CMPT 373
Software Development Methods

Thinking About Correctness

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  - By now you have first hand experience
  - Tracking down causes can be challenging (RCA/Root Cause Analysis)
  - Even just agreeing on what a bug is can be challenging

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- In reality, even agreeing on where a bug resides can be fraught
  - Many bugs do not even have a root cause in code!
- We need extra leverage to make the problem manageable

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Specifications also help establish root causes and guide fixing / maintenance.

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size_t find(const Range& r, const Value& v);
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PRECONDITION: r contains the value v
POSTCONDITION: returns an index of v in r

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template<class Collection, class Predicate>
Range partition(const Range& r, const Predicate& p);
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PRECONDITION: None
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Reorders r s.t. $\forall x,y \in r$, $p(x) \& !p(y) \rightarrow index(x) < index(y)$.
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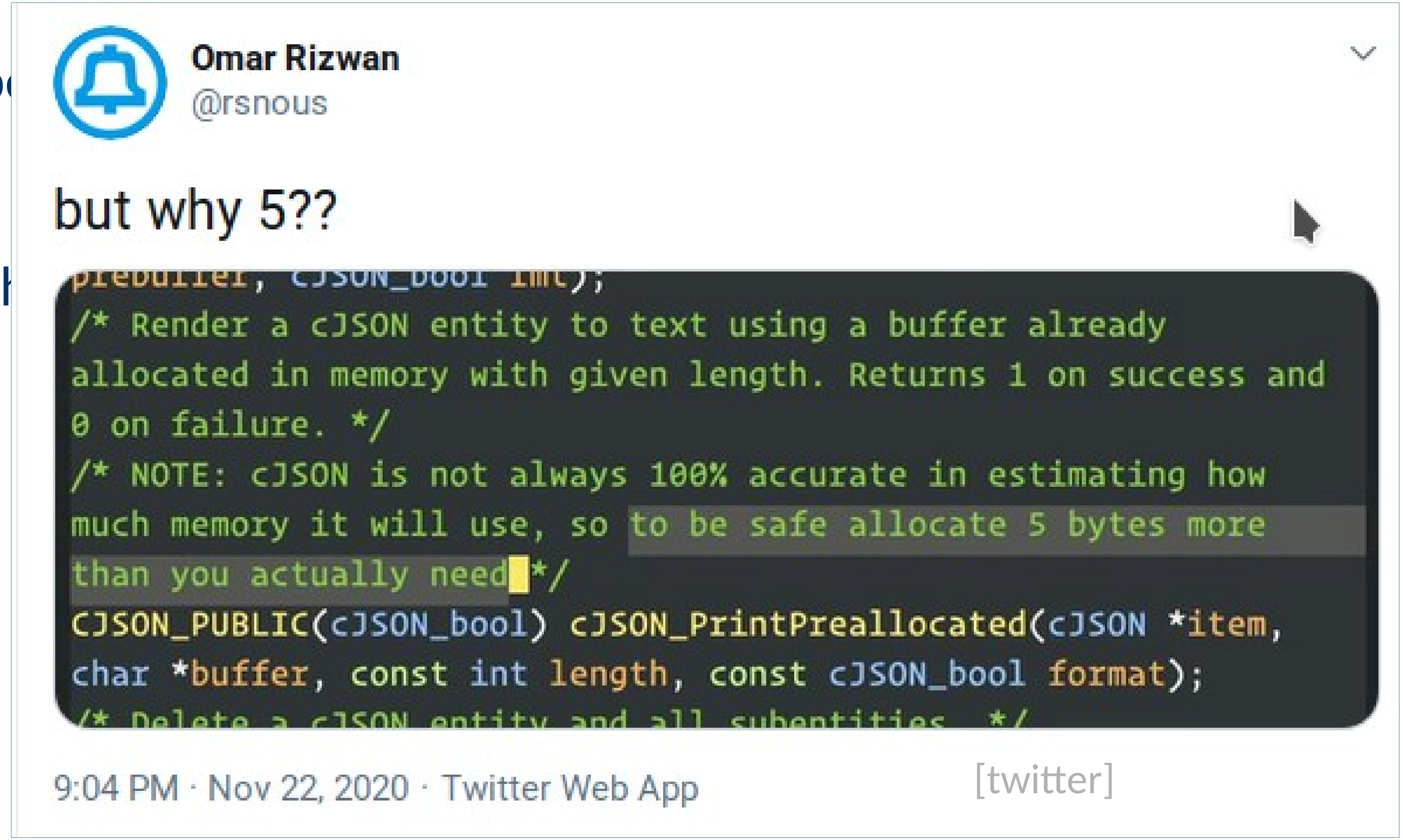

[twitter]

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    They can also drift from the implementation.
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- In practice, a *combination* of the two is frequently used.
  Being able to reason formally helps with designing systems.
  Managing risk/benefit is important.

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public static int search(int[] sortedArray, int value) {
    assert sortedArray != null && 0 < sortedArray.length;
    assert isSorted(sortedArray) : "Array not sorted";
    ...
    assert -1 <= result && result < array.length;
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Trade offs?

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$$\{P\}\ c\ \{Q\}$$

  - When P holds before a component c, Q will hold after

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    Be conservative in what you do. Be liberal in what you accept.
  - This is now regarded as problematic, poorly maintainable,
    & prone to security problems

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How are *constructors* related?

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In fact, I've used invariants to help design some of the demos we've seen in class!

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//@ ghost boolean containsValue =
   (\exists int i; 0 <= i < sortedArray.length; sortedArray[i] == value);
if (value < sortedArray[0]) return -1;
if (value > sortedArray[sortedArray.length-1]) return -1;
int lo = 0;
int hi = sortedArray.length-1;

//@ loop_invariant 0 <= lo < sortedArray.length
                && 0 <= hi < sortedArray.length;
//@ loop_invariant containsValue ==>
  sortedArray[lo] <= value <= sortedArray[hi];
//@ loop_invariant \forall int i; 0 <= i < lo; sortedArray[i] < value;
//@ loop_invariant \forall int i; hi < i < sortedArray.length;
  value < sortedArray[i];
//@ loop_decreases hi - lo;
while (lo <= hi) {
    int mid = lo + (hi-lo)/2;
    if (sortedArray[mid] == value) {
        return mid;
    } else if (sortedArray[mid] < value) {
        lo = mid+1;
    } else {
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int hi = sortedArray.length-1;

//@ loop_invariant 0 <= lo < sortedArray.length
                && 0 <= hi < sortedArray.length;
//@ loop_invariant containsValue ==>
   sortedArray[lo] <= value <= sortedArray[hi];
//@ loop_invariant \forall int i; 0 <= i < lo; sortedArray[i] < value;
//@ loop_invariant \forall int i; hi < i < sortedArray.length;
   value < sortedArray[i];
//@ loop_decreases hi - lo;
while (lo <= hi) {
     int mid = lo + (hi-lo)/2;
     if (sortedArray[mid] == value) {
          return mid;
     } else if (sortedArray[mid] < value) {
          lo = mid+1;
     } else {
          hi = mid-1;
     }
}
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```

In

```
//@ ghost boolean containsValue =
   (\exists int i; 0 <= i < sortedArray.length; sortedArray[i] == value);
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ign

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- Major philosophies at extremes:
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  - The client must fulfill its obligations in order to use the component

Design by contract (obligation of the client)

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- You document & formalize a the contract
- A component may assume that its preconditions hold
- The client may use the strong contract to guard program behavior early & enforce consistency
- If a violation occurs, the contracts may be used to guide debugging

Defensive programming (obligation of provider)

- The component author includes all checks necessary for correctness
- If a contract is violated at runtime,
  then the author notifies the client via some error mechanism

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- Frequently in practice:
  - Assertions
  - Exceptions

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List<Integer> integers = newArrayList(1, 2, 3);
for (Integer integer : integers) {
    integers.remove(1);
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[Baeldung 2019]

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How may these patterns relate to software architecture?

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```
#include <cassert>
constexpr Image ascii[256] = ...

Image& getCharGlyph(int asciiCode) {
  assert(0 < asciiCode && asciiCode < 256
         && "ASCII code out of range.");
  return ascii[asciiCode];
}
```

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  - Both assertions & exceptions should be used with input validation at the boundaries of an interface!
- Exact exception semantics differ across languages, but prefer to
  1) catch & manage specific exception types
  2) consider exceptions hard failures

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- In practice, there is often not much you can do to recover from spec violations
  - Termination is often the right thing
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CHECK_LT(index, size) << "Index out of bounds.";
CHECK_NOTNULL(ptr);
```

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- Logging too little or too much can be a problem
  - Might miss what you want
  - Might create a haystack for your needle
  - Might spend too many resources!

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- Log all events needed for auditing
- Log logic that provides context for possible errors
- Make your log easy to use
  - Machine parsable if possible
  - What / When / Why / Where should be clearly captured

Summary

- Specification can be a powerful tool for reasoning about program correctness
- You can apply a specification using
  - Design by contract (client managed)
  - Defensive programming (provider managed)
- Logging provides a key mechanism for getting more value our of specifications in practice