Lecture 5

Abstract Data Types

Procedural and data abstractions

Procedural abstraction:
- Abstract from details of procedures (e.g., methods)
- Specification is the abstraction
  - Abstraction is the specification
- Satisfy the specification with an implementation

Data abstraction:
- Abstract from details of data representation
- Also a specification mechanism
  - A way of thinking about programs and design
- Standard terminology: Abstract Data Type, or ADT
Bad programmers worry about the code. Good programmers worry about data structures and their relationships.

-- Linus Torvalds

Show me your flowcharts and conceal your tables, and I shall continue to be mystified. Show me your tables, and I won’t usually need your flowcharts; they’ll be obvious.

-- Fred Brooks

The need for data abstractions (ADTs)

Organizing and manipulating data is pervasive

– Inventing and describing algorithms less common

Start your design by designing data structures

– How will relevant data be organized
– What operations will be permitted on the data by clients
– Cf. CSE 332

Potential problems with choosing a data abstraction:

– Decisions about data structures often made too early
– Duplication of effort in creating derived data
– Very hard to change key data structures (modularity!)

An ADT is a set of operations

• ADT abstracts from the organization to meaning of data
• ADT abstracts from structure to use
• Representation should not matter to the client
  – So hide it from the client

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Instead, think of a type as a set of operations

create, getBase, getAltitude, getBottomAngle, …

Force clients to use operations to access data

class RightTriangle {
    float base, altitude;
}
class RightTriangle {
    float base, hypot, angle;
}
Are these classes the same?

```java
class Point {
    public float x;
    public float r;
    public float y;
    public float theta;
}
```

```java
class Point {
    public float x;
    public float r;
    public float y;
    public float theta;
}
```

Different: cannot replace one with the other in a program

Same: both classes implement the concept “2-d point”

Goal of ADT methodology is to express the sameness:
  – Clients depend only on the concept “2-d point”

Benefits of ADTs

If clients “respect” or “are forced to respect” data abstractions…
  – For example, “it’s a 2-D point with these operations…”

• Can delay decisions on how ADT is implemented
• Can fix bugs by changing how ADT is implemented
• Can change algorithms
  – For performance
  – In general or in specialized situations
• …

We talk about an “abstraction barrier”
  – A good thing to have and not cross (also known as violate)

Concept of 2-d point, as an ADT

```java
class Point {
    // A 2-d point exists in the plane, ...
    public float x();
    public float y();
    public float r();
    public float theta();
    // ... can be created, ...
    public Point(); // new point at (0,0)
    public Point centroid(Set<Point> points);
    // ... can be moved, ...
    public void translate(float delta_x, float delta_y);
    public void scaleAndRotate(float delta_r, float delta_theta);
}
```
Abstract data type = objects + operations

Implementation is hidden

Only operations on objects of the type are provided by abstraction

Specifying a data abstraction

A collection of procedural abstractions

Not a collection of procedures

An abstract state

Not the (concrete) representation in terms of fields, objects, ...

“Does not exist” but used to specify the operations

Concrete state, not part of the specification, implements the abstract state (more in upcoming lecture)

Each operation described in terms of “creating”, “observing”, “producing”, or “mutating”

No operations other than those in the specification

Specifying an ADT

Immutable

1. overview
2. abstract state
3. creators
4. observers
5. producers
6. mutators

Mutable

1. overview
2. abstract state
3. creators
4. observers
5. producers (rare)
6. mutators

• Creators: return new ADT values (e.g., Java constructors)
• Producers: ADT operations that return new values
• Mutators: Modify a value of an ADT
• Observers: Return information about an ADT

Implementing an ADT

To implement a data abstraction (e.g., with a Java class):

– See next two lectures
– This lecture is just about specifying an ADT
– Nothing about the concrete representation appears in spec
Poly, an immutable datatype: overview

/**
 * A Poly is an immutable polynomial with
 * integer coefficients. A typical Poly is
 * \[ c_0 + c_1 x + c_2 x^2 + \ldots \]
 **/

class Poly {

Overview:
- State whether mutable or immutable
- Define an abstract model for use in operation specifications
  - Difficult and vital!
  - Appeal to math if appropriate
  - Give an example (reuse it in operation definitions)
- State in specifications is abstract, not concrete

Poly: creators

// effects: makes a new Poly = 0
public Poly()

// effects: makes a new Poly = cx^n
// throws: NegExponent if n < 0
public Poly(int c, int n)

Creators
- New object, not part of pre-state: in effects, not modifies
- Overloading: distinguish procedures of same name by parameters (Example: two Poly constructors)

Footnote: slides omit full JavaDoc comments to save space; style might not be perfect either – focus on main ideas

Poly: observers

// returns: the degree of this, i.e., the largest exponent with a non-zero coefficient.
// Returns 0 if this = 0.
public int degree()

// returns: the coefficient of the term of this whose exponent is d
// throws: NegExponent if d < 0
public int coeff(int d)

Notes on observers

Observers
- Used to obtain information about objects of the type
- Return values of other types
- Never modify the abstract value
- Specification uses the abstraction from the overview
  - The particular Poly object being accessed
  - Target of the invocation
  - Also known as the receiver

Poly x = new Poly(4, 3);
int c = x.coeff(3);
System.out.println(c);   // prints 4
Poly: producers

```java
public Poly add(Poly q)
// returns: this + q (as a Poly)

public Poly mul(Poly q)
// returns: the Poly equal to this * q

public Poly negate()
// returns: -this
```

Notes on producers

Operations on a type that create other objects of the type
Common in immutable types like java.lang.String
– String substring(int offset, int len)
No side effects
– Cannot change the abstract value of existing objects

IntSet, a mutable datatype:
overview and creator

```java
class IntSet {

    // effects: makes a new IntSet = {}
    public IntSet()

    // Overview: An IntSet is a mutable, unbounded set of integers. A typical IntSet is { x1, ..., xn }.
}
```

IntSet: observers

```java
public boolean contains(int x)
// returns: true if and only if x ∈ this

public int size()
// returns: the cardinality of this

public int choose()
// returns: some element of this
// throws: EmptyException when size()==0
```
IntSet: mutators

// modifies: this
// effects: \( \text{this}_{\text{post}} = \text{this}_{\text{pre}} \cup \{x\} \)
public void add(int x)

// modifies: this
// effects: \( \text{this}_{\text{post}} = \text{this}_{\text{pre}} - \{x\} \)
public void remove(int x)

Notes on mutators

Operations that modify an element of the type

- Rarely modify anything (available to clients) other than \texttt{this}
  - List \texttt{this} in modifies clause (if appropriate)

- Typically have no return value
  - “Do one thing and do it well”
  - (Sometimes return “old” value that was replaced)

- Mutable ADTs may have producers too, but that is less common

Coming up…

Very related next lectures:
- Representation invariants
- Abstraction functions

Distinct, complementary ideas for ADT reasoning