CSE 331
Software Design & Implementation

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Data Abstraction: Abstract Data Types (ADTs)

(Based on slides by Mike Ernst, David Notkin, Hal Perkins)

Outline

This lecture:

1. What is an Abstract Data Type (ADT)?
2. How to specify an ADT?
3. Design methodology for ADTs

Very related next lectures:

- Representation invariants
- Abstraction functions

Two distinct, complementary ideas for reasoning about ADTs

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

Why we need Data Abstractions (ADTs)

Organizing and manipulating data is pervasive

- Inventing and describing algorithms is 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

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

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

Instead, think of a type as a set of operations

`create, getBase, getAltitude, getBottomAngle, …`

Force clients to use operations to access data

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*)

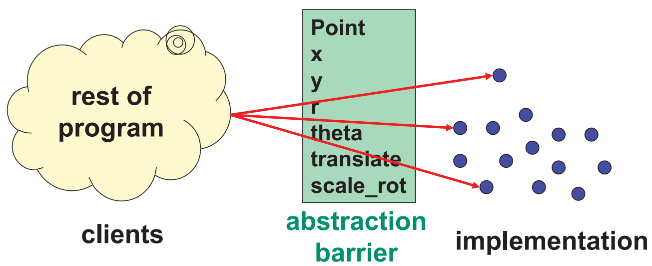
Concept of 2-d point, as an ADT

```
class Point {
  // A 2-d point exists in the plane, ...
  public float x();
  public float y();                      Observers
  public float r();
  public float theta();

  // ... can be created, ...
  public Point(); // new point at (0,0)             Creators/
  public Point centroid(Set<Point> points);         Producers

  // ... can be moved, ...
  public void translate(float delta_x,
                        float delta_y);
  public void scaleAndRotate(float delta_r,          Mutators
                             float delta_theta);
}
```


Abstract data type = objects + operations



- Implementation is hidden
- The only operations on objects of the type are those provided by the 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 the specification

Poly, an immutable datatype: overview

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

Abstract state (specification fields)

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

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 { x1, ..., xn }.
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: $this_{post} = this_{pre} \cup \{x\}$
```
public void add(int x)
```

// modifies: this
// effects: $this_{post} = this_{pre} - \{x\}$
```
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