CSE 331
Software Design & Implementation

Hal Perkins

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Abstract Data Types – Examples and Recap

(Based on slides by Mike Ernst and David Notkin)

ADT operations and mutation

- Creators/Producers
  - Creators: return new ADT values (e.g., Java constructors). Effects, not modifies
  - Producers: ADT operations that return new values
- Mutators: Modify a value of an ADT
- Observers: Return information about an ADT

- Mutable ADTs: creators, observers, and mutators
- Immutable ADTs: creators, observers, and producers

Three examples

- A primitive type as an (immutable) ADT
- An immutable type as an ADT
- A mutable type as an ADT

Primitive data types are ADTs

- **`int`** is an immutable ADT:
  - creators: **`0, 1, 2, ...`**
  - producers: **`+ - * / ...`**
  - observer: **`Integer.toString(int)`**

- Peano showed we only need one creator for basic arithmetic
  - Why might that not be the best programming language design choice?

Poly, an immutable datatype: overview

```
/**
 * A Poly is an immutable polynomial with
 * integer coefficients.  A typical Poly is
 *           c0 + c1x + c2x2 + ...
 **/
class Poly {
```

- Overview:
  - Always state whether mutable or immutable
  - Define an abstract model for use in operation specifications
    - Often difficult and always vital!
    - Appeal to math if appropriate
    - Give an example (reuse it in operation definitions)
- In all ADTs, the state in specifications is abstract, not concrete
  - (coefficients are the abstract state in the above Poly spec.)

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: **`effects`**, not **`modifies`**
  - Overloading: distinguish procedures of same name by parameters (Example: two **`Poly`** constructors)

Footnote: 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; if no such
//    exponent exists, return 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 accessed
  - 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()
```

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
  - That is, they can affect the program state but cannot have a side effect on the existing values of the ADT

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 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)
```

Notes on mutators

- Operations that modify an element of the type
- Rarely modify anything other than **`this`**
  - Must list **`this`** in modifies clause (as appropriate)
- Typically have no return value
- Mutable ADTs may have producers too, but that is less common

Quick recap

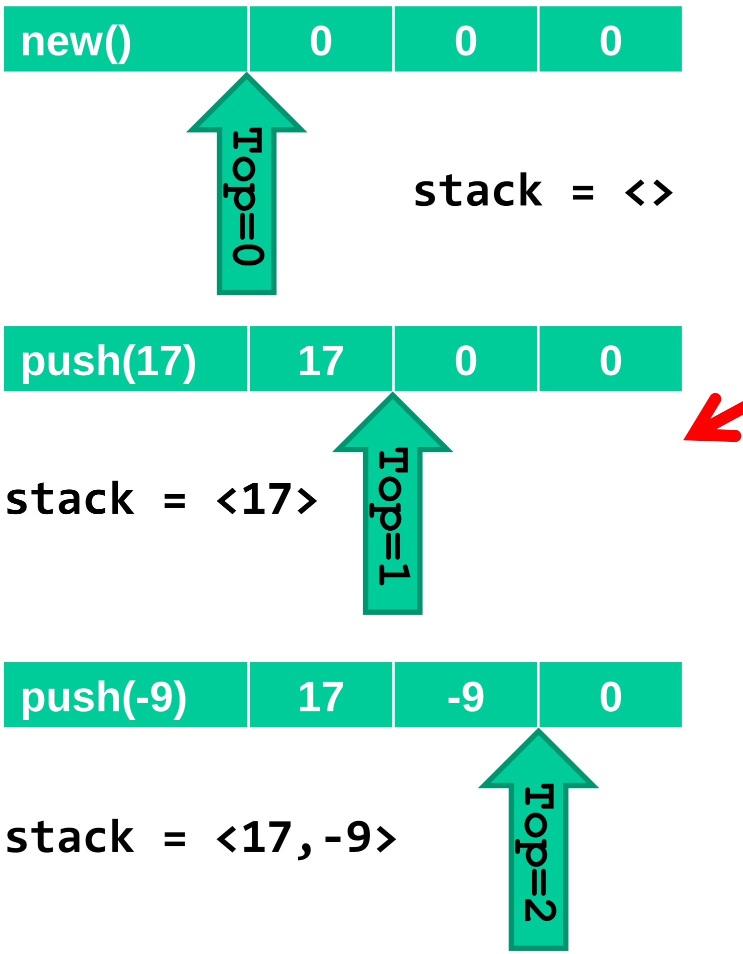
- The examples focused on the abstract specification – with no connection at all to a concrete implementation
- To connect them we need the abstraction function (AF), which maps values of the concrete implementation of the ADT into abstract values in the specification
- The representation invariant (RI) ensures that values in the concrete implementation are well-defined – that is, the RI must hold for every element in the domain of the AF

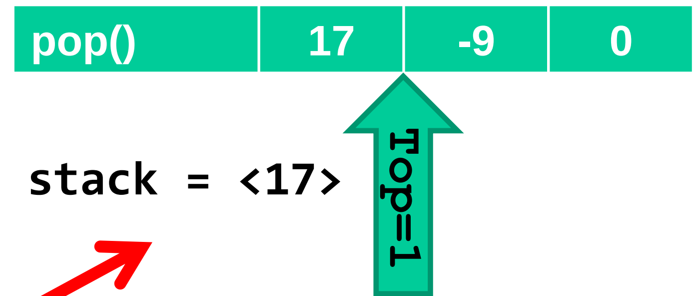
The abstraction function is a function

- Why do we map concrete to abstract rather than vice versa?
- It's not a function in the other direction.
  - E.g., lists **`[a,b]`** and **`[b,a]`** each represent the set **`{a, b}`**
- It's not as useful in the other direction.
  - We can manipulate abstract value through abstract operations

Brief example

Abstract stack with array and "top" index implementation





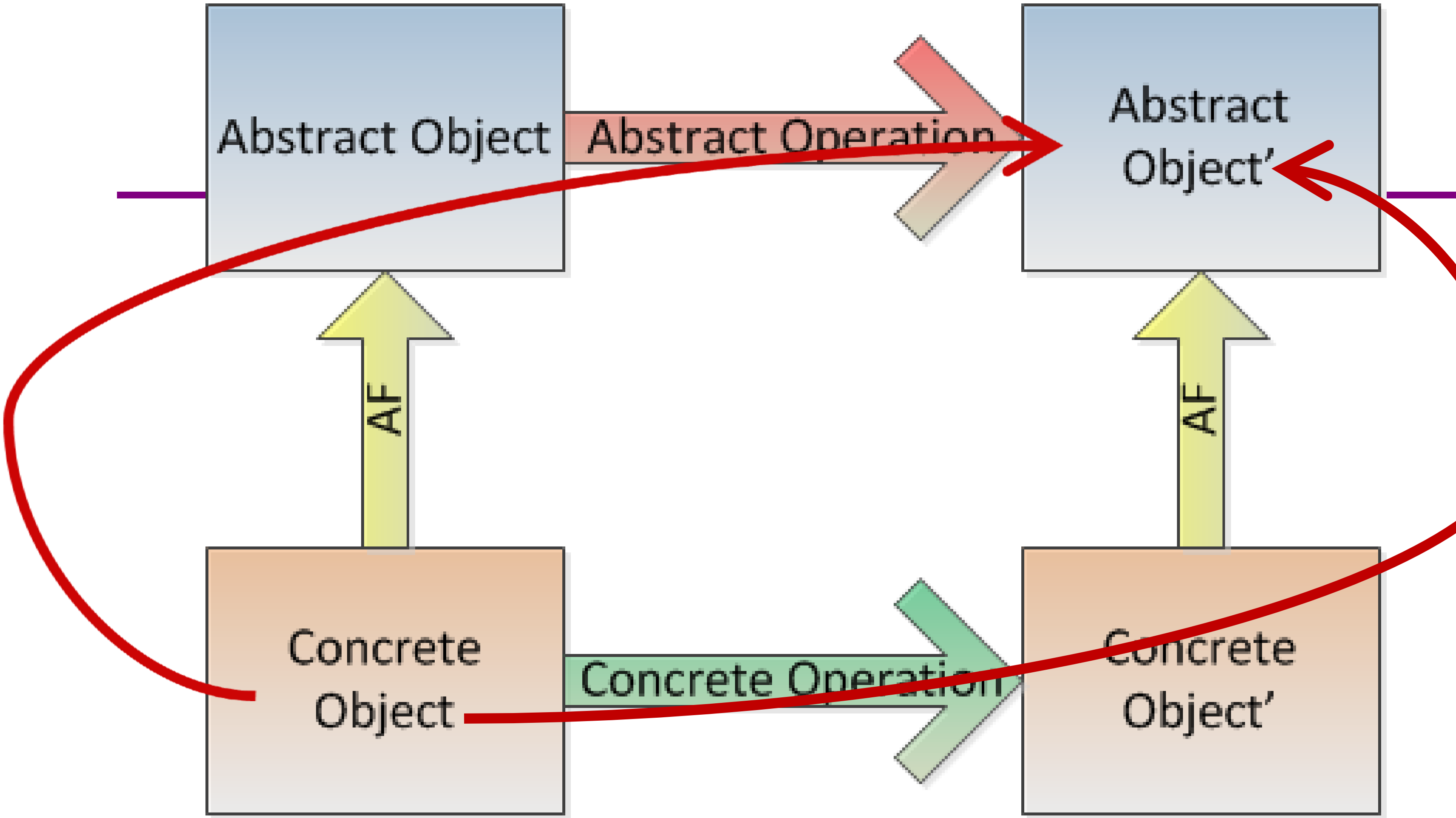
Abstract states are the same
`stack = <17> = <17>`

Concrete states are different
`<[17,0,0], top=1>`
≠
`<[17,-9,0], top=1>`

AF is a function
AF^{-1} is not a function

Writing an abstraction function

- The domain: all representations that satisfy the rep invariant
- The range: can be tricky to denote
  - For mathematical entities like sets: easy
  - For more complex abstractions: give names to fields or derived values
    - AF defines the value of each "specification field"
    - "derived specification fields" more complex
- The overview section of the specification should provide a way of writing abstract values
  - A printed representation is valuable for debugging



- ❑ Creating the concrete object must establish the representation invariant
- ❑ Every concrete operation must maintain the rep invariant
- ❑ Creating the abstraction object must establish the abstraction function
- ❑ Every abstract operation must maintain the AF to provide consistent semantic meaning to the client
- ❑ If things are right, either red arrow above will give the same result

ADTs and Java language features

- Java classes
  - 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
  - Prefer interface types instead of specific classes in declarations (e.g., **`List`** instead of **`ArrayList`** for variables and parameters)

Representation exposure redux

- Hiding the representation of data in the concrete implementation increases the strength of the specification contract, making the rights and responsibilities of both the client and the implementer clearer
- Defining the fields as **`private`** in a class is not sufficient to ensure that the representation is hidden
- *Representation exposure* arises when information about the representation can be determined by the client

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

A half-step backwards

- Why focus so much on invariants (properties of code that do not – or are not supposed to – change)?
- Why focus so much on immutability (a specific kind of invariant)?

- Software is complex – invariants/immutability etc. allow us to reduce the intellectual complexity to some degree
- That is, if we can assume some property remains unchanged, we can consider other properties instead
- Simplistic to some degree, but reducing what we need to think about in a program can be a huge benefit