CSE 331
Software Design and Implementation

Lecture 5
Abstract Data Types

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Platonic Forms

- Quote

Announcements

Announcements

- Section tomorrow!
  - Loop reasoning
    - useful for HW2
    - historically one of the most challenging concepts in 331
  - Development environment setup
    - please install Eclipse and bring your laptop
    - Eclipse installation instructions on the Course Website

Announcements

- Please attend the section that you are formally enrolled in
  - Makes it possible to earn your section participation grade
  - Makes your TAs' lives much easier!
- HW0 feedback published on gradescope
- Reading assignment 2 posted, Quiz 2 coming soon!
  - Due tomorrow: Thursday 6/28 at 10 pm
- HW2 is out! Due Monday 7/2 at 10 pm
  - Topic is loop reasoning – harder than HW1 so start early

What is an ADT?

Procedural and data abstractions

lec04

Method Specification (abstraction)

Method Body
(concrete code)

lec05 (today)

Abstract Data Type (abstraction)

Data Structure
(concrete code)

Procedural and data abstractions

Procedural abstraction:

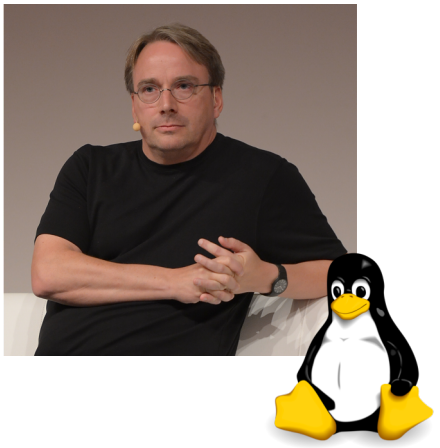
- Abstract from details of *procedures* (e.g., methods)
- Specification is the abstraction
  - Abstraction is the specification
- Satisfy the specification with an implementation

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

Good programmers worry about data structures and their relationships.

-- Linus Torvalds



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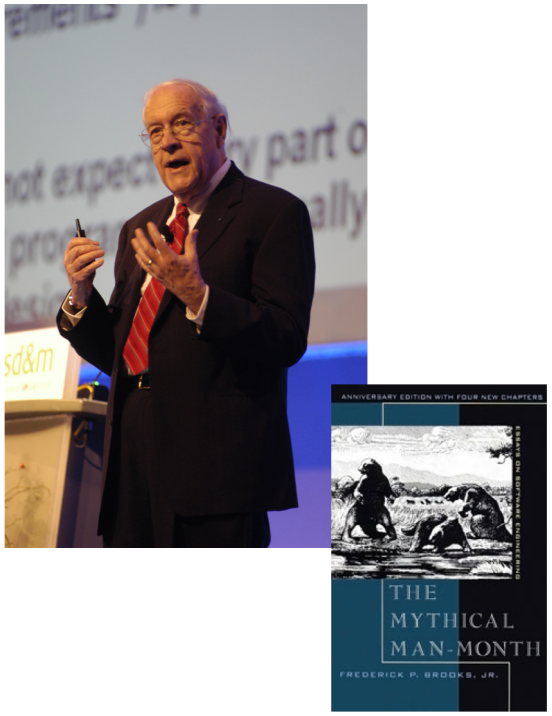
Show me your flowcharts and conceal your tables, and I shall continue to be mystified. Show me your tables, and I won't usually need your flowcharts; they'll be obvious.

-- Fred Brooks



The need for data abstractions (ADTs)

Organizing and manipulating data is pervasive

- See also: CSE 332 – Data Structures & Parallelism

Start your design by designing data abstractions

- What is the meaning of the data?
- What operations will be permitted on the data by clients?

Later, you can choose a data structure

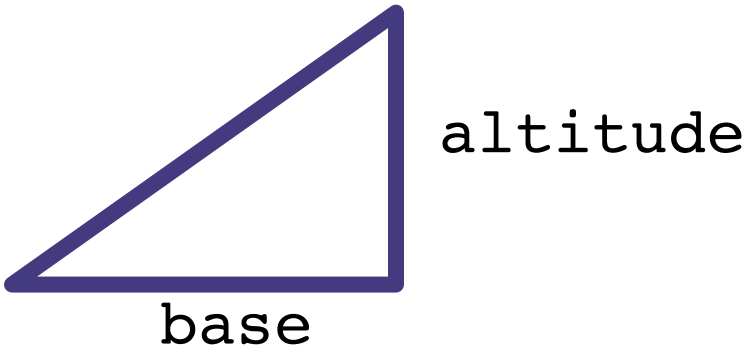
- This means writing the implementation
- Decisions about data structures often made too early
- Very hard to change key data structures (modularity!)

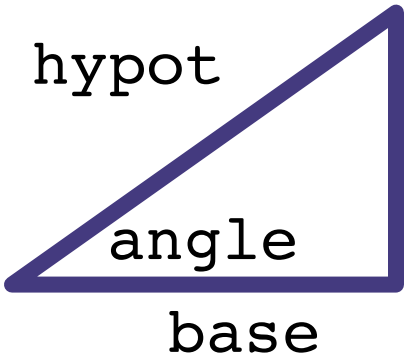
An ADT is a set of operations

- ADT abstracts from the *organization* to *meaning* of data
- ADT abstracts from *structure* to *use*
- Here are two bad examples of how to implement a triangle class
  - Why are they bad?

```
class BadRightTriangle1 {
  float base, altitude;
}
```

```
class BadRightTriangle2 {
  float base, hypot, angle;
}
```





An ADT is a set of operations

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- ADT abstracts from *structure* to *use*
- Here are two bad examples of how to implement a triangle class
  - Why are they bad?

```
class BadRightTriangle1 {
  float base, altitude;
}
```

```
class BadRightTriangle2 {
  float base, hypot, angle;
}
```

Instead, we should think of a type as a set of operations

`create, getBase, getAltitude, getBottomAngle,` …

Force clients to use operations to access data

An ADT is a set of operations

```
class BadRightTriangle1 {
  float base, altitude;
}
```

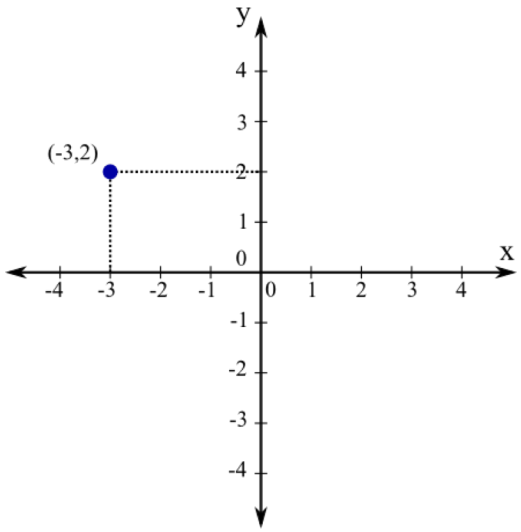
```
class BadRightTriangle2 {
  float base, hypot, angle;
}
```

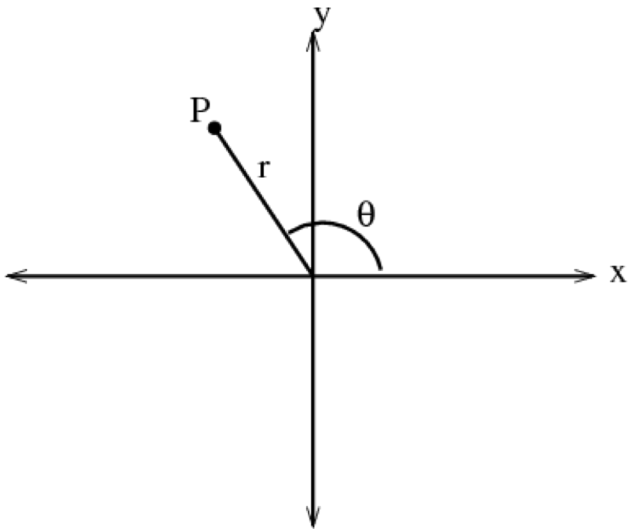
```
class RightTriangle {
  // fields don't matter to client!
  // Not part of ADT
  private float ...;

  // Operations are the important stuff.
  // Same ops, regardless of which fields we use
  public RightTriangle create();
  public float getBase();
  public float getAltitude();
  public float getBottomAngle();
  ...
}
```

Are these classes the same?

```
class BadPoint1 {
  public float x;
  public float y;
}
```

```
class BadPoint2 {
  public float r;
  public float theta;
}
```





Are these classes the same?

```
class BadPoint1 {
  public float x;
  public float y;
}
```

```
class BadPoint2 {
  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"

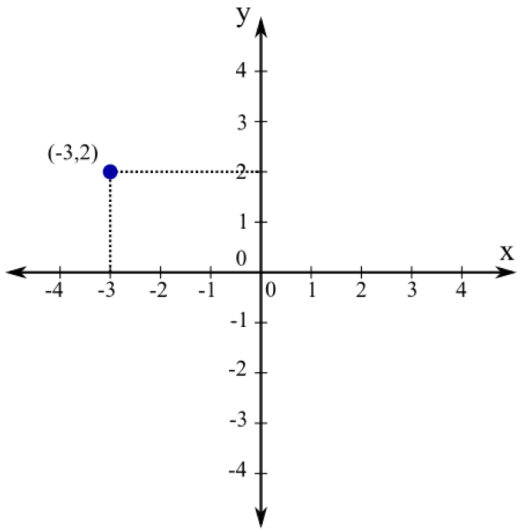
Goal of ADT methodology is to express the sameness:

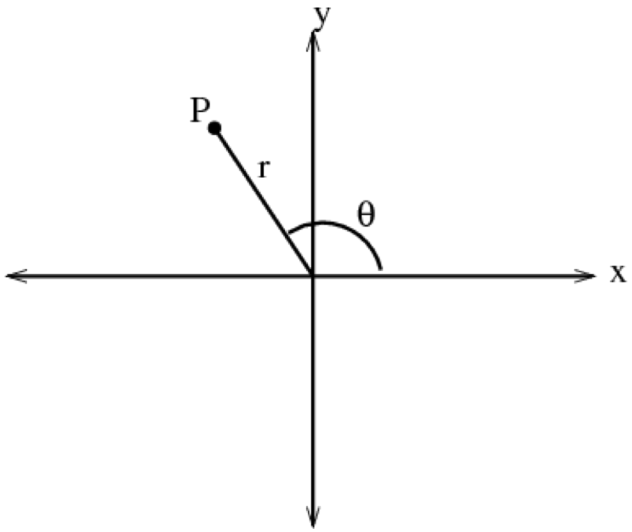
- Analogy with Platonic Forms
- Clients depend only on the concept "2-d point"

Are these classes the same?

```
class Point1 {
  private float x;
  private float y;
  // public ops..
}
```

```
class Point2 {
  private float r;
  private float theta;
  // public ops..
}
```





Concept of 2-d point, as an ADT

Informal notation warning

```
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

Benefits of ADTs

Suppose clients respect our data abstractions…

- For example, "it's a 2-D point with these operations…"

Then, as the implementer, we can do these good things:

- 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

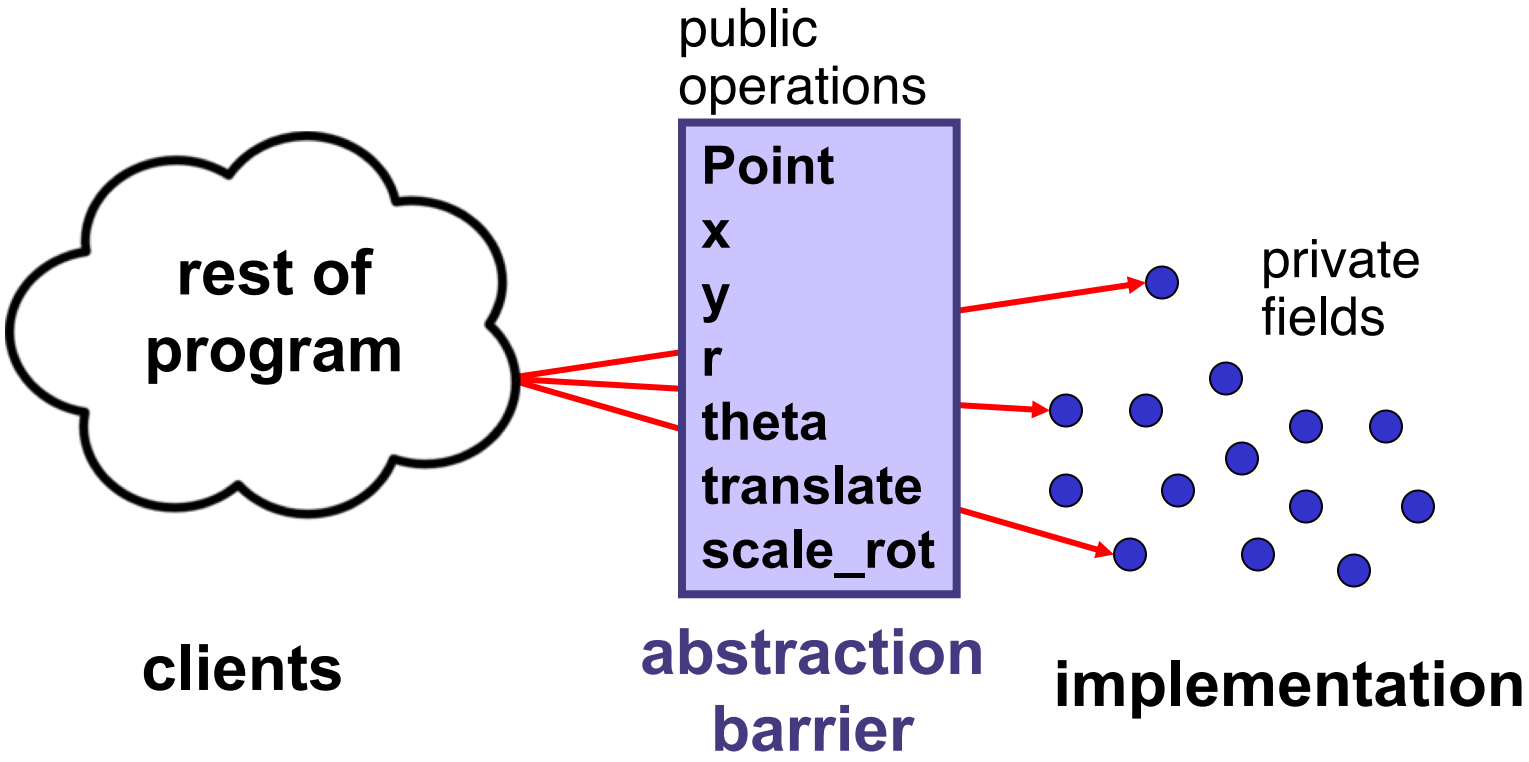
Debuggable 

Flexible 

We talk about an "*abstraction barrier*"

- A good thing to have and not *cross*

Abstract data type = objects + operations



- Implementation is hidden
- Only operations on objects of the type are provided by abstraction

Specifying an ADT

Specifying a data abstraction

An abstract state

- Not the (concrete) representation in terms of fields, objects, …
- “Does not exist” but used to specify the operations
- Excludes concrete state that implements the abstract state (more in upcoming lecture)

Abstract vs. Concrete State Example

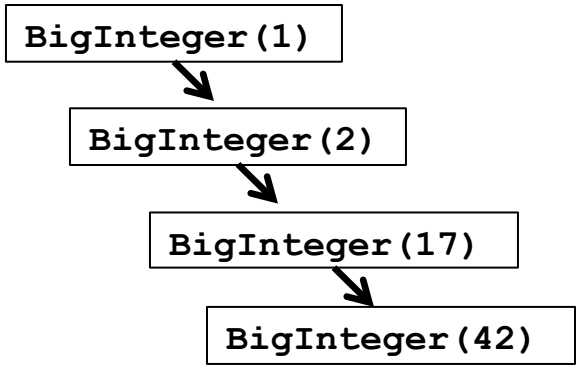
Abstract State of an int list:
Ordered sequence of integer values

1, 2, 17, 42

One Abstract State to rule them all!

generalize across

Possible Concrete State of an int list:
Linked list of BigInteger



Possible Concrete State of an int list:
Array of primitive ints

```
[1, 2, 17, 42]
```

Many more possible Concrete States...!

Specifying a data abstraction

An abstract state

e.g. the fact that an int list is a sequence of integer values

- Not the (concrete) representation in terms of fields, objects, …
- "Does not exist" but used to specify the operations
- Excludes concrete state that implements the abstract state (more in upcoming lecture)

A collection of procedural abstractions

e.g. a well specified set of list operations on an int list

- aka operations; aka method specs
- Excludes code
- 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

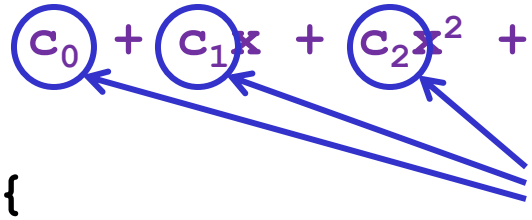
Implementing an ADT

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 spec

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)

1. Overview:
   - English description, states whether mutable or immutable
2. Define Abstract State for use in operation specifications
   - Difficult and vital!
   - Appeal to math if appropriate
   - Give an example (reuse it in operation definitions)
   - Excludes concrete state

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)
```

3. Creators
   - New object, not part of pre-state: in **`effects`**, not **`modifies`**
   - Overloading: distinguish procedures of same name by parameters (Example: two **`Poly`** constructors)

Informal Notation Warning: 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

4. 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

5. 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 ∪ {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

Mutable/Immutable ADTs (revisited)

Immutable

1. **overview**
2. **abstract state**
3. **creators**
4. **observers**
5. **producers**
6. ~~**mutators**~~

Mutable

1. **overview**
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- Creators: return new ADT values (e.g., Java constructors)
- Producers: ADT operations that return new values
- Mutators: Modify a value of an ADT
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Why immutable?

- If you are curious, read Effective Java!
  - Minimize Mutability (EJ2: 39; EJ3: 50)

Procedural and data abstractions

lec04

Method Specification (abstraction)

Method Body
(concrete code)

lec05 (today)

Abstract Data Type (abstraction)

Data Structure
(concrete code)

Coming up…

Very related next lectures:

- Representation invariants
- Abstraction functions

Distinct, complementary ideas for ADT reasoning

Closing

Closing

- Section tomorrow!
  - install eclipse and bring laptop
- Quiz 2 due Thursday
- HW2 due Monday