Connecting implementations to specs

**Representation Invariant**: maps Object → boolean
- Indicates if an instance is well-formed
- Defines the set of valid concrete values
- Only values in the valid set make sense as implementations of an abstract value
- For implementors/debuggers/maintainers of the abstraction: no object should ever violate the rep invariant
  - Such an object has no useful meaning

**Abstraction Function**: maps Object → abstract value
- What the data structure means as an abstract value
- How the data structure is to be interpreted
- Only defined on objects meeting the rep invariant
- For implementors/debuggers/maintainers of the abstraction:
  - Each procedure should meet its spec (abstract values) by “doing the right thing” with the concrete representation

Rep inv. constrains structure, not meaning

An implementation of `insert` that preserves the rep invariant:
```java
public void insert(Character c) {
    Character cc = new Character(encrypt(c));
    if (!elts.contains(cc))
        elts.addElement(cc);
}
```
```java
public boolean member(Character c) {
    return elts.contains(c);
}
```

Program is still wrong
- Clients observe incorrect behavior
- What client code exposes the error?
- Where is the error?
- We must consider the meaning
- The abstraction function helps us

Abstraction function: rep → abstract value

The abstraction function maps the concrete representation to the abstract value it represents
AF: Object → abstract value
AF(CharSet this) = \{ c | c is contained in this.elts \}

Not executable because abstract values are “just” conceptual

The abstraction function lets us reason about what [concrete] methods do in terms of the clients’ [abstract] view

Abstraction function and `insert`

Goal is to satisfy the specification of insert:
```java
// modifies: this
// effects: this_post = this_pre U \{c\}
public void insert(Character c) {...
```

The AF tells us what the rep means, which lets us place the blame
AF(CharSet this) = \{ c | c is contained in this.elts \}

Consider a call to `insert`:
- On entry, meaning is AF(this\_pre) = elts\_pre
- On exit, meaning is AF(this\_post) = AF(this\_pre) U (encrypt('a'))

What if we used this abstraction function instead?
AF(this) = \{ c | encrypt(c) is contained in this.elts \}
  = \{ decrypt(c) | c is contained in this.elts \}

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
  - Example: lists \{a, b\} and \{b, a\} might each represent the set \{a, b\}
- It’s not as useful in the other direction
  - Purpose is to reason about whether our methods are manipulating concrete representations correctly in terms of the abstract specifications
Stack AF example

Abstract stack with array and "top" index implementation

new() 0 0 0

push(17) 17 0 0
stack = <17>
Top=1

push(-9) 17 -9 0
stack = <17, -9>
Top=2

pop() 17 -9 0
stack = <17>
Top=1

ABSTRACT STATES ARE THE SAME
stack = <17> = <17>
Concrete states are different

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Benevolent side effects

Different implementation of `member`

```java
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`
  - Precise reasoning/explanation for "clients can’t tell"

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For any correct operation...

Writing an abstraction function

**Domain**: all representations that satisfy the rep invariant

**Range**: can be tricky to denote
- For mathematical entities like sets: easy
- For more complex abstractions: give names to specification
  - `AF defines the value of each “specification field”`

Overview section of the specification should provide a notation of writing abstract values
- Could implement a method for printing in this notation
  - Useful for debugging
  - Often a good choice for `toString`

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Data Abstraction: Summary

**Rep invariant**
- Which concrete values represent abstract values

**Abstraction function**
- For each concrete value, which abstract value it represents

Together, they modularize the implementation
- Neither one is part of the ADT’s specification
- Both are needed to reason an implementation satisfies the specification

In practice, representation invariants are documented more often and more carefully than abstraction functions
- A more widely understood and appreciated concept

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