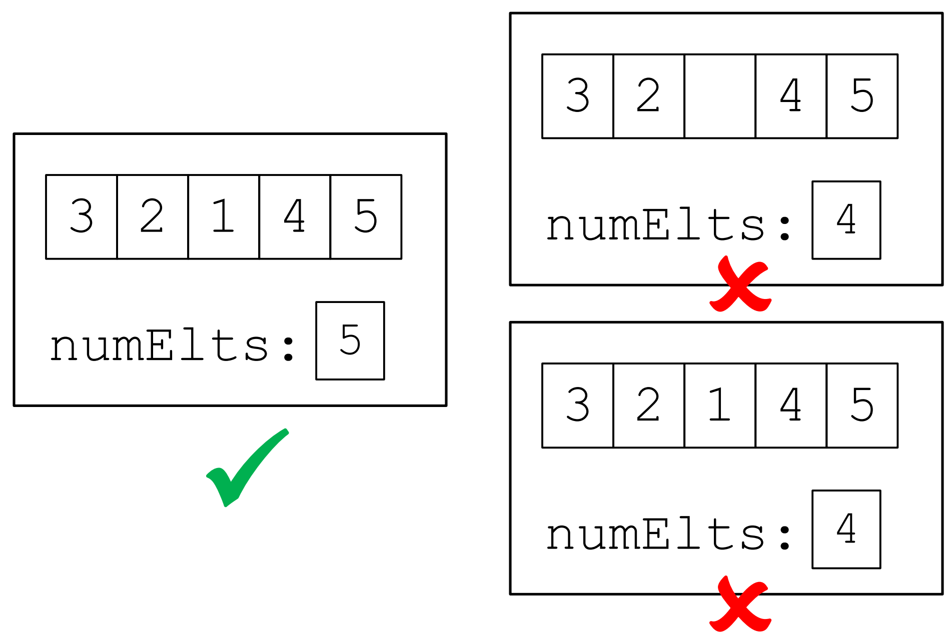
Abstract Data Types

Using Classes

- Start with a representation for the set itself:
  - Use an array.
  - Represent a set of size N as an **unordered** array of integers with no duplicates, stored in the first N slots of the array.
  - `int numElts`: maintains the number of elements currently in the array.

rep invariant

```
class IntSet {
   int elts[100];
   int numElts;
   ...
};
```



Abstract Data Types

Using Classes

- Since this is an array, and arrays have maximum sizes, we have to choose a maximum size and modify the `OVERVIEW`:

```
// OVERVIEW: a mutable set of
//           integers, |set| <= 100
```

- We also have to change the `EFFECTS` clause of `insert`:

```
// EFFECTS: this = this + {v} if
//          room available, throws int
//          100 otherwise
```

100 is arbitrary. What is a better way to specify such size?

Abstract Data Types

Using Classes

```
const int MAXELTS = 100;
class IntSet {
    // OVERVIEW: a mutable set of integers, |set| <= MAXELTS
    int         elts[MAXELTS];
    int         numElts;
  public:
    void insert(int v);
      // MODIFIES: this
      // EFFECTS: this = this + {v} if room,
      //          throws int MAXELTS otherwise
    void remove(int v);
      // MODIFIES: this
      // EFFECTS: this = this - {v}
   bool query(int v);  // RME omitted for space
    int  size();        // RME omitted for space
};
```

Use a global constant like we have talked about.

Abstract Data Types

Using Classes

Given this representation, and the representation invariants, we can write the methods.

```
const int MAXELTS = 100;
class IntSet { // OVERVIEW omitted for space
    int        elts[MAXELTS];
    int        numElts;
  public:
    void insert(int v); // RME omitted for space
    void remove(int v); // RME omitted for space
    bool query(int v);  // RME omitted for space
    int  size();        // RME omitted for space
};
```

```
int IntSet::size() {
  return numElts;
}
```

Because our rep invariant says that `numElts` is always the size of the set, we can return it directly.

References

- **Problem Solving with C++ (8th Edition)**, by *Walter Savitch*, Addison Wesley Publishing (2011)
  - Chapter 10.3 Abstract Data Types
  - Chapter 10.2 Classes