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Model-Based Performance Testing of Web Services Using Probabilistic Timed Automata

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Abstract: In this paper, we present an approach for performance testing of web services in which we use abstract models, specified using Probabilistic Timed Automata, to describe how users interact with the system. The models are used in the load generation process to generate load against the system. The abstract actions from the model are sent in real-time to the system via an adapter. Different performance indicators are monitored during the test session and reported at the end of the process. We exemplify with an auction web service case study on which we have run several experiments.

1 Introduction

Today, we see advancements in cloud computing and more and more software applications being adapted to a cloud environment. Applications deployed in the cloud are delivered to users as a service, without the need for the users to install anything. This means that most of the processing is done on the server side and this puts a frightful amount of stress on the back-end of the system. Performance characteristics such as throughput, response times, and resource utilization are crucial quality attributes of such applications and systems.

The purpose of performance testing is to determine how well the system performs in terms of responsiveness, stability, and resource utilization under a particular synthetic workload in a controlled environment. The synthetic workload (Ferrari, 1984) should mimic the expected workload (Shaw, 2000) as closely as possible, once the system is in operational use, otherwise it is not possible to draw any reliable conclusions from the test results.

Performance tests are typically implemented as usage scenarios that are either manually scripted (e.g., using *httperf* or *JMeter*) or pre-recorded (e.g., using Selenium (SeleniumHQ, 2012) in the case of web applications). The usage scenarios are then executed concurrently against the system under test. A major drawback with this approach is that the manually coded scripts and pre-recorded scenarios seldom represent real-life traffic and that certain combinations of user inputs may remain untested. Repeating the same

script over and over may lead to unrealistic results because of caching and other operating system optimization mechanisms. Performance testing is done efficiently when it is executed in an iterative manner and uses techniques that simulate real life work load as closely as possible (Menasce, 2002). This means that load is incrementally increased until a certain threshold (saturation) is reached, beyond which the performance of the system begins to degrade.

In this paper, we propose a model-based approach to evaluate the performance of a system by incrementally exercising different kinds of loads on the system. The main contributions of this work are:

- we use abstract models, specified as Probabilistic Timed Automata (PTA) to model the user profiles, including the *actions* or *sequences of actions* the user can send, the probabilistic distribution of the actions, and individual *think time* for each action,
- the load is generated in real-time from these models and sent to the system under test (SUT) via an adapter which converts abstract actions into concrete interactions with the SUT and manages data dependencies between different actions;

The rest of the paper is structured as follows: In Section 2 we give an overview of the work related to our approach. Section 3 presents our model-based testing process, while Section 4 presents an auction web service case study and an experiment using our approach. Finally, in Section 5, we present our conclusions and we discuss future work.

2 Related Work

There is already a large body of work on workload characterization and a more limited one on load generation from performance models. In the following, we briefly enumerate several works that are closer to our approach.

Barna et al., (Barna et al., 2011) present a model-based testing approach to test the performance of a transactional system. The authors make use of an iterative approach to find the workload stress vectors of a system. An adaptive framework will then drive the system along these stress vectors until a performance stress goal is reached. They use a system model, represented as a two-layered queuing network, and they use analytical techniques to find a workload mix that will saturate a specific system resource. Their approach differs from ours in the sense that they use a model of the system instead of testing against a real implementation of a system.

Other related approaches can be found in (Shams et al., 2006) and (Ruffo et al., 2004). In the former, the authors have focused on generating valid traces or a synthetic workload for inter-dependent requests typically found in sessions when using web applications. They describe an application model that captures the dependencies for such systems by using Extended Finite State Machines (EFSMs). Combined with a workload model that describes session inter-arrival rates and parameter distributions, their tool *SWAT* outputs valid session traces that are executed using a modified version of *httperf* (Mosberger and Jin, 1998). The main use of the tool is to perform a sensitivity analysis on the system when different parameters in the workload are changed, e.g., session length, distribution, think time, etc. In the latter, the authors suggest a tool that generates representative user behavior traces from a set of Customer Behavior Model Graphs (CBMG). The CBMG are obtained from execution logs of the system and they use a modified version of the *httperf* utility to generate the traffic from their traces. The methods differ from our approach in the sense they both focus on the trace generation and let other tools take care of generating the load/traffic for the system, while we do on-the-fly load generation from our models.

(Denaro et al., 2004) propose an approach for early performance testing of distributed software when the software is built using middleware components technologies, such as J2EE or CORBA. Most of the overall performance of such a system is determined by the use and configuration of the middleware (e.g. databases). They also note that the coupling between the middleware and the application architecture

determines the actual performance. Based on architectural designs of an application the authors can derive application-specific performance tests that can be executed on the early available middleware platform that is used to build the application with. This approach differs from ours in that the authors mainly target distributed systems and testing of the performance of middleware components.

3 Performance Testing Process

Our performance testing process is depicted in Figure 1. In brief, we build a workload model of the system by analyzing different sources of information, and subsequently we generate load in on-the-fly against the system. During the process, different performance indicators are measured and a test report is created at the end.

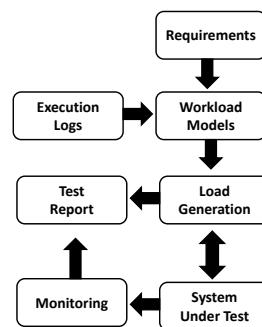


Figure 1: Our performance testing process.

In our work, we have used various *Key Performance Indicators* (KPIs) to provide quantifiable measurements for our performance goals. For instance, we specify the *target KPIs* before the testing procedure is started and later on we compare them against the *actual measured KPIs*.

3.1 Workload characterization

The first step in our process is characterizing the workload of the system. According to (Menascé and Almeida, 2001), the workload of a system can be defined as the set of all inputs the system receives from the environment during any given period of time.

Traditionally, performance analysis starts first with identifying key performance scenarios, based on the idea that certain scenarios are more frequent than others or certain scenarios impact more on the performance of the system than other scenarios. A performance scenario is a sequence of actions performed by an identified group of users (Petriu and Shen, 2002).

In order to build the workload model, we start by looking and analyzing the requirements and the system specifications, respectively. During this phase we try to form an understanding of how the system is

used, what are the different types of users, and what are the key performance scenarios that will impact most on the performance of the system. A user type is characterized by the distribution and the types of actions it performs.

The main sources of information for workload characterization are: Service Level Agreements (SLAs), system specifications, and standards.

By using these sources we identify the inputs of the system with respect to types of transactions (actions), transferred files, file sizes, arrival rates, etc. following the generic guidelines discussed in (Calzarossa et al., 2000). In addition, we extract information regarding the KPI's, such as the number of concurrent users the system should support, expected throughput, response times, expected resource utilization demands etc. for different actions under a given load. We would like to point out that this is a manual step in the process. However, automating this step could be achieved analyzing log files of the system and using various clustering algorithms for determining e.g., different user types, which is subject for future work.

The following steps are used for analyzing the workload:

1. Identify the actions that can be executed against the system.
 - (a) Determine the required input data for each action. For instance, the request type and the parameters.
 - (b) Identify dependencies between actions. For example, a user can not execute a logout action before a login action.
2. Identify the most relevant user types, based for instance on the amount of interactions with the system.
3. Define the distribution of actions that are performed by each user type.
4. Estimate an average *think time* per action.

With *think time* we refer to the time between two consecutive actions. In our approach, the think time for the same action can vary from one user to another, or from one test scenario to another.

3.2 Workload models

The results of the workload characterization are aggregated in a workload model based on Probabilistic Timed Automata.

We take the definition of a *probabilistic timed automaton* (PTA) as defined by (Kwiatkowska et al., 2006). A (PTA) $P = (L, \bar{l}, X, \Sigma, inv, prob)$ is a tuple consisting of a finite set L of locations with the

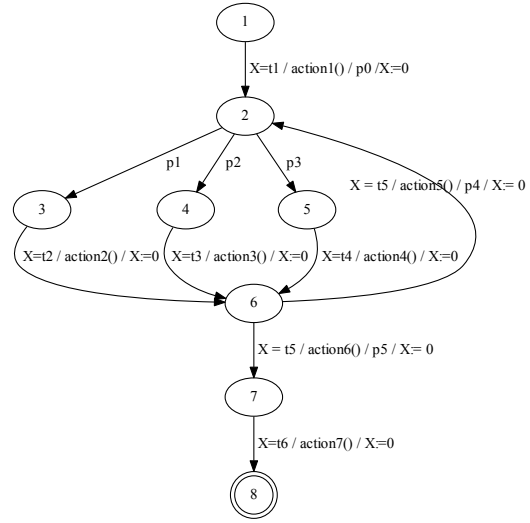


Figure 2: Example of a probabilistic timed automaton.

initial location $\bar{l} \in L$; a finite set X of clocks; a finite set of Σ of actions; a function $inv : L \rightarrow CC(X)$ associating an invariant condition with each location, where $CC(X)$ is a set of clock constraints over X ; a finite set $prob \subseteq L \times CC(X) \times \Sigma \times Dist(2^X \times L)$ of probabilistic transitions, such that, for each $l \in L$, there exists at least one $(l, \rightarrow, \rightarrow) \in prob$; and a labeling function $\delta : L \rightarrow 2^{AP}$, where AP denote a set of atomic propositions.

A probabilistic transition $(l, g, p, a) \in prob$ is a quadruple containing (1) a source location l , (2) a clock constraint g , called *guard* or *invariant condition*, (3) a *probability* p , and (4) an *action*. The *probability* indicates the chance of that transition being taken. The *action* describes what action to take when the transition is used, and the *clock* indicates how long to wait before firing the transition. The behavior of a PTA is similar to that of a timed automaton (Alur and Dill, 1994): in any location, time can advance as long as the invariant holds, and a probabilistic transition can be taken if its guard is satisfied by the current values of the clocks. Every automaton has an *end location*, depicted with a double circle, which will eventually be reached. It is possible to specify loops in the automaton. We note that not all transitions have both a *guard* and a *probability*. For simplicity, we do not explicitly specify location invariants, but they implicitly evaluate to **true**. One such workload model is created for each identified user type.

3.3 Load generation

The resulting workload models are used for generating load in real-time against the system under test, by

creating traces from the corresponding PTA. The user types are selected based on their reciprocal distribution. The PTA of each user type will be executed concurrently by selecting the corresponding actions and sending them to the system. By executing the PTA of a given user, in each step an action is chosen based on the probabilistic values in the automaton.

The load generation is based on a deterministic choice with a probabilistic policy. This introduces certain randomness into the test process and that can be useful for uncovering certain sequences of actions which may have a negative impact of the performance. Such sequences would be difficult or maybe impossible to discover if static test scripts are used, where a fixed order of the actions is specified, and repeated over and over again. Every PTA has an *exit* location which will eventually be reached. By modifying the probability for the *exit* action, it is also possible to adjust the average length of the generated sequences.

3.4 Performance monitoring

During the load generation, we constantly monitor target KPIs for the entire test duration. At the end, we collect all the gathered data and compute descriptive statistics, like the mean and peak response times for different actions, number of concurrent users, the amount of transferred data, the error rate, etc. All the gathered information is presented in a test report. The resource utilization of the system under test is also monitored and reported. Besides computing different kinds of statistical values from the raw data we have, the test report also contains graphs such as how the response time varied over time with the number of concurrent users. The test report also shows the CPU, disk, network and memory usage on the target system.

Tool support for load generation is provided via the MBPeT tool (Abbors et al., 2012). Due to space limitations we defer more details about the approach and support to (Ahmad et al., 2013)

4 Case Study and Experiments

In this section, we demonstrate our approach by using it to evaluate the performance of an *auction web service*, generically called YAAS. The YAAS application was developed as a stand-alone application and is used for the evaluation of our approach. The YAAS has a *RESTful* (Richardson and Ruby, 2007) interface based on the HTTP protocol and allows registered users to create, change, search, browse, and bid on auctions that other users have created. The application maintains a database of the created auctions

and the bids that other users have placed on the auctioned objects. The YAAS application is implemented using Python (Python, 2012) and the Django (Django, 2012) framework.

Test Architecture. The test architecture is shown in Figure 4. The MBPeT tool has a scalable architecture where a master node controls several slave nodes. The SUT runs an instance of the YAAS application on top of the Apache web server. All nodes (master, slaves, and the server) feature an 8-core CPU, 16 GB of memory, 1Gb Ethernet, 7200 rpm hard drive, and Fedora 16 operating system. The nodes were connected via a 1Gb Ethernet.

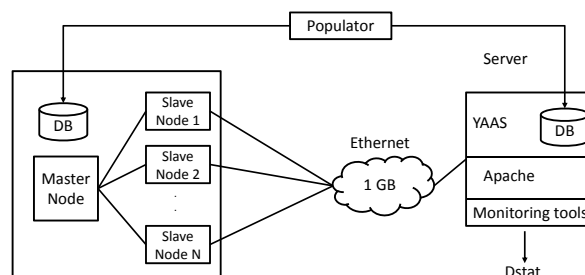


Figure 4: A caption of the test architecture.

A *populator* script is used to generate input data (i.e., populate the test databases) on both the client and server side, before each test session. This ensures that the test data on either side is consistent and easy to rebuild after each test session.

Workload Modeling. We analyzed the workload following the steps described in Section 3. Based on this analysis, three user types were identified: *aggressive_bidders*, *passive_bidders*, and *non-bidders*. From this information, we constructed a PTA model for each user type. Figure 3 shows the PTA for a *aggressive_bidder*.

Figure 3 shows that each action has a think time parameter, modeled as a clock variable associated with it, that specifies how much time should elapse before firing a transition. This variable is denoted with the symbol X and it is reset to 0 after the transition is fired. Upon firing the transition, the action associated with that transition is sent to the SUT.

Adapter. An adapter is used to translate abstract actions generated from the model into concrete HTTP requests by adding the necessary HTTP parameters and encapsulation to the SUT. All slaves run identical adapters. The models as such are system independent, but an adapter module need to be written for every system that one chooses to interface with. Since YAAS is based on the HTTP protocol, it will understand the basic HTTP commands like GET, POST, PUT, etc. Whenever a new action is selected from

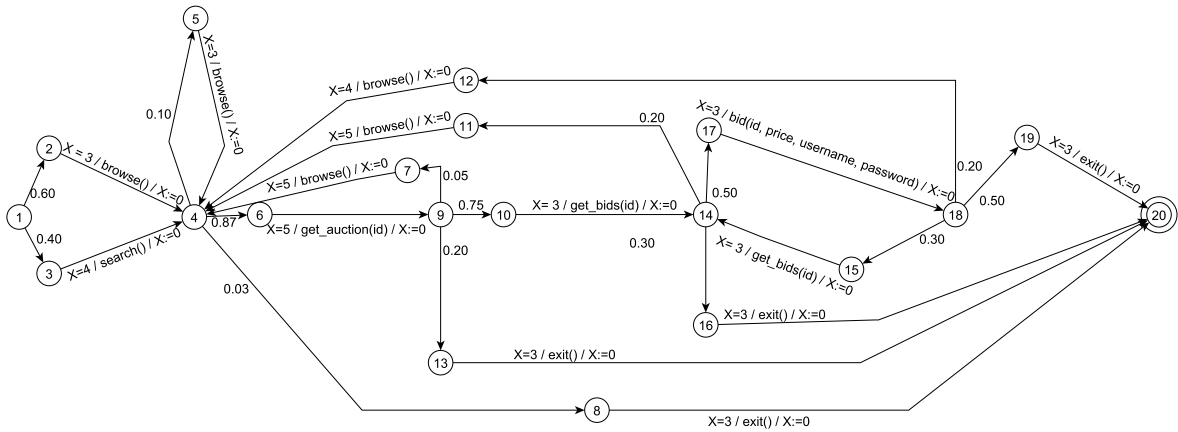


Figure 3: PTA model for an *aggressive-bidder* user type.

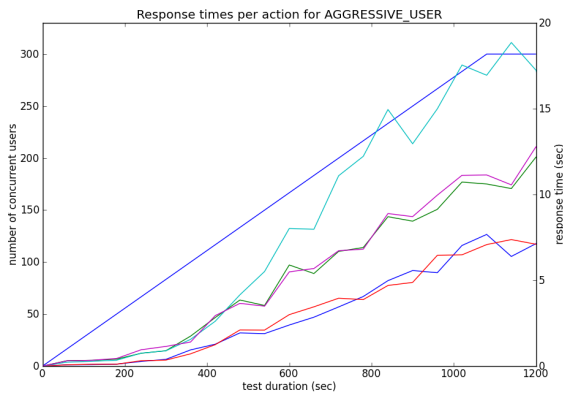


Figure 5: Average response times for *get_auction* and *get_bids* (bottom), *search* and *browse* (middle), and *bid* (top) when ramping up from 0 to 300 users.

the model, the corresponding HTTP request is created and, when needed, the associated data is automatically attached to the request from the local database.

Experiments. In the case study, an experiment was conducted to find out how the YAAS application performs under load. As a rule of thumb for ensuring accurate results, the experiment was run three times.

In the experiment, we set out to test *how many concurrent users the host node can support without exceeding the specified target response time values.*

Table 1 shows the average and max response time limits (see column *Target Response Time*) that were selected for each type of action. For instance, the average response time limit for action *browse()* was set to 4.0 seconds, while the max response time was set to 8.0 seconds. If any of the set limits (average and max) are breached during the test run, the tool will mark the time of the breach and the number of concurrent users at that time (see Table 1 - *Time of breach*). The length

of the test run was 20 minutes (1200 seconds). Figure 5 shows how the response times of different actions increase over time for the *aggressive_user* type as the number of concurrent users are ramped up from 0 to 300. In this experiment the tool generated a total of 1504 unique test sequences from the models. Several of the unique test sequences were executed more than 100 times and the variance on the test sequence length was from 1 up to 50 actions.

Table 1 also shows the time when a target response time (average and/or max) value was exceeded and the number of concurrent users at that time. For example, the average response time for the *search()* action was exceeded at 229 seconds into the test run by the *aggressive user* type. The tool was when running 64 concurrent users. From this table we concluded that the current configuration of the server can support a maximum of 64 concurrent users before exceeding the threshold value of 3 seconds set for action *search()*. A closer inspection of the monitored values of the server showed that the database was the bottleneck, due to the fact a *sqlite database* was used and the application locked the whole database for write operations.

Additional experiments, including a comparison of our approach against JMeter can be found in (Ahmad et al., 2013). The experiment showed that our tool has similar capabilities as JMeter for instance when comparing the throughput (actions/sec) against the SUT.

5 Conclusion and Future Work

In this paper, we have presented a model-based performance testing approach that uses probabilistic models to generate synthetic load in real-time. The

Actions	Target Response Time		Non-Bidders (22 %)		Passive Users (33 %)		Aggressive users 45 %		Verdict
	Average (sec)	Max (sec)	Time of breach (sec)	Time of breach (sec)	Time of breach (sec)	Time of breach (sec)	Time of breach (sec)	Time of breach (sec)	
browse()	4.0	8.0	279 (78 users)	394 (110 users)	323 (90 users)	394 (110 users)	279 (78 users)	394 (110 users)	Failed
search(string)	3.0	6.0	279 (78 users)	394 (110 users)	279 (78 users)	394 (110 users)	229 (64 users)	327 (92 users)	Failed
get_action(id)	2.0	4.0	280 (79 users)	325 (91 users)	279 (78 users)	279 (78 users)	276 (77 users)	325 (91 users)	Failed
get_bids(id)	3.0	6.0	279 (78 users)	446 (130 users)	325 (91 users)	394 (110 users)	327 (92 users)	394 (110 users)	Failed
bid(id,price, username, password)	5.0	10.0	—	—	327 (92 users)	474 (132 users)	328 (92 users)	468 (131 users)	Failed

Table 1: Response time measurements for user actions when ramping up from 0 to 300 users.

models are based on the Probabilistic Timed Automata, and include statistical information that describes the distribution between different actions and corresponding think times. With the help of probability values, we can make it so that a certain action is more likely to be chosen over another action, whenever the virtual user encounters a choice in the PTA. We believe that the PTA models are well suited for performance testing and that the probability aspect that the PTA holds is good for describing dynamic user behavior, allowing us to include a certain level of randomness in the load generation process. This is important because we wanted the virtual users to be able to mimic real user behavior as closely as possible, and minimize the effect of caches on the performance evaluation.

The approach is supported by a set of tools, including the MBPeT load generator. MBPeT has a scalable distributed architecture which can be easily deployed to cloud environments. The tool has a ramping feature which describes at what rate new users are added to the system and also supports the ability to specify a think time. When the test duration has ended the MBPeT tool will gather measured data, process it and create a test report.

In the future we will look into if parts of the model creation can be automated. At the moment it is done manually. There are indications that certain parts of creating the models can be automated e.g. by automatically analyzing the log data and using different clustering algorithms.

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