Data abstraction:
Abstract Data Types (ADTs)

CSE 331
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Outline

1. What is an abstract data type (ADT)?
2. How to specify an ADT
   – immutable
   – mutable
3. The ADT design methodology

Procedural and data abstraction

Recall procedural abstraction

- Abstracts from the details of procedures
- A specification mechanism
- Reasoning connects implementation to specification

Data abstraction (Abstract Data Type, or ADT):

- Abstracts from the details of data representation
- A specification mechanism
  + a way of thinking about programs and designs
- Next lecture: ADT implementations
  - Representation invariants (RI), abstraction functions (AF)

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
  - Write 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, getBase, getAltitude, getBottomAngle, ...

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 because:

- Delay decisions
- Fix bugs
- Change algorithms (e.g., performance optimizations)

Concept of 2-d point, as an ADT

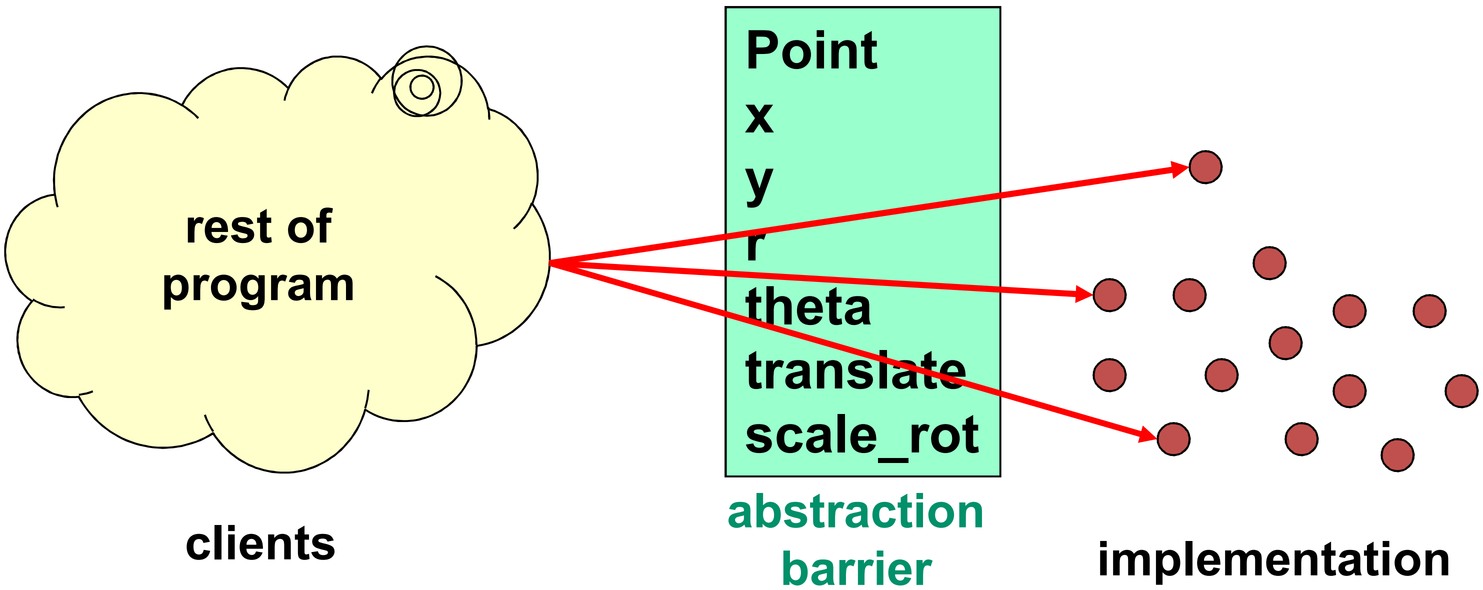
```
class Point {
  // A 2-d point exists somewhere in the plane, ...
  public float x();
  public float y();
  public float r();
  public float theta();

  // ... can be created, ...
  public Point();           // new point at (0,0)
  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: x(), y(), r(), theta()

Creators/ Producers: Point(), centroid(...)

Mutators: translate(...), scaleAndRotate(...)

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): next lecture

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 {
```

Abstract state (specification fields)

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*, not concrete

- Refers to specification fields, not implementation fields

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)
```

Creators

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

Slides omit full Javadoc comments to save space

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

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 worked on
- The 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 = this * q
public Poly mul(Poly q)

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

Producers

- 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
  - Cannot change the abstract value of existing objects

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

- Operations that modify an element of the type
- Rarely modify anything other than **`this`**
  - Must list **`this`** in <u>modifies</u> 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

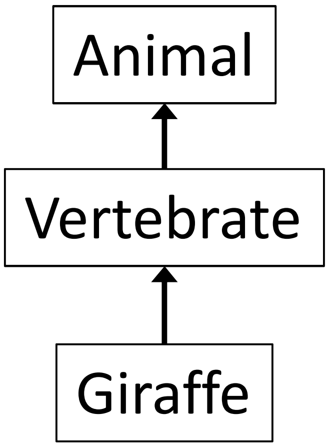
- Write and rely upon careful specifications

Subtyping and substitutability

A stronger specification can be substituted for a weaker

Applies to types as well as to individual methods

```
class Vertebrate extends Animal {
    // number of bones in neck; result > 0
    int neckBones() { … }
}
```



Method use:

```
    Giraffe g = new Giraffe();
    Animal a = g;
    g.neckBones();   // OK
    a.neckBones();   // compile-time error!
```

Which can be used as a subtype?

```
class Vertebrate extends Animal {
  // returns > 0
  abstract int neckBones();
}

// Java subtype of Vertebrate, but not true subtype
class Squid extends Vertebrate {
  @Override
  int neckBones() { return 0; }
}

// True subtype of Vertebrate, but not Java subtype
class Human {
  int neckBones() { return 7; }
}
```

A possible use:

```
  // return average length of vertebrae in neck
  int vertebraLength(Vertebrate v) {
    return v.neckLength()/v.neckBones();
  }
```

Java subtypes vs. 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

Don't write a Java subtype that is not a true subtype

- Causes unexpected, confusing, incorrect behavior