Specifications

CSE 331
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2 goals of software system building

1. Building the right system
   – Does the program meet the user's needs?
   – Determining this is usually called *validation*
2. Building the system right
   – Does the program meet the specification?
   – Determining this is usually called *verification*

In CSE 331, the second goal is the focus: creating a correctly functioning artifact

– It's surprisingly hard to specify, design, implement, test, and debug even simple programs

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: Fixing problems
  - Maintain: 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?

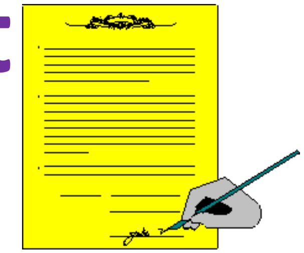
The challenge of scaling software

- 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?

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
  - This helps dampen interactions between parts
- Formalized through the idea of a specification

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 by *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

Isn’t the interface sufficient?

The interface defines the boundary between the implementers and users:

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

Interface provides the syntax

But nothing about the behavior and effects

Why not just read code?

```
boolean sub(List<?> src, List<?> part) {
    int part_index = 0;
    for (Object o : src) {
        if (o.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?

Code is complicated

- Code gives more detail than needed by the client
- Understanding or even reading every line of code is an excessive burden
  - Suppose you had to read the source code of Java libraries in order 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

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 just bug fixes?
  - Implementer needs to know what features the client depends on, and which can be changed

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"
boolean sub(List<?> src, List<?> part) {
        ...
}
```

Problem: ambiguity remains

- *e.g. what if src and part are both empty lists?*

From vague comments to specifications

- ***Properties of a specification:***
  - The client agrees to rely *only* on information in the description in their use of the part.
  - The 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 simply running it, then depending on the results
  - This leads to bugs and to programs with unclear dependencies, reducing simplicity and flexibility

Recall the sublist example

```
<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
// sub-sequence in "src".

needs to be given some caveats (why?):

// * src and part cannot be null
// * If src is an 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...

It’s better to simplify than to describe complexity

A 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
boolean sub(List<?> src, List<?> part)
```

Mathematical flavor is not necessary, but can help avoid ambiguity

“Declarative” style *is* important

- avoid reciting or depending on implementation details

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 the cost of forcing client to understand the details is too high

Examples of specifications

- Javadoc
  - Sometimes can be daunting; get used to using it
- Javadoc convention for writing specifications
  - method signature (prototype)
  - text description of method
  - @param: description of what gets passed in
  - @return: description of what gets returned
  - @throws: list of exceptions that may occur

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

CSE 331 specifications

- 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 the final state of modified objects
  - returns: describes return value (Javadoc uses this too)

Example 1

static 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 now newelt

---

```
static 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;
}
```

Example 2

static List<Integer> listAdd(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 the same size where the *i*th element is the sum of the *i*th elements of lst1 and lst2

```
static List<Integer> listAdd(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

static void listAdd2(List<Integer> lst1, List<Integer> lst2)

requires lst1 and lst2 are non-null.
lst1 and lst2 are the same size

modifies lst1

effects *i*th element of lst2 is added to the *i*th element of lst1

returns none

```
static void listAdd2(List<Integer> lst1,
                     List<Integer> lst2) {
    for(int i = 0; i < lst1.size(); i++) {
        lst1.set(i, lst1.get(i) + lst2.get(i));
    }
}
```

Example 4

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);
}
```

Example: java.util.Arrays.binarySearch

public static int binarySearch(int[] a,int key)

Searches the specified array of ints for the specified value using the binary search algorithm. The array must be sorted (as by the `sort` method, above) prior to making this call. If it is not sorted, the results are undefined. If the array contains multiple elements with the specified value, there is no guarantee which one will be found.

Parameters:

`a`- the array to be searched.

`key`- the value to be searched for.

Returns:

index of the search key, if it is contained in the list; otherwise, `(-(insertion point) - 1)`. (long description...)

Improved binarySearch specification

public static int **binarySearch**(int[] a, int key)

requires: a is sorted in ascending order

returns:

- some i such that a[i] = key if such an i exists,
- otherwise -1

(Returning `(-(`*`insertion point`*`) - 1)` *is an invitation to bugs and confusion. See the full Javadoc. The designers had a reason; what was it, and what are the alternatives? We'll return to the topic of exceptions and special values in a later lecture.)*

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
  - *Why does binarySearch impose a precondition rather than simply failing if list is not sorted?*
- Rule of thumb: Check if it is cheap to do so
  - *Example: list must be non-null → check*
  - *Example: list must be sorted → don’t check*

Comparing specifications

- Occasionally, we need to compare different versions of a specification (*Why?*)
  - For that, we 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 I,
    - I satisfies S_2 => I satisfies S_1
    - but the opposite implication does not hold in general

Compare two specificationss

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

Compare two specifications

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

Stronger and weaker specifications

- A stronger specification is
  - Harder to satisfy (harder to implement)
  - Easier to use (more guarantees, more predictable)
- 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
    - effects clause harder to satisfy, and/or fewer objects in modifies clause
  - asking less of client
    - requires clause easier to satisfy
- Weaken a specification by:
  - promising less
    - effects clause easier to satisfy, and/or extra objects in modifies clause
  - asking more of the client
    - requires clause harder to satisfy

Choosing specifications

- There can be different specifications for the same implementation!
  - Specification declares which properties are essential
    - The implementation leaves that ambiguous
  - Clients know what they can rely on, implementers know what they are committed to
- Which is *better*: a strong or a weak specification?
  - It depends!
  - Criteria: simple, promotes reuse & modularity, efficient

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, as we'll see shortly