

Lecture 5

Abstract Data Types

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Abstract Data Types

Administrivia

HW2 (due Jan 19 by 10am) posted!

Readings posted!

HW3: Java warmup & project logistics posted tomorrow

- Should go quickly, but *please start early* so we can fix setup problems before the last minute
- Help each other out on Piazza and in 006!!

Procedural and data abstractions

Procedural abstraction:

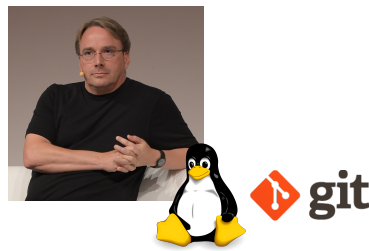
- Abstract from details of *procedures* (e.g., methods)
- Specification is the abstraction
 - Abstraction is the specification
- Satisfy the specification with an implementation

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



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](#)

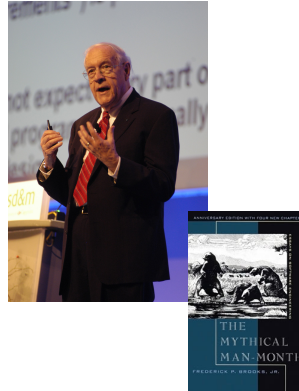
- How will relevant data be organized
- What operations will be permitted on the data by clients
- Cf. CSE 332

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!)

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



An ADT is a set of operations

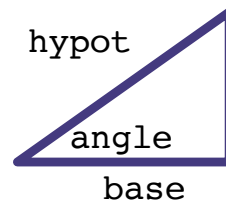
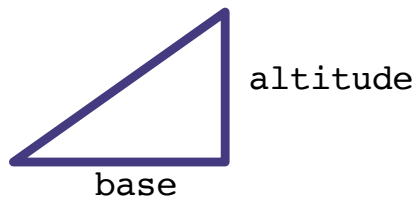
- ADT abstracts from the *organization* to *meaning* of data
- ADT abstracts from *structure* to *use*
- Representation should not matter to the client
 - So hide it from the client

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;  
}
```



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

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

Instead, think of a type as a [set of operations](#)

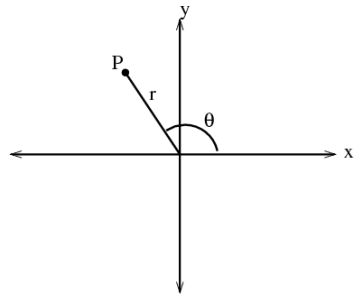
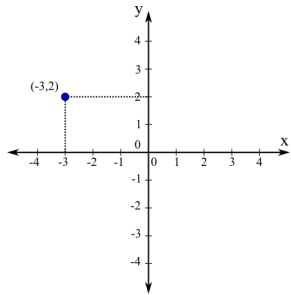
`create, getBase, getAltitude, getBottomAngle, ...`

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;
}
```



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

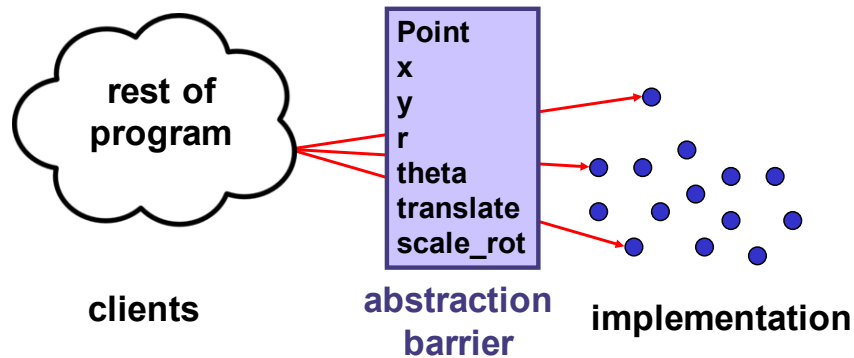
```
class Point {
    // A 2-d point exists in the plane, ...
    public float x();
    public float y();
    public float r();
    public float theta();
    // ... can be created, ...
    public Point(); // new point at (0,0)
    public Point centroid(Set<Point> points);
    // ... can be moved, ...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

Observers

Creators/Producers

Mutators

Abstract data type = objects + operations



Implementation is hidden

Only operations on objects of the type are provided by abstraction

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

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

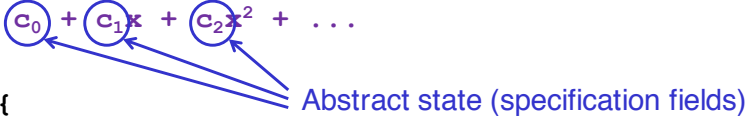
Implementing an ADT

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
 *
 *  $c_0 + c_1x + c_2x^2 + \dots$ 
 */
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: 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)
```

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

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()
```

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()
```

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: 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()
```

IntSet: mutators

```
// modifies: this
// effects:  thispost = thispre ∪ {x}
public void add(int x)

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

Coming up...

Very related next lectures:

- Representation invariants
- Abstraction functions

Distinct, complementary ideas for ADT reasoning

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