A Verified Application of Genetic Programming: QoS Time Series Modeling and Forecasting for Web Services

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ABSTRACT

In both academia and industry, Web services (WSs) technology (also called Web APIs in recent years) has been a fervid research target for years. In industry, software developers now often develop their application systems with diverse WSs on the internet (i.e., these developers often use service-oriented software engineering, SOSE). However, many companies and organizations, including most tech giants, such as *Google*, *Meta*, and *Amazon*, expose their services and business functionalities in the form of RESTful WSs (Web APIs) for external access (e.g., *Amazon Web Services*). As a focus of research in services computing, many topics and subjects regarding WSs have been identified, investigated, and addressed. A practical research issue that receives broad attention is the understanding (modeling) and prediction of the time-aware (time-varying) dynamic quality of service (QoS) of WSs.

Based on a comprehensive survey and investigation presented in [1]: Y. Syu and C. M. Wang, "QoS Time Series Modeling and Forecasting for Web Services: A Comprehensive Survey", IEEE Transactions on Network and Service Management (TNSM), Vol. 18, P.P. 926-944, 2021, this abstract paper concisely reports to the GECCO community a justified application of genetic programming (GP) on the modeling and forecasting of WS QoS time series. By introducing this employment of GP and the targeted research problem to the community, the purpose is to encourage and attract people in this field to further revise and improve GP to obtain a better solution to the problem or to try to use other evolutionary techniques to better address the problem.

CCS CONCEPTS

- Computing methodologies → Genetic programming
- Mathematics of computing → Time series analysis
- Software and its engineering → Search-based software engineering

KEYWORDS

Genetic programming, Web services, Service-oriented software engineering, Time series forecasting, Machine learning

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1 INTRODUCTION

Since WSs are usually components that are outside their users (service consumers) and under the management and maintenance of external service providers, when these components are being accessed, a critical concern is their QoS, such as response time, availability, and throughput. Thus, published QoS data and advertisements are referred to and considered when composing or selecting WSs to use. However, the problem is that some QoS attributes (e.g., response time) are dynamic and vary constantly over time. Therefore, the static QoS values offered and claimed by service providers are unreliable, and there must be a way to profoundly understand and accurately predict dynamic QoS values so that informed and proper QoS-based decisions can be made. A detailed review and introduction to the different applications of time-varying dynamic QoS values and the prediction approaches of these applications can be found in [2].

To address this issue and satisfy the demand for a time-aware WS QoS prediction approach, at the beginning, people in services computing and software engineering employ and develop time series forecasting techniques (e.g., ARIMA models and exponential smoothing) because the problem in essence is an instance and application of time series prediction, as reviewed in [1]. In addition to these traditional statistical time series methods, computer science and machine learning (ML) approaches, such as artificial neural networks (ANNs), have also been tried and used. Unlike these conventional studies, the authors originally proposed and implemented the notion of employing GP to tackle the problem in [3] [4]. Simply speaking, the idea is that with historical time-varying QoS observations (namely, training/learning data), we exercise GP to evolve a mathematical expression-based QoS model (i.e., predictor) for the performance of QoS time series forecasting. More specifically, the whole process includes two phases. First, GP is used to evolutionarily determine an expression model that can best explain QoS history

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and accurately model the data varying patterns implied in the data. Subsequently, this GP-evolved model, which is supposed to capture the regularity of the prediction target upon the target's past behavior (i.e., QoS history), is exercised to generate the model's thought about the future (i.e., the forecasted QoS values).

To verify the idea of employing GP for the targeted problem and compare the performance of GP with that of other existing solutions in [4] with real-world QoS time series data, we conduct experiments of comparison in terms of forecasting accuracy. Moreover, in addition to using the basic criterion (i.e., prediction accuracy), we also measure and consider the performance cost of QoS modeling and forecasting in a large-scale empirical investigation presented in [5]. Here, the cost measured and considered is the time consumption of GP (and other approaches included for comparison) on evolving (producing) a predictor model and generating a prediction value. Finally, to further verify and confirm the performance and superiority of GP on the problem, in [6], we test and compare the GP-based approach under a variety of problem configurations and settings, such as disparate lengths of training/learning data available and different granularities of time of QoS time series.

Based on the abovementioned studies and the reported paper of this abstract [1], our overall observation is that GP outperforms other time series methods and ML techniques that have ever been considered and compared in terms of both modeling and forecasting accuracy. However, as anticipated, this superiority in accuracy comes with the price that GP is also the most time-consuming solution in the generation (evolution) of a QoS time series predictor model.

2 SUMMARY OF THE PAPER

The reported paper [1] is one of our latest efforts in using GP to predict future QoS values. In this paper, we exhaustively analyze and compare all the current studies, including our GP-based studies mentioned before, on this research subject. In [1], the targeted subject, namely, QoS time series modeling and forecasting for WSs, is identified and divided into four major research concerns: the addressed problem, the proposed or employed approach, the considered performance measure, and the adopted QoS time series dataset. In the paper, as a whole, we review and discuss all the collected literature in terms of each of the four identified research concerns to try to determine common patterns and different places so that a well-organized structure and framework of the research subject can be recognized, defined, and used later. In addition, we also propose and describe some potential future research directions in the subject at the end of this paper.

Regarding the first research concern, although the surveyed studies all concentrate on the same subject, there are still some distinctions between these studies' defined and studied detailed problem specifications, such as univariant versus multivariant time series and one-step-ahead versus multiple-step-ahead predictions. The second research concern focuses on the over 15 different solutions that have ever been used; these solutions can be divided into three broad categories: baseline methods, statistical approaches, and ML techniques (GP). The third concern is about how to quantitatively and fairly evaluate the goodness of each solution to the problem so that impartial and referable comparisons can be made. As mentioned before, forecasting accuracy and time consumption have been the two major criteria in this area. The last research concern considers the WS QoS time series datasets that have been collected and tested to verify the developed or employed solutions to the problem.

3 FUTURE WORK

Since this research work has been widely verified and tested with massive experiments and comparisons, our future plan of this research work is to further improve the GP-based approach toward two objectives: higher forecasting accuracy and lower prediction cost (i.e., shorter predictor generation time). One of the potential research directions is, with the goal of overcoming and suppressing the overfitting phenomenon observed during our previous studies, importing and applying other more advanced GP designs, such as the minimum description length (MDL)-based fitness function for better generality [7] and the evolution with a gradually increased tree depth for the simplicity of evolved predictors. In addition, for a more precise and efficient regional (local) search of predictors (especially for the fine-grained values of expression/predictor coefficients), an integration and combination of GP with a traditional optimal approach (e.g., a classical gradient descent) may be worth trying [8].

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