CLOUD TESTING: A STATE-OF-THE-ART REVIEW

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Abstract: This paper provides a state-of-the-art review of cloud testing. Cloud computing, a new paradigm for developing and delivering computing applications and services, has gained considerable attention in recent years. Cloud computing can impact all software life cycle stages, including the area of software testing. TaaS (Testing as a Service) or *cloud testing*, which includes testing the cloud and testing *using* the cloud, is a fast developing area of research in software engineering. The paper addresses the following three areas: (1) general research in cloud testing, (2) specific cloud testing research, i.e., tools, methods, and systems under test, and (3) commercial TaaS tools and solutions..

Keywords: Cloud computing, TaaS, Testing as a Service, cloud testing, testing tools.

Introduction

Cloud testing is an important part of cloud computing, a new direction in information technology. Cloud computing has gained considerable interest in recent years as a new paradigm for developing and delivering computing applications and services. As it is typical for new ideas, different cloud computing definitions have emerged. We follow the definition given by the National Institute of Standards and Technology (NIST, USA): "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models."[1] NIST further considers the following related characteristics and models are considered:

- Essential characteristics: On-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service;

- Service models: Cloud Software as a Service (SaaS), Cloud Platform as a Service (PaaS), and Cloud Infrastructure as a Service (IaaS);
- Deployment models: Private cloud, community cloud, public cloud, and hybrid cloud.

Cloud computing affects all stages of software life cycle, including software testing. Similar to an acceptance of standard terminologies such as SaaS, PaaS, and Iaas in cloud computing literature, the term TaaS (Testing as a Service) is acknowledged today as an essential concept for consideration and study.[2] Typically, TaaS is understood to include both the testing of the cloud and testing *using* the cloud [3] (We will refer to both as *cloud testing* for simplicity).This paper reviews cloud testing in terms of general research and its practical issues in three sub-areas:

- General research in cloud testing;
- Specific research issues (tools, methods and systems under test) in cloud testing;
- Commercial TaaS tools and solutions.

General Research in Cloud Testing

Cloud testing is a rapidly developing area of research in software engineering. The first research works on cloud testing appeared two to three years ago. Two specialized workshops on Software Testing in the Cloud (STITC) were organized in 2009 [4] and 2010.[5] However, it is too early to talk about significant success or fundamental research advances in cloud testing. Research on cloud testing lags in some measure behind practical results in this area. At the same time, it is safe to say that quantitative and qualitative intensification of research activities in cloud testing can be expected in the future.

Riungu, Taipale, and Smolander provide a comprehensive discussion of cloud testing issues based on interviews conducted with several practitioners in the field.[6] These issues were derived from interviews with practitioners from different software organizations. This study reflects the practical needs and expectations in cloud testing, and is analyzed using three categories: application, management, and legal and financial issues. In terms of application, the following issues are discussed:

- Applications suitable for online software testing;
- Readymade online performance testing packages for any customer;
- Quality checks for applications tested in the cloud;
- Harmonization of the test processes across multiple players;
- Online testing solutions for E-business systems.

Identifying applications that are suitable for online testing is an important issue that an organization must consider before it starts thinking about moving testing to the cloud. Cloud testing has costs and risks, and therefore, is not necessarily suitable for all types of users and all types of software. Parveen and Tilley discuss migration testing to the cloud from two perspectives: the type of application under test and the type of testing performed on the application. According to these authors, software is suitable for cloud testing when there are:[7]

- Test cases that are independent of each other;
- A self-contained and easily identifiable operational environment;
- A programmatically accessible interface suitable for automated testing.

Based on these considerations, the authors conclude that the most suitable cases for cloud type testing are:

- Unit testing and regression testing;
- High volume automated testing;
- Performance testing.

Various types of users have their own requirements to cloud testing. Candea, Bucur, and Zamfir [8] compare three different cloud testing approaches:

- TaaS for developers to test code;
- TaaS for end users to check the software installed;
- TaaS for certification to assess software reliability, safety, and security.

The authors claim that for all users "the combination of recent advances in test automation and the availability of compute clouds can offer unprecedented levels of testing quality."[9]

Other efforts on cloud testing research include investigations on clustering, scheduling, and monitoring testing tasks,[10] testing criteria based on formal graph models of cloud applications,[11] service composition and testing for cloud computing.[12]

Hardware of cloud systems includes a large number of processors, hard disks, memories and other equipment. Various hardware failures are possible so special recovery strategies should be used to deal with failures. In turn, these recovery strategies and recovery software should be thoroughly tested. This problem was considered by Gunawi, et al.[13] Two new testing frameworks for cloud recovery, FATE (Failure Testing Service) and DESTINI (Declarative Testing Specifications), were suggested. FATE systematically tests cloud systems using various scenarios of multiple failures. To achieve this, the authors suggest a failure abstraction for expressing failure scenarios, a failure service (workload driver, failure surface, failure server, and filters), and fail-

ure prioritization strategies. DESTINI is designed for clear and precise specifications of recovery procedures. For these purposes, Datalog, a declarative relational logic language, is used. The authors address the following advantages of DESTINI:

- it facilitates checks, expectations, facts, failure events, and precise timings;
- specifications can be written from different views;
- different types of violations can be specified;
- different types of failures can be incorporated; and
- specifications can be incrementally added or refined.

Specific Research Issues (Tools, Methods and Systems Under Test) in Cloud Testing

Different types of computer systems and software applications require the use of different testing methods and approaches. This is true for cloud testing as well. Thus far, there are very few specific instances of cloud testing reflected in the research literature. One of such examples is the testing of dependable, parallel, and distributed systems for which a cloud computing testing environment called D-Cloud [14] has been proposed. D-Cloud uses multiple virtual machine nodes, QEMU as the virtualization software, and Eucalyptus as the cloud management software. D-Cloud uses cloud resources to run the software of a distributed system. Virtual machines allow the creation of various configurations of the system (with differences in the number of processors, size of memory, etc.). To test fault-tolerance features of the system, D-Cloud emulates hardware faults using fault injection as a part of test scenarios. Faults in different hardware devices, such as a hard disk, network, and memory, can be emulated.

Another cloud testing method has been suggested for testing network management systems.[15] Here, a cloud computing infrastructure is used for creating a large number of virtual network elements. Though the authors provide only a very general description of their approach, the advantages and disadvantages of cloud-based testing are considered in detail. Avaya Communication Manager Branch Edition, a Voice-over-IP telephony switching system, is used as a case study.

Some cloud testing approaches have been implemented as software tools, often as prototypes. Thus, Cloud9 [16] is a cloud-based testing service that uses parallel symbolic execution techniques. Traditional symbolic execution is the systematic exploration of the programs' execution trees. This technique has some problems due to its path explosion, CPU-intensive constraint solving, and high memory usage. In contrast, Cloud9 runs on the Amazon EC2 cloud environment that allows for advantages available through parallel symbolic execution. The authors analyze several case

studies to show that Cloud9 can find bugs because of specific interactions with the environment, and to show the effectiveness of Cloud9 for regression testing.

YETI [17] (York Extensible Testing Infrastructure), is also an example of a prototype cloud testing tool. Using YETI on a single computer for testing the software in large projects leads to problems in performance and security. Moving YETI into the cloud allows to solve these problems and significantly improves its performance.

Along with cloud software tools, specific testing approaches have also been investigated from the perspective of the cloud. They include security testing,[18] autonomic self-testing,[19] presence service testing,[20] testing of interoperability of cloud computing infrastructures,[21] testing cloud storage systems,[22] and cloud testing for mobile applications.[23]

Commercial TaaS Tools and Solutions

There is a great demand for tools and service in cloud testing and many companies are working to fill this niche. Some TaaS products that are currently available are briefly considered below. IBM has introduced an "Integrated Development and Test Environment for Cloud"[24] which integrates cloud infrastructure with testing processes and tools. This includes the following services on the IBM Cloud:

- IBM Testing Services for Cloud (application virtualization and performance testing), including performance test infrastructure and tools;
- IBM Rational Load Testing on the IBM Cloud, using the Rational Performance Tester tool for large-scale performance testing on the "IBM Smart Business Development and Test on the IBM Cloud" environment.

As a part of IBM Testing Services for Cloud, IBM recommends the following assessments to help companies establish a business case for conversion to a cloud test environment:[25]

- The IBM Defect Analysis Starter to identify high priority cost reduction opportunities associated with software test practices;
- The IBM Defect Analysis Starter (DAS) for the Environment to identify cost reduction opportunities associated with implementing a cloud and application virtualization solution for the test environment;
- Server Consolidation/Virtualization Assessment to help organizations build a business case and cloud testing strategy through in-depth analysis of their current environment.

IT giant Hewlett Packard (HP) is also a main cloud computing provider. Testing-as-a-Service Solution [26] from HP Enterprise Services is a mix of cloud and outsourcing

models. HP offers applications for different types of testing and manages outsourced testing through its testing centers. HP's TaaS Solution includes:

- Accelerated Test, a regression testing service using HP's test automation approach. This includes, in particular, a test automation framework, HP's reusable test automation objects, and the well-known QuickTest Pro software tool;
- Performance Test, including, in particular, a service with experienced test engineers (Performance test factory), HP performance test processes and best practices, and the well-known LoadRunner tool;
- Application Security Testing, application code scanning and vulnerability testing, including HP software tools and expertise to reveal security vulnerabilities;
- SAP Test Service, regression and performance testing of SAP environments.

In HP viewpoint paper "Why Your IT Organization Should Move from Traditional Application Testing to Testing-as-a-Service,"[27] the significant advantages, which TaaS delivers to quality-oriented organizations, are considered. According to this paper, the Testing-as-a-Service utility model:

- Improves agility by using highly automated solutions to reduce testing cycles;
- Leverages a transaction pricing model to give organizations more predictable and affordable testing solutions;
- Reduces cycle time, thus supporting more frequent testing coverage;
- Reduces business risk by leveraging comprehensive regression and performance testing;
- Maximizes automation and economies of scale to reduce overall QA costs;
- Ensures application performance meets business requirements;
- Delivers application security assurance, identifying vulnerabilities;
- Protects critical business software assets from fault-related failures.

SOASTA [28] is a California-based technology company that specializes in cloud testing. SOASTA's CloudTest is a cloud software for functional, load, and performance testing of web sites and web applications. SOASTA's products include CloudTest On-Demand, CloudTest Pro, CloudTest Appliance, and Global Test Cloud, which are available on-demand from the cloud or as an appliance installed inside users' environments. CloudTest On-Demand allows testing web sites for normal and extreme traffic. For extreme situations, spikes in traffic can be simulated. CloudTest Pro is a new integrated platform for testing Web and mobile applications. CloudTest Pro sup-

ports test building, test management, and real-time analysis of software performance. Global Test Cloud provides emulation of real-world conditions at different levels of scale. Traffic can be simulated for millions of users from many locations around the globe. Global Test Cloud makes possible cross-cloud testing from the world's leading cloud providers, such as Amazon, IBM, and Microsoft. The SOASTA performance test methodology is discussed by Lounibos [29] including testing in the performance lab, testing in production, and planning and strategy of testing.

iGATE Patni [30] is a new alliance of the two organizations – iGATE and Patni, one of India's largest IT service companies with headquarters across the Americas, Europe, and Asia. Patni's Testing-as-a-Service Solution is a cloud-based framework for dynamically scalable and low-cost test automation. It allows the consolidation oftesting tools that customers already use. The company claims that cloud-based test solutions can help "manage a wide range of test projects of varying scale and duration, from very small test tasks to large projects involving continuous testing."[31]

iTKO [32]—a Dallas, Texas, based company—provides software for testing, validating, and virtualizing enterprise applications, including cloud applications. LISA Test is a program for automated testing for cloud applications. This software allows complete test coverage and builds executable test cases for functional, load, and performance testing. The use of this tool along with other iTKO's products, such as LISA Virtualize and LISA DevTest Cloud Manager, can help manage service virtualization, development and test cloud platforms, as well as end-to-end software validation.

Load Impact [33] is a cloud-based service developed by Gatorhole AB (Sweden). Load Impact provides load and stress testing of customers' websites over the Internet. It is possible to simulate access of tens of thousands of users simultaneously. The Load Test tool allows simulation of traffic to a website generating different types of tests (ramp-up tests, timeout tests, fixed tests). The Page Analyzer tool provides information about website performance by emulating well-known web browsers, such as Internet Explorer, Firefox, Chrome, Opera, and Safari. Its analyzed performance metrics include connect time, download time, time in queue, time to first byte, etc.

The list of other available cloud testing tools and solutions includes Sauce OnDemand by Sauce Labs Inc.,[34] CloudTestGo by CSS Corp.,[35] STaaS by Sogeti,[36] and Janova Test Suites by Janova.[37]

Conclusions

Cloud testing is a rapidly emerging area in cloud computing. This paper provides a review of recent research results, approaches, and software tools in this area. Though cloud testing is still maturing, some interesting theoretical and practical results have

been achieved. There is little doubt, however, that this promising area will garner increasing attention in the coming years and will continue to expand.

Notes:

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