How Good Are the Specs?

A Study of the Bug-Finding Effectiveness of Existing Java API Specifications

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What is a Specification (Spec)?

"A spec is **a way to use an API** as asserted by the developer or analyst, and **which encodes information about the behavior of a program** when an API is used"

--Robillard et al.[*]

- Violating a spec **may or may not** be a bug

[*] M. P. Robillard, E. Bodden, D. Kawrykow, M. Mezini, and T. Ratchford. Automated API property inference techniques. TSE, 39(5):613–637, 2013.

An Example Spec in our Study - CSC

- CSC = Collections_SynchronizedCollection

- CSC is specified in the Javadoc for java.util.Collections:

> “It is **imperative** that the user manually synchronize on the returned collection when iterating over it ... Failure to follow this advice **may** result in non-deterministic behavior” [*]

- CSC was formalized to enable checking this spec

[*] https://docs.oracle.com/javase/7/docs/api/java/util/Collections.html#synchronizedCollection(java.util.Collection)

CSC Formalized in JavaMOP

- JavaMOP is a runtime verification tool that can check program executions against formal specs

```
Collections_SynchronizedCollection (Collection c, Iterator i) {
  Collection c;
  creation event sync after() returning (Collection c):
    call (Collections.synchronizedCollection(Collection)) || ... { this . c = c ; }
  event syncMk after (Collection c) returning (Iterator i):
    call (Collection+.iterator()) && target (c) && condition (Thread.holdsLock(c)) {}
  event asyncMk after (Collection c) returning (Iterator i):
    call ( Collection+.iterator() && target(c) && condition (!Thread.holdsLock(c)) {}
  event access before (Iterator i):
    call ( Iterator.(..)) && target (i) && condition (!Thread.holdsLock(this.c)) {}
  ere : ( sync asyncMk) | (sync syncMk access)
  @match { RVMLogging.out.println ( Level.CRITICAL, __DEFAULT_MSG); … }
}
```

Illustrative Example

CODE + TESTS → **JavaMOP** ← **CSC SPEC**

Spec Violations

CSC was violated on… (SuiteHTMLReporter.java:365)… A synchronized collection was accessed in a thread−unsaf manner

```
364  im = Collections.synchronizedList(…);
365  for (IInvokedMethod iim : im) { … }
```

Pull Request

```
364     im = Collections.synchronizedList(…);
365 +  synchronized (im) {
366        for (IInvokedMethod iim : im) { … }
367 +  }
```

Line 365 invokes im.iterator() without first synchronizing on im

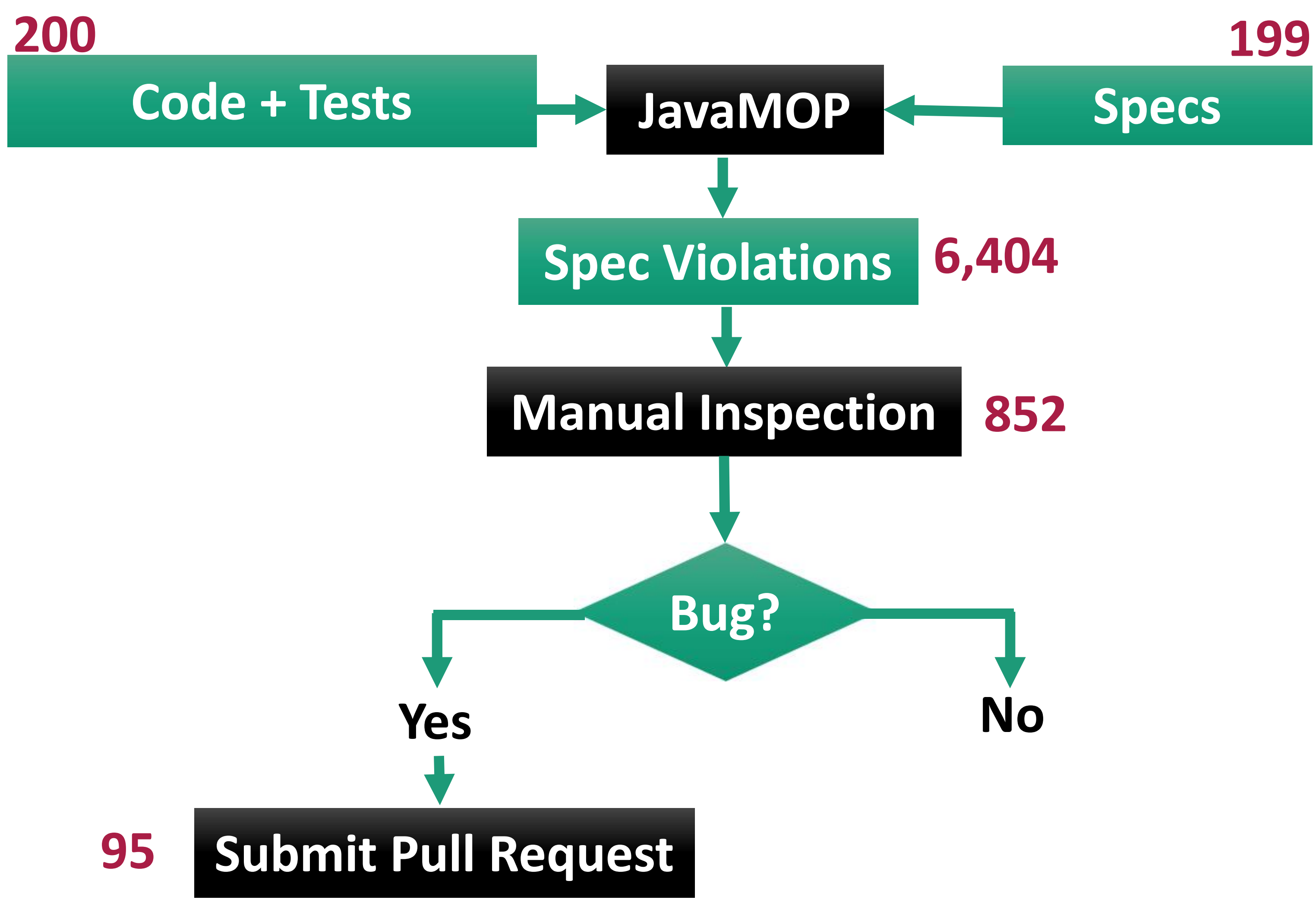
Accepted by TestNG developers

Rejected by XStream developers

Specs in SE Research

- Researchers have proposed many specs by writing manually or mining automatically
- This is the first large-scale study of the effectiveness of these specs for finding bugs during testing
- **An effective spec catches true bugs without generating too many false alarms**

Overview of Our Study



Experimental Subjects

- 200 open-source projects were selected from GitHub
  - Average project size: 6 KLOC
  - Average number of tests: 90.3

- Each selected project satisfies four criteria:
  ✓Uses Maven (for ease of automation)
  ✓Contains at least one test
  ✓Tests pass when not monitored with JavaMOP
  ✓Tests pass when monitored with JavaMOP

Specs Used in our Study

- 182 manually written specs formalized by Luo et al. [1]
- 17 automatically mined specs provided by Pradel et al. [2]
- All specs in our study are publicly available online

[1] Q. Luo, Y. Zhang, C. Lee, D. Jin, P. O. Meredith, T. F. Serbanuta, and G. Rosu. RV-Monitor: Efficient parametric runtime verification with simultaneous properties. In RV, pages 285–300, 2014.
[2] M. Pradel, C. Jaspan, J. Aldrich, and T. R. Gross. Statically checking API protocol conformance with mined multi-object specifications. In ICSE, pages 925–935, 2012.

Tools Used in our Study

- JavaMOP (runtime verification tool)
  - Easy to use: integrate into pom.xml and run “mvn test”
  - JavaMOP allows to monitor multiple specs simultaneously

- Randoop (automatic test generation tool)
  - **Does type of tests affect the bug-finding effectiveness of specs?**
  - We generated tests for 122 of 200 projects
  - Average number of generated tests = 17.5K
  - Total number of generated tests = 2.1M

Inspecting & Classifying Violations

- We inspected 852 (of 6,404) unique spec violations
  - We did not inspect violations from 21 manually written specs
  - We sampled 200 violations of 1,141 automatically mined specs
- Multiple co-authors inspected most violations
- Classification
  - FalseAlarm (716)
  - TrueBug (114)
  - HardToInspect (22)

Research Questions

- RQ1: What is the runtime overhead of monitoring?
  - ✓ Runtime overhead: 4.3x
- RQ2: How many bugs are found from spec violations?
  - ✓ We reported 95 bugs: 74 accepted, 3 rejected so far
- RQ3: What are the false alarm rates among violations?
  - ✗ 82.81% for manually written specs
  - ✗ 97.89% for automatically mined specs

RQ1: Time Overhead of Monitoring

$$Overhead = \frac{mop - base}{base}$$

mop: time to run tests with monitoring
base: time to run tests without monitoring

- Average overhead: 4.3x
- Average additional time: 12.5s
- Specs are monitored simultaneously

RQ2: Bugs in Subject Programs

	Count	Breakdown	
Total TrueBugs	**114**	**From manual specs**	**110**
		From auto specs	**4**
Unique TrueBugs	**97**		
Already fixed TrueBugs	**2**		
Reported TrueBugs	**95**	**Accepted**	**74**
		Rejected	**3**
		Pending	**18**

- Bugs accepted in Joda-Time, TestNG, XStream, BCEL, etc.

RQ3: False Alarm Rates (FAR)

$$FAR = \frac{FalseAlarms}{FalseAlarms+TrueBugs} * 100\%$$

- FAR = 82.81 % for manually written specs
- FAR = 97.89 % for automatically mined specs
- All inspected violations were in 99 projects:

FAR [%]	
FAR = 100%	69
50% ≤ FAR < 100%	20
0% ≤ FAR < 50%	3
FAR = 0%	7

RQ3: FAR vs. Project Characteristics

Type of specs	FAR [%]
Manually written specs	**82.81**
Libraries	86.55
Project code	80.82
Single-module	81.87
Multi-module	86.23
Manually written tests	82.51
Automatically generated tests	84.21
Automatically mined specs	**97.89**
Libraries	100.00
Project code	94.87
Single-module	97.84
Multi-module	98.04

FAR was very high along all dimensions considered

Slightly higher FAR in libraries than in project code

RQ3: FAR among Inspected Specs

Manually written specs	Count
Total	182
Number of specs not violated	119
Number of specs not inspected	21
Number of inspected specs	42

FAR	Count
FAR = 100%	31
50% ≤ FAR < 100%	6
0% ≤ FAR < 50%	4
FAR = 0%	1

- Only 11 of 182 manually written specs helped find a bug
- Only 3 of 17 automatically mined specs helped find a bug
  - FSM162, FSM33, and FSM373
  - 87.50%, 90.00% and 98.06% FAR, respectively

Example False Alarm

- Consider the Iterator_HasNext spec: “hasNext() must return true before calling next() on an iterator”
  - 150 FalseAlarms, 97.40% FAR

Highlighted Iterator_HasNext violation is a false alarm

```
ArrayList<Integer> list = new ArrayList<>(); list.add(1);
Iterator<Integer> it = list.iterator();
if ( it.hasNext() ){ int a = it.next();}
if ( list.size() > 0 ){ int b = list.iterator().next();}
```

Rejected Pull Requests

- XStream (a CSC violation)
  - "...there's no need to synchronize it... As explicitly stated ..., XStream is not thread-safe ... this is documented ..."
- JSqlParser (no check for validity of s in parseLong(s, int))
  - "...parser ... ensures that only long values are passed ... do you have a ... SQL, that produces a NumberFormatException?"
- threerings.playn (stream not flushed)
  - "[class] automatically flushes the target stream when done() is called ... an additional flush is unnecessary."

Positive Developer Responses

- Developers asked us for more fixes
  - “I found the following... Can you please check these out as well?”

- Developers accepted better exception messages
  - “Looks good, I’ll … add that more helpful error message.”

- Developers liberally accepted some pull requests
  - “While I’m not convinced it is necessary, this will cause no harm.”

Recommendations for the Future

- Open and community-driven spec repositories
  - We could have evaluated more specs if these existed
- More work on spec testing and filtering of false alarms
- Greater emphasis on bug-finding effectiveness

- Better categorization of specs
- Complementing benchmarks with OSS
- Confirming spec violations with developers

Conclusions

- The first large-scale evaluation of existing Java API specs
  - ✓ 199 specs and 200 open-source projects
  - ✓ Average runtime overhead was 4.3x
  - ✓ Found many bugs that developers are willing to fix
  - ✗ False alarm rates are too high

- We made some recommendations for future research

- Study data is online: http://fsl.cs.illinois.edu/spec-eval

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