
CSE 331

Software Design & Implementation

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Lecture 4 - Specifications
(Based on slides by Mike Ernst, Hal Perkins)

2 Goals of Software System Building

- Building the *right system*
 - Does the program meet the user's needs?
 - Determining this is usually called *validation*
- Building the *system right*
 - Does the program meet the specification?
 - Determining this is usually called *verification*
- CSE 331: the second goal is the focus – creating a correctly functioning artifact
 - Surprisingly hard to specify, design, implement, test, and debug even simple programs

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Where we are

- We've started to see how to reason about code
- We'll build on those skills in many places:
 - *Specification*: What are we supposed to build?
 - *Design*: How do we decompose the job into manageable pieces? Which designs are "better"?
 - *Implementation*: Building code that meets the specification
 - *Testing*: Systematically finding problems
 - *Debugging*: Systematically fixing problems
 - *Maintenance*: How does the artifact adapt over time?
 - *Documentation*: What do we need to know to do these things? How/where do we write that down?

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The challenge of scaling software

- Small programs are simple and malleable
 - Easy to write
 - Easy to change
- Big programs are (often) complex and inflexible
 - Hard to write
 - Hard to change
- Why does this happen?
 - Because *interactions* become unmanageable
- How do we keep things simple and malleable?

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A discipline of modularity

- Two ways to view a program:
 - The implementer's view (how to build it)
 - The client's view (how to use it)
- It helps to apply these views to program parts:
 - While implementing one part, consider yourself a client of any other parts it depends on
 - Try *not* to look at those other parts through an implementer's eyes
 - Helps dampen interactions between parts
- Formalized through the idea of a *specification*

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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
 - Isolate client from implementation details
 - Isolate implementer from how the part is used
 - Discourages implicit, unwritten expectations
- Facilitates change
 - Reduces the "Medusa effect": the specification, rather than the code, gets "turned to stone" by client dependencies



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Isn't the interface sufficient?

The interface defines the boundary between implementers and users:

```
public interface List<E> {
    public E get(int);
    public void set(int, E);
    public void add(E);
    public void add(int, E);
    ...
    public static <T> boolean isSub(List<T>, List<T>);
}
```

Interface provides the *syntax and types*

But nothing about the *behavior and effects*

- Provides too little information to clients

Note: Code above is right concept but is not legal Java

- Parameters need names; no static interface methods until Java 8

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Why not just read code?

```
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;
}
```

Why are you better off with a specification?

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

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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

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Comments are essential

Most comments convey only an informal, general idea of what that the code does:

```
// This method checks if "part" appears as a
// sub-sequence in "src"
static <T> boolean sub(List<T> src, List<T> part) {
    ...
}
```

Problem: ambiguity remains

- What if `src` and `part` are both empty lists?
- When does the function return `true`?

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From vague comments to specifications

- Roles of a specification:
 - Client agrees to rely *only* on information in the description in their use of the part
 - Implementer of the part promises to support everything in the description
 - Otherwise is perfectly at liberty
- Sadly, much code lacks a specification
 - Clients often work out what a method/class does in ambiguous cases by running it and depending on the results
 - Leads to bugs and programs with unclear dependencies, reducing simplicity and flexibility

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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;
}
```

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A more careful description of sub

```
// Check whether "part" appears as a sub-sequence in "src"
```

needs to be given some caveats (why?):

```
// * 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...
```

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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 sequences A, B exist such that

// src = A : part : B

// where ":" is sequence concatenation

```
static <T> boolean sub(List<T> src, List<T> part) {
```

- Mathematical flavor not always necessary, but often helps avoid ambiguity
- “Declarative” style is important: avoids reciting or depending on operational/implementation details

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Sneaky fringe benefit of specs #1

- 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
 - `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

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Writing specifications with Javadoc

- Javadoc
 - Sometimes can be daunting; get used to using it
- 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

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Example: Javadoc for `String.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
```

```
Since:
```

```
1.5
```

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- 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
 - `@throws`: lists possible exceptions (Javadoc uses this too)
 - `@effects`: gives guarantees on final state of modified objects
 - `@return`: describes return value (Javadoc uses this too)

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Example 1

```
static <T> int change(List<T> lst, T oldelt, T newelt)
  requires lst, oldelt, and newelt are non-null.
           oldelt occurs in lst.
  modifies lst
  effects  change the first occurrence of oldelt in lst to newelt
           & makes no other changes to lst
  returns  the position of the element in lst that was oldelt and
           is now newelt
```

```
static <T> int change(List<T> lst,
                    T oldelt, T newelt) {
    int i = 0;
    for (T curr : lst) {
        if (curr == oldelt) {
            lst.set(newelt, i);
            return i;
        }
        i = i + 1;
    }
    return -1;
}
```

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Example 2

```
static List<Integer> zipSum(List<Integer> lst1, List<Integer> lst2)
  requires lst1 and lst2 are non-null.
           lst1 and lst2 are the same size.
  modifies none
  effects  none
  returns  a list of same size where the ith element is
           the sum of the ith elements of lst1 and lst2
```

```
static 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;
}
```

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Example 3

```
static void listAdd(List<Integer> lst1, List<Integer> lst2)
  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
```

```
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));
    }
}
```

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Example 4 (Watch out for bugs!)

```
static void uniquify(List<Integer> lst)
  requires ???
           ???
  modifies ???
  effects  ???
  returns  ???
```

```
static void uniquify(List<Integer> lst) {
    for (int i=0; i < lst.size()-1; i++)
        if (lst.get(i) == lst.get(i+1))
            lst.remove(i);
}
```

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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 polite, nevertheless, to *fail fast*: to provide an immediate error, rather than permitting mysterious bad behavior
- Preconditions are common in “helper” methods/classes
 - In public libraries, it’s friendlier to deal with all possible input
 - *Example: binary search would normally impose a precondition rather than simply failing if list is not sorted. Why?*
- Rule of thumb: Check if cheap to do so
 - *Example: list has to be non-null → check*
 - *Example: list has to be sorted → skip*

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Satisfaction of a specification

Let M be an implementation and S a specification

M satisfies S if and only if

- Every behavior of M is permitted by S
- “The behavior of M is a subset of S”

The statement “M is correct” is meaningless!

- Though often made!

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

- “One person’s feature is another person’s bug.”
- Usually better to change the program than the spec

Sneaky fringe benefit of specs #2

- Specification means that client doesn’t need to look at implementation
 - So the code may not even exist yet!
- Write specifications first, make sure system will fit together, and then assign separate implementers to different modules
 - Allows teamwork and parallel development
 - Also helps with testing (future topic)

Comparing specifications

- Occasionally, we need to compare different versions of a specification (*Why?*)
 - For that, talk about “weaker” and “stronger” specifications
- A weaker specification gives greater freedom to the implementer
 - If specification S_1 is weaker than S_2 , then for any implementation M,
 - M satisfies $S_2 \Rightarrow$ M satisfies S_1
 - but the opposite implication does not hold in general
- Given two specifications, they may be *incomparable*
 - Neither is weaker/stronger than the other
 - *Some* implementations might still satisfy them both

Why compare specifications?

We wish to relate [procedures to specifications](#)

- Does the procedure satisfy the specification?
- Has the implementer succeeded?

We wish to compare [specifications to one another](#)

- Which specification (if either) is stronger?
- A procedure satisfying a stronger specification can be used anywhere that a weaker specification is required
 - Substitutability principle

Example 1

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

- Specification A
 - requires: value occurs in a
 - returns: i such that $a[i] = \text{value}$
- Specification B
 - requires: value occurs in a
 - returns: *smallest* i such that $a[i] = \text{value}$

Example 2

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

- Specification A
 - requires: value occurs in a
 - returns: i such that $a[i] = \text{value}$
- Specification C
 - returns: i such that $a[i]=\text{value}$, or -1 if value is not in a

Stronger and weaker specifications

- A stronger specification is
 - Harder to satisfy (more constraints on the implementation)
 - Easier to use (more guarantees, more predictable, client can make more assumptions)
- A weaker specification is
 - Easier to satisfy (easier to implement, more implementations satisfy it)
 - Harder to use (makes fewer guarantees)

Strengthening a specification



- Strengthen a specification by:
 - Promising more – any or all of:
 - Effects clause harder to satisfy
 - Returns clause harder to satisfy
 - Fewer objects in modifies clause
 - Fewer possible exceptions
 - Asking less of client
 - Requires clause easier to satisfy
- Weaken a specification by:
 - (Opposite of everything above)

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”

More formal stronger/weaker

- A specification is a logical formula
 - S1 stronger than S2 if S1 implies S2
 - From implication all things follows:
 - Example: S1 stronger if requires is weaker
 - Example: S1 stronger if returns is stronger
- As in all logic (cf. CSE311), two rigorous ways to check implication
 - Convert entire specifications to logical formulas and use logic rules to check implication (e.g., $P1 \wedge P2 \Rightarrow P2$)
 - Check every *behavior* described by stronger also described by the other
 - CSE311: truth tables
 - CSE331: *transition relations*

Transition relations

- There is a program state before a method call and after
 - All memory, values of all parameters/result, whether exception happened, etc.
- A specification “means” a set of pairs of program states
 - The legal pre/post-states
 - This is the transition relation defined by the spec
 - Could be infinite
 - Could be multiple legal outputs for same input
- Stronger specification means the transition relation is a subset
- Note: Transition relations often are infinite in size