CSE 331
Software Design & Implementation

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Abstract Data Types – Examples / Summary

(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 can define **`int`** with only one creator

Would this be a good programming language design choice? Why might we want to do this?

Poly, an immutable datatype: overview

```
/**
 * A Poly is an immutable polynomial with
 * integer coefficients.  A typical Poly is
 *          c0 + c1x + c2x^2 + ...
 **/
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 above refer to specification, not implementation.)

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; 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
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

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 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)

// 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 (if appropriate)

Typically have no return value

(sometimes return “old” value that was replaced)

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) that 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 – i.e., 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 and not vice versa?

It’s not a function in the other direction.

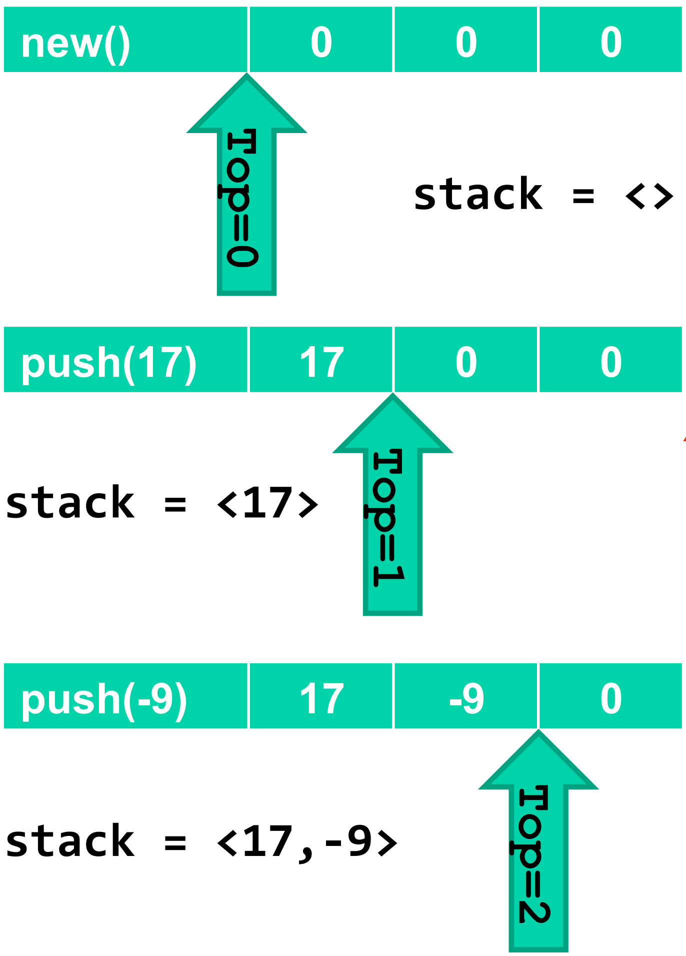
E.g., lists **`[a,b]`** and **`[b,a]`** each represent the set **`{a, b}`**

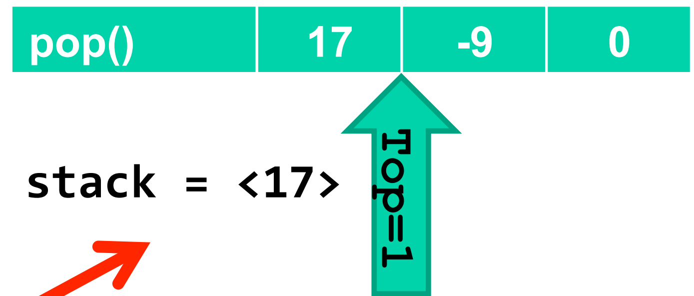
It’s not as useful in the other direction.

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>`

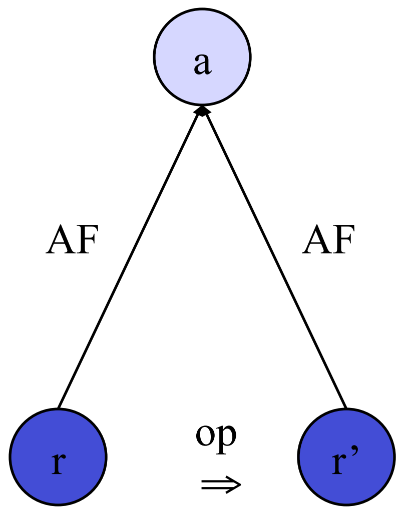
Concrete states are different
`<[17,0,0], top=1>`
$\neq$
`<[17,-9,0], top=1>`

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

Benevolent side effects

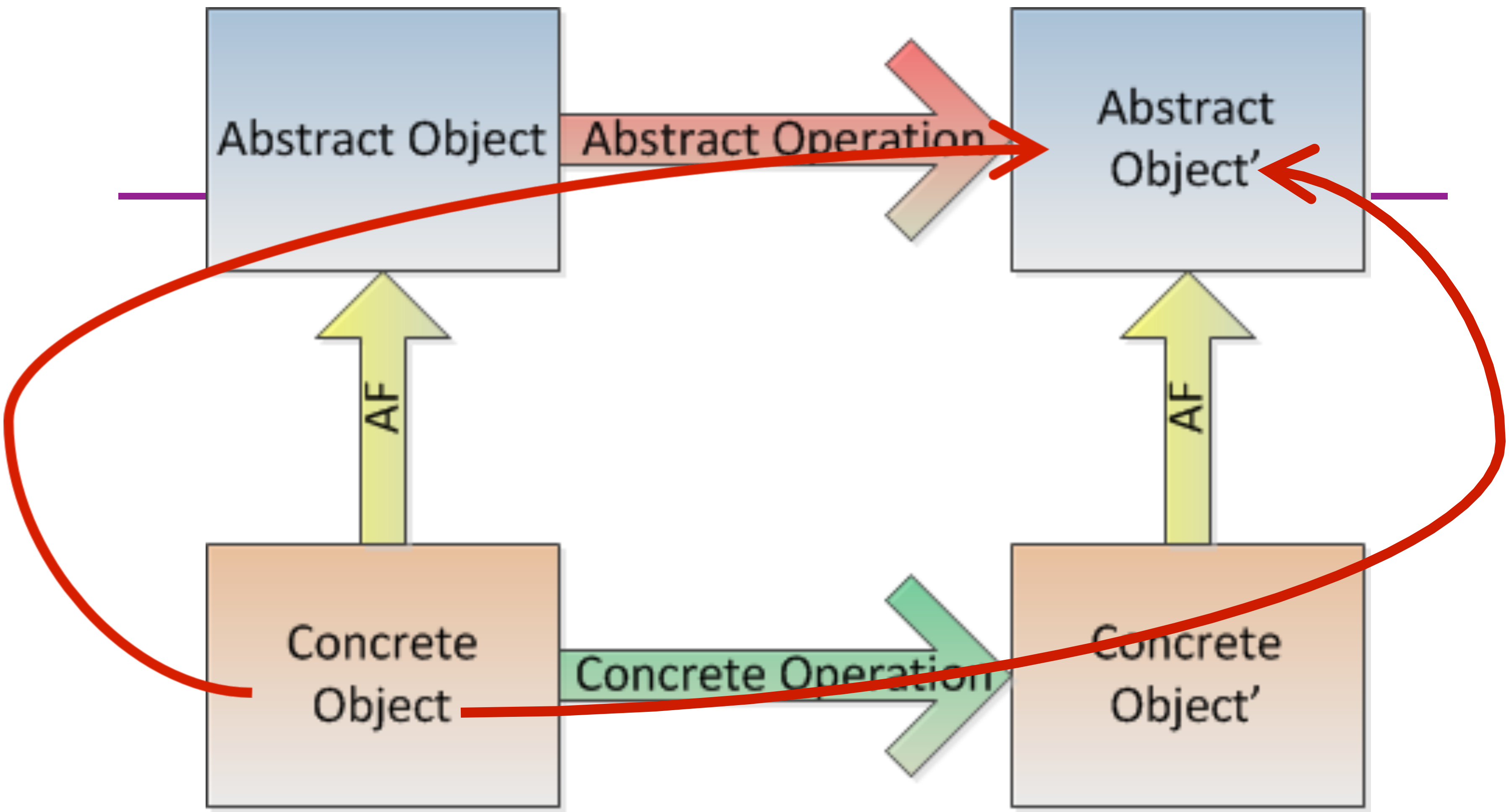
Different implementation of member:

```
boolean member(Character c1) {
  int i = elts.indexOf(c1);
  if (i == -1)
    return false;
  // move-to-front optimization
  Character c2 = elts.elementAt(0);
  elts.set(0, c1);
  elts.set(i, c2);
  return true;
}
```



Move-to-front speeds up repeated membership tests
Mutates rep, but does not change *abstract* value

AF maps both reps to the same abstract value



- ❑ 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

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

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