Abstract Data Types

CSE 331

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Outline

- What is an abstract data type (ADT)?
- How to specify an ADT
  - immutable
  - mutable
- The ADT methodology

What is an ADT?

- Recall procedural abstraction
  - Abstracts from the details of procedures
  - A specification mechanism
- Data abstraction (ADT):
  - Abstracts from the details of data representation
  - A specification mechanism
    + a way of thinking about programs and designs

Why we need Abstract Data Types

- Organizing and manipulating data is pervasive
  - Inventing and describing algorithms is rare
- Start your design by designing data structures
  - Code to access and manipulate data
- Potential problems with choosing a data structure
  - Decisions about data structures are made too early
  - Duplication of effort in creating derived data
  - Very hard to change key data structures

An ADT is a set of operations

- ADT abstracts from the organization to meaning of data
- ADT abstracts from structure to use
- Representation does not matter; this choice is irrelevant

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

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

- Instead, think of a type as a set of operations
  - **`create`**, **`base`**, **`altitude`**, **`bottomAngle`**, …
- Force clients (users) to call operations to access data

Are these classes the same or different?

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

```
class Point {
  public float r;
  public float theta;
}
```

- Different: can't replace one with the other
- 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"
- Good for
  - delaying decisions
  - fixing bugs
  - performance optimizations

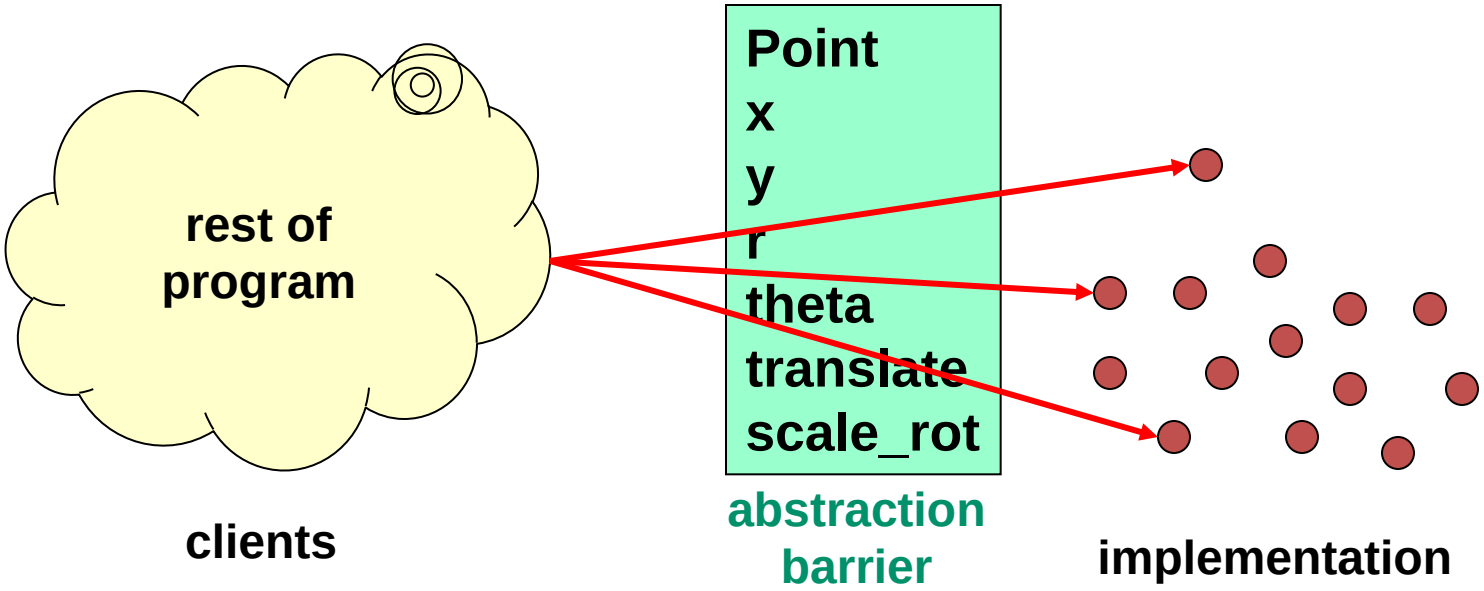
2-d point as an ADT

```
class Point {
  // A 2-d point exists somewhere 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)

  // ... 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



- The implementation is hidden
- The *only* operations on objects of the type are those provided by the abstraction

How to Specify an ADT

immutable

```
class TypeName {
  1. overview
  2. abstract fields
  3. creators
  4. observers
  5. producers
}
```

mutable

```
class TypeName {
  1. overview
  2. abstract fields
  3. creators
  4. observers
  5. mutators
}
```

Abstract fields (a.k.a. specification fields): later

Primitive Data Types Are ADTs

`int` is an immutable ADT

creators: **`0`**, **`1`**, **`2`**, …

producers: **`+ - * /`** …

observer: **`Integer.toString(int)`**

- It is possible to define **`int`** with a single creator
  - Why would we want to do that?

Poly, an immutable datatype: overview

```
/**
 * A Poly is an immutable polynomial with
 * integer coefficients.  A typical Poly is
 *              c0 + c1x + c2x^2 + ...
 **/
class Poly {
```

- Overview:
  - Always state whether mutable or immutable
  - Define abstract model for use in specs of operations
    - Difficult and vital!
    - Appeal to math if appropriate
    - Give an example (reuse it in operation definitions)
- In all ADTs, state in specs is *abstract*: refers to specification fields, not implementation

Poly: creators

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

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

- New object, not part of prestate: in effects, not modifies
- Overloading: distinguish procedures of same name by parameters
  - Example: two Poly constructors

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
public int coeff(int d)
```

Notes on 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`** is the particular Poly object being worked on – that is, the target of the invocation

```
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 = this * q
public Poly mul(Poly q)

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

- Operations on a type that create other objects of the type
- Common in immutable types, e.g., `java.lang.String`:
  - `String substring(int offset, int len)`
- No side effects

IntSet, a mutable datatype: overview and creators

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

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

IntSet: observers

```
// returns: true if x ∈ this
//          else returns false
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_post = this_pre ∪ {x}
public void add(int x)          // insert an element

// modifies: this
// effects:  this_post = this_pre - {x}
public void remove(int x)
```

- Mutators are operations that modify an element of the type
- Rarely modify anything other than **`this`**
- Must list **`this`** in modifies clause (if appropriate)
- Typically have no return value
- Mutable ADTs may have producers too, but that is less common

Representation exposure

```
Point p1 = new Point();
Point p2 = new Point();
Line line = new Line(p1,p2);
p1.translate(5, 10);  // move point p1
```

- Is **`Line`** mutable or immutable?
- It depends on the implementation!
  - If **`Line`** creates an internal copy: immutable
  - If **`Line`** stores a reference to **`p1,p2`**: mutable
- Lesson: storing a mutable object in an immutable collection can expose the representation

ADTs and Java language features

- Java classes – how to use them
  - Make operations in the ADT public
  - Make other ops and fields of the class private
  - Clients can only access ADT operations
- Java interfaces
  - Clients only see the ADT, not the implementation
  - Multiple implementations have no code in common
  - Cannot include creators (constructors) or fields
- Both classes and interfaces are sometimes appropriate
  - Write and rely upon careful specifications

Preview: subtyping

- A stronger specification can be substituted for a weaker
  - Applies to types as well as to individual methods
- Java subtypes are *not necessarily* true subtypes
- A Java subtype is indicated via **`extends`** or **`implements`**
  - Java enforces signatures (types), but not behavior
- A true subtype is indicated by a stronger specification
  - Also called a "behavioral subtype"
  - Every fact that can be proved about supertype objects can also be proved about subtype objects

Subtyping example

```
class A {
  // returns: 0
  int zero(int i) { return 0; }
}

// Java subtype of A, but not true subtype
class B extends A {
  // returns: negative of argument
  int zero(int i) { return -i; }    // overriding method
}

// True subtype of A, but not Java subtype
class C {
  // returns: 0
  int zero(int i) { return i - i; }
}
```