CSE 331

Software Design & Implementation

Topic: Specifications; Abstract Data Types

Discussion: What is something you are weirdly good/bad at?

Reminders

- Prefer if regrade requests on Gradescope.
- Ask questions about HW2 in OH or on the discussion board
  - When possible, make your questions public
  - When reasoning about loops, keep the “?” explanations *short*

Upcoming Deadlines

- HW2 due Thursday (6/29)

Code Review

“Hey, can you check if my code is correct?”

```
int maxLoc(int[] arr, int n) {
    ...
}
```

The Code

```
int maxLoc(int[] arr, int n) {
    int maxIndex = 0;
    int maxValue = arr[0];
    // Inv: maxValue = max of arr[0] .. arr[i-1] and
    //      maxValue = arr[maxIndex]
    for (int i = 1; i < n; i++) {
        if (arr[i] > maxValue) {
            maxIndex = i;
            maxValue = arr[i];
        }
    }
    return maxIndex;
}
```

Is this code correct?

What if n = 0?

What if n > arr.length?

What if there are two maximums?

Specifications

To prove correctness of our method, need

- precondition
- postcondition

Without these, we can't say whether the code is correct
These tell us what it means to be correct

They are the *specification* for the method

Correctness = Validity of
{{ P }} S {{ Q }}

Unexpected Behavior?

✓ Returns the index of the maximum element from the first `n` elements of `arr`. Assume `1 <= n < arr.length.`

✗ Returns the index of the maximum element from the first `n` elements of `arr.`

✗ Returns the index of maximum element from `arr` after index `n`.

✗ Returns the location of Max’s office which is 103.

How to Check Correctness

- Step 1: need a **specification** for the function
  - can't argue correctness if we don't know what it should do
  - surprisingly difficult to write!

- Step 2: determine whether the code meets the specification
  - apply **reasoning**
  - usually easy with the tools we learned

Last Time…

- Loop invariants
  - maximum of array
  - Dutch National Flag
  - Binary Search
- Reasoning Summary
- Specifications

Today's Agenda

- Why Specifications?
- JavaDoc
- Comparing Specifications

Goals

We want our code to be:

1. Correct
   - everything else is secondary
2. Easy to change
   - most code written is changing existing systems
3. Easy to understand
   - corollary of previous two
4. Easy to scale
   - modular

A specification is a contract

- A set of requirements agreed to by the user and the manufacturer of the product
  - describes their expectations of each other

- Facilitates simplicity via *two-way* isolation (modularity)
  - client promises to meet precondition, gets postcondition
  - implementer assumes precondition, promises postcondition
  - discourages implicit, unwritten expectations

Importance of Specifications

Specifications are essential to **correctness**

They are also essential to **changeability**

- need to know what changes will break code using it

They are also essential to **understandability**

- need to tell readers what it is supposed to do

They are also essential to **modularity**

- need to tell clients what it will do so they can start building their own parts of the system

Isn't the interface sufficient?

The interface defines the boundary between implementers and users:

```
public class MyList implements List<E> {
    public E get(int x) { return null; }
    public void set(int x, E y){}
    public void add(E elem) {}
    public void add(int index, E elem){}
    …
}
```

Interface provides the *syntax and types*

But nothing about the *behavior and effects*

- provides **too little** information to clients

Why not just read code?

```
static <T> boolean ???(List<T> src, List<T> part) {
     int part_index = 0;
     for (T elt : src) {
         if (elt.equals(part.get(part_index))) {
             part_index++;
             if (part_index == part.size()) {
                 return true;
             }
         } else {
             part_index = 0;
         }
     }
     return false;
 }
```

How long does it take you to figure out what this does?

Sublist example

```
static <T> boolean sub(List<T> src, List<T> part) {
    int part_index = 0;
    for (T elt : src) {
        if (elt.equals(part.get(part_index))) {
            part_index++;
            if (part_index == part.size()) {
                return true;
            }
        } else {
            part_index = 0;
        }
    }
    return false;
}
```

Code is complicated

- Code gives more detail than needed by client

- Understanding or even reading every line of code is an excessive burden
  - suppose you had to read source code of Java libraries to use them
  - same applies to developers of different parts of the libraries
  - would make it impossible to build million-line programs

- Client cares only about *what* the code does, not *how* it does it

Code is ambiguous

- Code seems unambiguous and concrete
  - but which details of code's behavior are essential, and which are incidental?

- Code invariably gets rewritten
  - client needs to know what they can rely on
    - what properties will be maintained over time?
    - what properties might be changed by future optimization, improved algorithms, or bug fixes?
  - implementer needs to know what features the client depends on, and which can be changed

Comments are essential

Most comments convey only a vague idea of what that the code does:

```
// Returns the location of the largest value
// in the first n elements of the array arr
int maxLoc(int[] arr, int n) {
```

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// This method checks if "part" appears as a
// subsequence in "src"
static <T> boolean sub(List<T> src, List<T> part)
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- should be True if **`part`** is empty

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// subsequence in "src"
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```

Ambiguity remains:

- should be True if **`part`** is empty and False if **`src`** is empty
- what if **`src`** and **`part`** are both empty?

A more careful description of **`sub`**

```
// Check whether "part" appears as a subsequence in "src"
```

needs to be given some caveats:

```
// * src and part cannot be null
// * If src is empty list, always returns false
```

Recall the sublist example

```
static <T> boolean sub(List<T> src, List<T> part) {
    int part_index = 0;
    for (T elt : src) {
        if (elt.equals(part.get(part_index))) {
            part_index++;
            if (part_index == part.size()) {
                return true;
            }
        } else {
            part_index = 0;
        }
    }
    return false;
}
```

A more careful description of **`sub`**

```
// Check whether "part" appears as a subsequence in "src"
```

needs to be given some caveats:

```
// * src and part cannot be null
// * If src is empty list, always returns false
// * Results may be unexpected if partial matches
//   can happen right before a real match; e.g.,
//   list (1,2,1,3) will not be identified as a
//   sub sequence of (1,2,1,2,1,3).
```

or replaced with a more detailed description:

```
// This method scans the "src" list from beginning
// to end, building up a match for "part", and
// resetting that match every time that...
```

A better approach

It's better to simplify than to describe complexity!

Complicated description suggests poor design

- rewrite **`sub`** to be more sensible, and easier to describe

```
// Returns true iff there exist sequences A and B (possibly
// empty) such that src = A + part + B, where + means concat
static <T> boolean sub(List<T> src, List<T> part) {
```

- Mathematical flavour not always necessary, but avoids ambiguity
- "Declarative" style is important: avoids reciting or depending on operational/implementation details

Sneaky fringe benefit of specs

- The discipline of writing specifications changes the incentive structure of coding
  - rewards code that is easy to describe and **understand**
  - punishes code that is hard to describe and **understand**
    - (even if it is shorter or easier to write)

- If you find yourself writing complicated specifications, it is an incentive to redesign
  - in **`sub`**, code that does exactly the right thing may be slightly slower than a hack that assumes no partial matches before true matches, but cost of forcing client to understand the details is too high

Writing specifications with Javadoc

- Javadoc
  - Sometimes can be daunting; get used to using it
  - Very important feature of Java (copied by others)

- Javadoc convention for writing specifications
  - Method signature
  - Text description of method
  - **`@param`**: description of what gets passed in
  - **`@return`**: description of what gets returned
  - **`@throws`**: exceptions that may occur

Example: Javadoc for `String.contains`

Javadoc is a tool that converts comments into webpages (HTML)

contains

`public boolean contains(CharSequence s)`

Returns true if and only if this string contains the specified sequence of char values.

Parameters:

s - the sequence to search for

Returns:

true if this string contains `s`, false otherwise

Throws:

`NullPointerException` - if s is `null`

Since:

1.5

CSE 331 specifications

Note: these are abbreviated. In your code, it must be `@spec.requires`, `@spec.modifies`, etc.

- The *precondition*: constraints that hold before the method is called (if not, all bets are off)
  - **`@requires`**: spells out any obligations on client

- The *postcondition*: constraints that hold after the method is called (if the precondition held)
  - **`@modifies`**: lists objects that may be affected by method; any object not listed is guaranteed to be untouched
  - **`@effects`**: gives guarantees on final state of modified objects
  - **`@throws`**: lists possible exceptions and conditions under which they are thrown
  - **`@return`**: describes return value

Example 1

```
requires   list is non-null
modifies   list
effects    change the first occurrence of oldelt in list to newElt
           (making no other changes to list)
returns    the position of the element in lst that was oldElt and
           is now newElt or -1 if oldElt not in list
```

```
static <T> int changeFirst(List<T> list, T oldElt, T newElt) {
    int i = 0;
    for (T curr : list) {
        if (curr == oldElt) {
            list.set(newElt, i);
            return i;
        }
        i = i + 1;
    }
    return -1;
}
```

Example 2

```
requires   lst1 and lst2 are non-null.
           lst1 and lst2 are the same size.
modifies   none   (or leave these off)
effects    none
returns    a list of same size where the ith element is
           the sum of the ith elements of lst1 and lst2
```

```
List<Integer> zipSum(List<Integer> lst1, List<Integer> lst2) {
    List<Integer> res = new ArrayList<Integer>();
    for(int i = 0; i < lst1.size(); i++) {
        res.add(lst1.get(i) + lst2.get(i));
    }
    return res;
}
```

Example 3

```
requires   lst1 and lst2 are non-null.
           lst1 and lst2 are the same size.
modifies   lst1
effects    ith element of lst2 is added to the ith element of lst1
returns    none  (or leave this off)
```

```
static void listAdd(List<Integer> lst1, List<Integer> lst2) {
    for(int i = 0; i < lst1.size(); i++) {
        lst1.set(i, lst1.get(i) + lst2.get(i));
    }
}
```

Should requires clause be checked?

- If the client calls a method without meeting the precondition, the code is free to do *anything*
  - including pass corrupted data back
  - it is a good idea to *fail fast*: to provide an immediate error, rather than permitting mysterious bad behaviour

- Rule of thumb: Check if cheap to do so
  - Example: number has to be positive → check
  - Example: list has to be sorted → skip
  - Be judicious if private / only called from your code

Comparing specifications

- Occasionally, we need to compare different specification:
  - comparing potential specifications of a new class
  - comparing new version of a specification with old
    - recall: most work is making changes to existing code

- For that, we often consider *stronger* and *weaker* specifications…

Satisfaction of a specification

Let M be an implementation and S a specification

M satisfies S if and only if

- for every input allowed by the spec precondition,
  M produces an output allowed by the spec postcondition

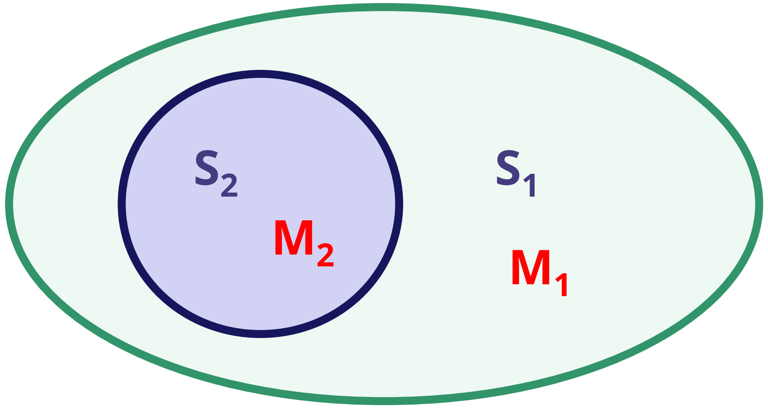
If M does not satisfy S, either M or S (or both!) could be "wrong"

- *"one person's feature is another person's bug."*

Stronger vs Weaker Specifications

Definition 1: specification S_2 is stronger than S_1 iff

- for any implementation M: M satisfies S_2 => M satisfies S_1
- i.e., S_2 is harder to satisfy



(satisfying **implementations**)

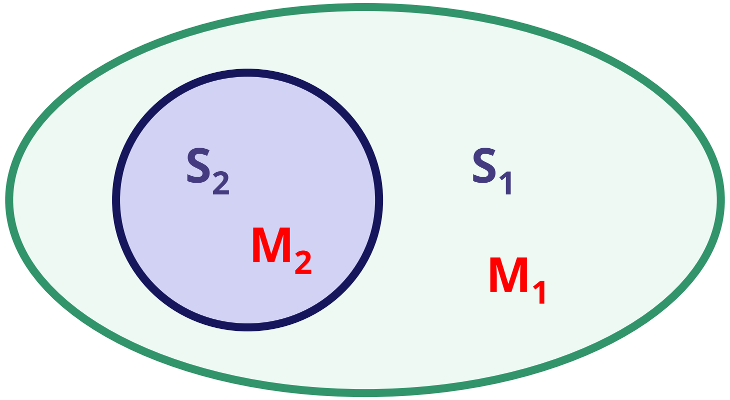
Two specifications may be *incomparable*

- but we are usually choosing between stronger vs weaker

Stronger vs Weaker Specifications

An implementation satisfying a stronger specification can be **used anywhere** that a weaker specification is required

- can **use** a method satisfying S_2 anywhere S_1 is expected



Making changes to a specification…

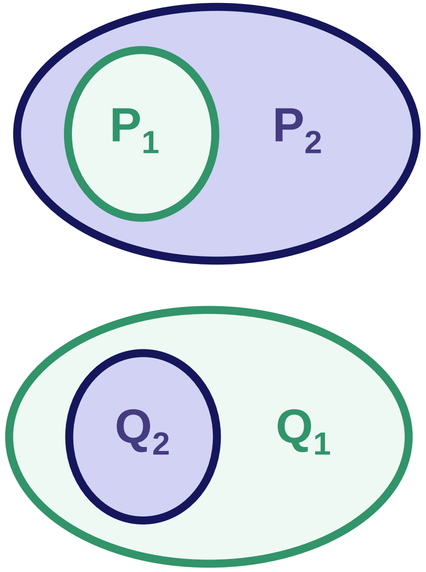
- Suppose S_2 and M_2. Changing from S_2 to S_1 should not break implementation
  - but it could break clients
- Suppose S_1 and M_1. changing from S_1 to S_2 should not break clients
  - but it could break implementations

Stronger vs Weaker Specifications

- **Definition 2**: specification S_2 is stronger than S_1 iff
  - precondition of S_2 is weaker than that of S_1
  - postcondition of S_2 is stronger than that of S_1
    (on all inputs allowed by both)

- A **stronger** specification:
  - is harder for implementer to satisfy
  - gives more guarantees to the client

- A **weaker** specification:
  - is easier for implementer to satisfy
  - gives the client fewer guarantees



Example 1 (stronger postcondition)

```
int find(int[] a, int value) {
    for (int i=0; i<a.length; i++) {
        if (a[i]==value)
          return i;
    }
    return -1;
}
```

Which is stronger?

- Specification A
  - requires: value occurs in **`a`**
  - returns: **`i`** such that **`a[i]`** = **`value`**
- Specification B
  - requires: value occurs in **`a`**
  - returns: *smallest* **`i`** such that **`a[i]`** = **`value`**

Example 2 (weaker precondition)

```
int find(int[] a, int value) {
    for (int i=0; i<a.length; i++) {
        if (a[i]==value)
          return i;
    }
    return -1;
}
```

Which is stronger?

- Specification A
  - requires: value occurs in **`a`**
  - returns: **`i`** such that **`a[i]`** = **`value`**

- Specification C
  - returns: **`i`** such that **`a[i]`** = **`value`**, or **`-1`** if value is not in **`a`**

Example 3

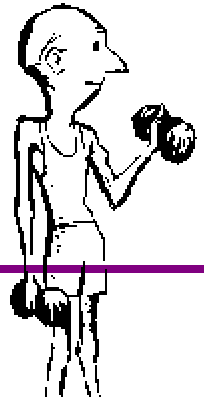
```
int find(int[] a, int value) {
    for (int i=0; i<a.length; i++) {
        if (a[i]==value)
          return i;
    }
    return -1;
}
```

Which is stronger?

- Specification B
  - requires: value occurs in **a**
  - returns: *smallest* **i** such that **a[i]** = **value**

- Specification C
  - returns: **i** such that **a[i]** = **value**, or **-1** if value is not in **a**

Strengthening a specification



- Strengthen a specification by:
  - Promising more (stronger postcondition):
    - returns clause harder to satisfy
    - effects clause harder to satisfy
    - fewer objects in modifies clause
    - more specific exceptions (subclasses)
  - Asking less of client (weaker precondition)
    - requires clause easier to satisfy

- Weaken a specification by:
  - (Opposite of everything above)

The curious case of @throws…

Compare:

S1:

@throws FooException if x<0

@return x+3

S2:

@return x+3

S3:

@requires x >= 0

@return x+3

- S1 & S2 are *stronger* than S3
- S1 & S2 are *incomparable* because they promise different, incomparable things when x<0

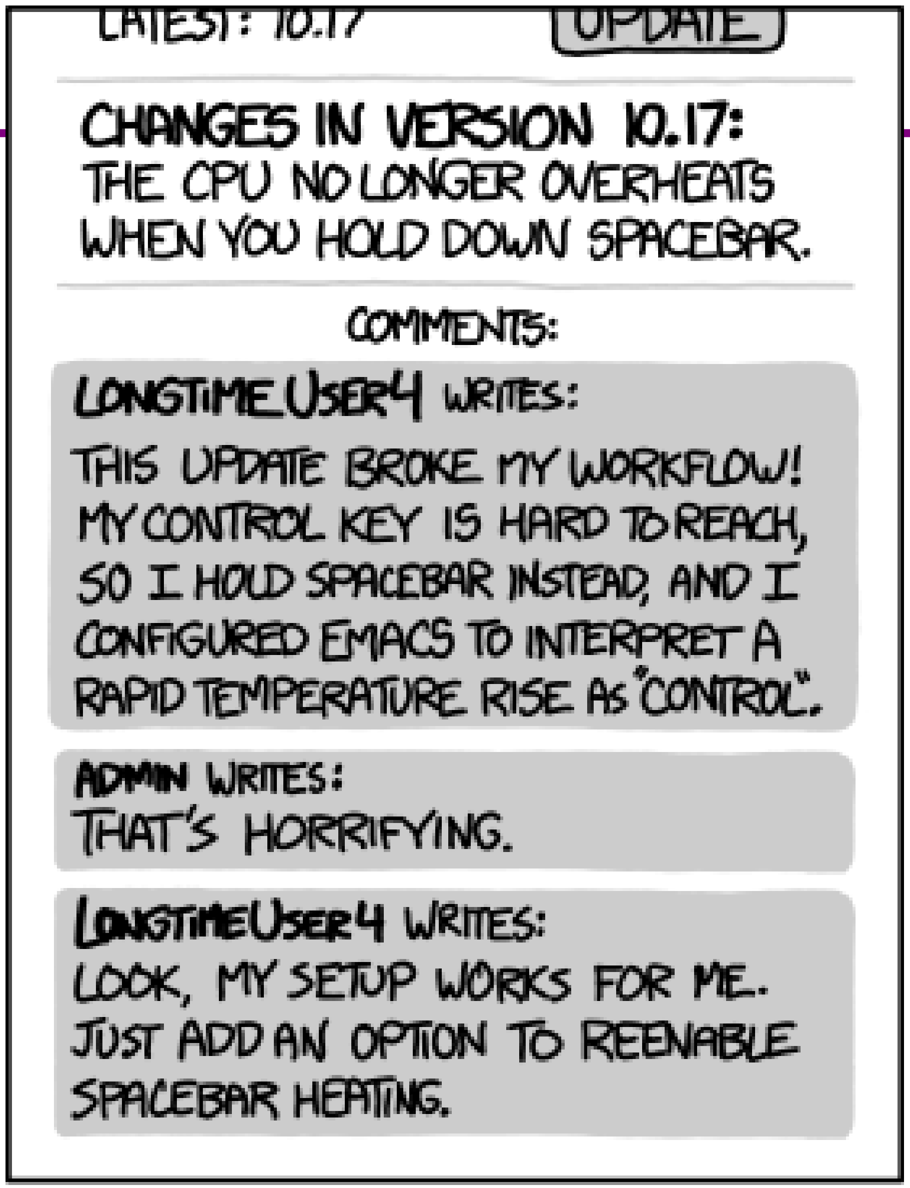
Which is better?

- Stronger does not always mean better!
- Weaker does not always mean better!

- Strength of specification trades off:
  - usefulness to client
  - ease of simple, efficient, correct implementation
  - promotion of reuse and modularity
  - clarity of specification itself

- “It depends”

XKCD
1172



EVERY CHANGE BREAKS SOMEONE'S WORKFLOW.

Back to Correctness…

Correctness Toolkit

- Learned forward and backward reasoning for
  - assignment
  - if statement
  - while loop

- One missing element: function calls
  - we needed specifications for that
  - now we have them

Reasoning about Function Calls

```
static int f(int a, int b) { … }
```

requires P(a,b) -- some assertion about a & b

returns R(a,b,c) -- some assertion about a, b, & c (returned)

Forward

{{ P1 }}

c = f(a, b);

Reasoning about Function Calls

```
static int f(int a, int b) { … }
```

requires P(a,b) -- some assertion about a & b
returns R(a,b,c) -- some assertion about a, b, & c (returned)

Forward

{{ P1 }}

```
  c = f(a, b);
```

{{ P1 and R(a,b,c) }}

if P1 implies P(a,b)

Reasoning about Function Calls

```
static int f(int a, int b) { … }
```

requires P(a,b) -- some assertion about a & b
returns R(a,b,c) -- some assertion about a, b, & c (returned)

Backward

{{ Q1 and P(a,b) }}

```
c = f(a, b);
```

{{ Q1 and Q(a,b,c) }}

if R(a,b,c) implies Q(a, b, c)

Reasoning about Objects

Outline

Previously looked at writing specifications for methods.
The situation gets more complex with object-oriented code…

This lecture:

1. What is an Abstract Data Type (ADT)?
2. How to write a specification for an ADT
3. Design methodology for ADTs

Next lecture(s):

- Documenting the *implementation* of an ADT
- Reasoning about the implementation of an ADT

Before next class...

1. Complete HW2!
   - Setup programming environment
   - Apply reasoning to code
   - Come to OH if you have any questions
   - Ensure that you submit your code **correctly**

2. Prepare for the tomorrow's section!
   - Overview of tools
   - Walkthrough of how to tag + submit code
   - Prepare you for HW3