Lecture 5
Abstract Data Types
Hello!

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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

```java
class RightTriangle {
    float base, altitude;
}
```

```java
class RightTriangle {
    float base, hypot, angle;
}
```
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

Instead, think of a type as a set of operations
  create, getBase, getAltitude, getBottomAngle, ...
Force clients to use operations to access data

```java
class RightTriangle {
    float base, altitude;
}

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

class Point {
    public float x;
    public float y;
}

class Point {
    public float r;
    public float theta;
}
Are these classes the same?

class Point {
    public float x;
    public float y;
}

class Point {
    public float r;
    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)
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

- 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

### Mutable

1. overview
2. abstract state
3. creators
4. observers
5. producers (rare)
6. mutators
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
 * \[ c_0 + c_1x + c_2x^2 + \ldots \]
 ***/
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

```java
// 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

this
  – 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

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

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

// returns: -this
public Poly negate()
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

// Overview: An IntSet is a mutable, unbounded set of integers. A typical IntSet is \{ x_1, \ldots, x_n \}.
class IntSet {

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

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

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

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

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

// modifies: this
// effects: this\textsubscript{post} = this\textsubscript{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 this
  – List 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