Metamorphic Testing of RESTful Web APIs

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ABSTRACT

Web *Application Programming Interfaces (APIs)* specify how to access services and data over the network, typically using Web services. Web APIs are rapidly proliferating as a key element to foster reusability, integration, and innovation, enabling new consumption models such as mobile or smart TV apps. Companies such as Facebook, Twitter, Google, eBay or Netflix receive billions of API calls every day from thousands of different third-party applications and devices, which constitutes more than half of their total traffic.

As Web APIs are progressively becoming the cornerstone of software integration, their validation is getting more critical. In this context, the fast detection of bugs is of utmost importance to increase the quality of internal products and third-party applications. However, testing Web APIs is challenging mainly due to the difficulty to assess whether the output of an API call is correct, i.e., the *oracle problem*. For instance, consider the Web API of the popular music streaming service Spotify. Suppose a search for albums with the query "redhouse" returning 21 total matches: Is this output correct? Do all the albums in the result set contain the keyword? Are there any albums containing the keyword not included in the result set? Answering these questions is difficult, even with small result sets, and often infeasible when the results are counted by thousands or millions.

Metamorphic testing alleviates the oracle problem by providing an alternative when the expected output of a test execution is complex or unknown. Rather than checking the output of an individual program execution, metamorphic testing checks whether multiple executions of the program under test fulfil certain necessary properties called *metamorphic relations*. For instance, consider the following metamorphic relation in Spotify: *two searches for albums with the same query should return the same number of total results regardless of the size of pagination*. Suppose that a new Spotify search is performed using the exact same query as before and increasing the maximum number of results per page from 20 (default value) to 50: This search returns 27 total albums (6 more matches than in the previous search), which reveals a bug. This is an example of a real and reproducible fault detected using the approach presented in this paper and reported to Spotify. According to Spotify developers, it was a regression fault caused by a fix with undesired side effects.

In this paper [1], we present a metamorphic testing approach for the automated detection of faults in RESTful Web APIs (henceforth also referred to as simply Web APIs). We introduce the concept of metamorphic relation output patterns. A *Metamorphic Relation Output Pattern (MROP)* defines an abstract output relation typically identified in Web APIs, regardless of their application domain. Each MROP is defined in terms of set operations among test outputs such as equality, union, subset, or intersection. MROPs provide a helpful guide for the identification of metamorphic relations, broadening the scope of our work beyond a particular Web API. Based on the notion of MROP, a methodology is proposed for the application of the approach to any Web API following the REST architectural pattern.

The approach was evaluated in several steps. First, we used the proposed methodology to identify 33 metamorphic relations in four Web APIs developed by undergraduate students. All the relations are instances of the proposed MROPs. Then, we assessed the effectiveness of the identified relations at revealing 317 automatically seeded faults (i.e., mutants) in the APIs under test. As a result, 302 seeded faults were detected, achieving a mutation score of 95.3%. Second, we evaluated the approach using real Web APIs and faults. In particular, we identified 20 metamorphic relations in the Web API of Spotify and 40 metamorphic relations in the Web API of YouTube. Each metamorphic relation was implemented and automatically executed using both random and manual test data. In total, 469K metamorphic tests were generated. As a result, 21 metamorphic relations were violated, and 11 issues revealed and reported (3 issues in Spotify and 8 issues in YouTube). To date, 10 of the reported issues have been either confirmed by the API developers or reproduced by other users supporting the effectiveness of our approach.

CCS CONCEPTS

• **Software and its engineering → Software testing and debugging**;

KEYWORDS

Metamorphic testing, REST, RESTful Web services, Web API

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