CSE 331
Software Design & Implementation

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Summer 2016

Data Abstraction: Abstract Data Types (ADTs)

(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins, Zach Tatlock)

Outline

This lecture:

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

Next lecture:

- Documenting an implementation of an ADT
  - representation invariants
  - abstraction functions

Procedural and data abstractions

Procedural abstraction:

- abstract from implementation details of *procedures* (methods)
- specification is the abstraction
- satisfy the specification with an implementation

Data abstraction:

- abstract from details of *data representation*
- also a specification mechanism
- way of thinking about programs and design
- standard terminology: Abstract Data Type, or ADT
  - invented by Barbara Liskov in the 70s
  - one of the fundamental ideas of computer science

Why we need Data Abstractions (ADTs)

Organizing and manipulating data is pervasive

- inventing and describing algorithms is less common

Often best to start your design by designing data structures

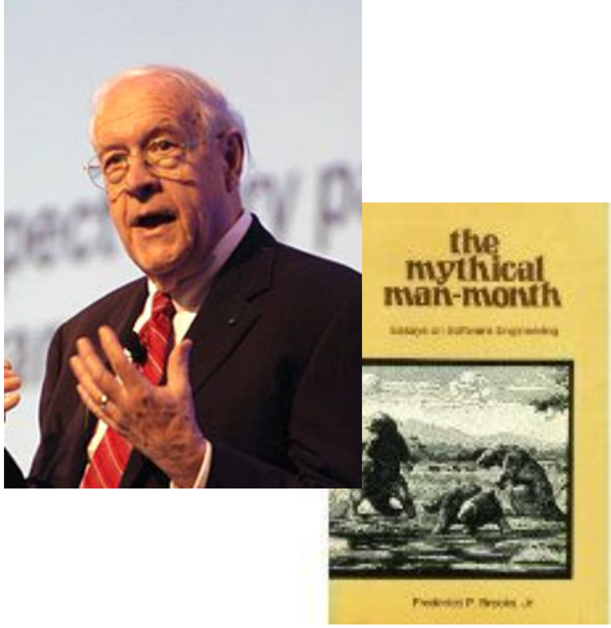
- how will relevant data be organized
- what operations will be permitted on the data by clients
- see CSE 332 & CSE 344

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



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Potential problems with choosing a data abstraction:

- hard to know ahead of time what to optimize
  - programmers are “notoriously” bad at this (Liskov)
- if not properly structured, 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 *data structure* to *use*
- Representation should not matter to the client
  - so hide it from the client

Alternative representations of a right trangle:

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

Different Details: cannot replace one with the other in a program

Same Concept: both classes implement the concept “2D point”

Goal of Point ADT is to express the sameness:

- – clients should depend only on the concept “2D point”
- – achieve this by specifying operations not the representation
- – write clients that can work with either representation

Benefits of ADTs

If clients “respect” or “are forced to respect” data abstractions…

- For example, “it’s a 2D 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* (a.k.a. *violate*)

Concept of 2D point, as an ADT

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

Observers / Getters

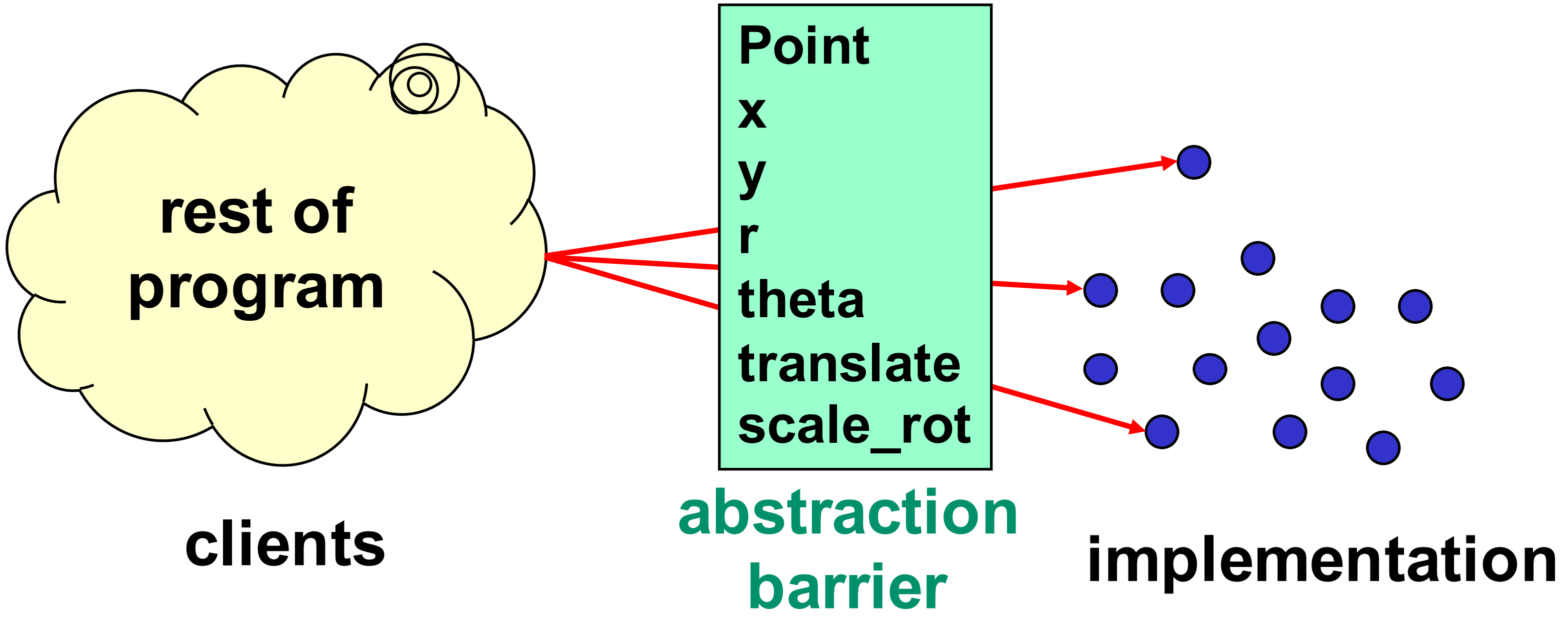
```
  // ... can be created, ...
  public Point(); // new point at (0,0)
  public Point centroid(Set<Point> points);
```

Creators/
Producers

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

Mutators

Abstract data type = objects + operations



- Implementation is hidden
- The only operations on objects are those provided by the abstraction

Specifying a data abstraction

- A *collection* of procedural abstractions
  - *(not* a collection of procedures)

- Need a way write specifications for these procedures
  - need a vocabulary for talking about what the operations do
  - need to avoid referencing the actual implementation

- Use “math” to specify these procedures
  - mathematical description of a state is called an **abstract state**
  - describes what the state “means” not the implementation
  - each operation described in terms of “creating”, “observing”, “producing”, or “mutating” the abstract state

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 / Getters: Return information about an ADT

Implementing an ADT

Next lecture will be about implementations of ADTs

This lecture is about the ADTs themselves

- these are specifications
- should have *no information* about the implementation
  - (latter called the ”concrete representation”)

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 + ...
 **/
class Poly {
```

Abstract state (specification fields)

Overview:

- state if immutable (default not)
- 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)
  - makes no reference to concrete representation

Poly: creators

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

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

Creators

- new object, so no pre-state: only `effects`, no `modifies`
- overloading: distinguish procedures of same name by parameters
  - use with care (see Effective Java)
  - will see alternative design patterns later on

(Note: Javadoc above omits many details.)

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)
```

(Note: Javadoc above omits many details.)

Notes on observers

Observers

- used to obtain information about objects of that type
- return values of other types
- **never** modify the abstract state
- specification uses the abstraction from the overview

`this`

- **abstract value** of particular **`Poly`** object being accessed
  - *target* of the method call (object on which the call was made)

```
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()
```

(Note: Javadoc above omits many details.)

Notes on producers

- Operations on a type that create other objects of the same type
- Common in immutable types like `java.lang.String`
  - `String substring(int offset, int len)`
- No side effects
  - **never** modify 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()
```

(Note: Javadoc above omits many details.)

IntSet: observers

```
// returns: true if and only if x in 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()
```

(Note: Javadoc above omits many details.)

IntSet: mutators

// modifies: this

// effects: $\text{this}_{post} = \text{this}_{pre} + \{x\}$

`public void add(int x)`

// modifies: this

// effects: $\text{this}_{post} = \text{this}_{pre} - \{x\}$

`public void remove(int x)`

(Note: Javadoc above omits many details.)

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
- 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