2013 IEEE Ninth World Congress on Services

CEEM: A Practical Methodology for Cloud Services Evaluation

Zheng Li
School of Computer Science
ANU and NICTA
Canberra, Australia
Zheng.Li@nicta.com.au

Liam O'Brien
ICT Innovation and Services
Geoscience Australia
Canberra, Australia
liamob99@hotmail.com

He Zhang
School of Arch. Comp. and Eng.
University of East London
London, UK
dr.hezhang@gmail.com

***Abstract*—Given an increasing number of Cloud services available in the market, evaluating candidate Cloud services is crucial and beneficial for both service customers (e.g. cost-benefit analysis) and providers (e.g. direction of improvement). When it comes to performing any evaluation, a suitable methodology is inevitably required to direct experimental implementations. Nevertheless, there is still a lack of a sound methodology to guide the evaluation of Cloud services. By borrowing the lessons from evaluation of traditional computing systems, referring to the guidelines for Design of Experiments (DOE), and summarizing the existing experiences of real experimental studies, we proposed a generic Cloud Evaluation Experiment Methodology (CEEM) for Cloud services evaluation. Furthermore, we have established a pre-experimental knowledge base and specified corresponding suggestions to make this methodology more practical in the Cloud Computing domain. Through evaluating the Google AppEngine Python runtime as a preliminary validation, we show that Cloud evaluators may achieve more rational and convincing experimental results and conclusions following such an evaluation methodology.**

***Keywords*-Cloud Computing; Cloud Services Evaluation; Evaluation Experiences; Evaluation Methodology; Design of Experiments (DOE)**

I. Introduction

Cloud services evaluation is crucial and beneficial for both service customers (e.g. cost-benefit analysis) and providers (e.g. direction of improvement) [18]. As one of the most promising computing paradigms [5], Cloud Computing has been increasingly accepted in industry. More and more commercial Cloud services offered by an increasing number of providers are available in the market [18], [22]. Given the diversity of Cloud services and price models, service selection would require deep understanding of how the different candidates may (or may not) match particular demands [6]. Unfortunately, on the one hand, customers have little knowledge and control over the precise nature of Cloud services even in the "locked down" environment [25]; on the other hand, the given indicators often lack providing comprehensive information about the overall performance of a service regarding specific tasks [14]. Consequently, service evaluation would be one of the prerequisites of employing Cloud Computing.

When it comes to evaluation implementations, a suitable methodology essentially plays a strategic role in directing evaluation activities [27]. However, according to our systematic literature review [19], there is a lack of a sound methodology to guide the practice of Cloud services evaluation. Although any of the existing studies must have (at least intuitively) followed a particular approach, not many evaluators are strictly concerned with or specified their evaluation methodologies. Different evaluation approaches described in different reports vary, and some of them may even have flawed considerations (cf. Section II).

Therefore, we proposed a generic and practical Cloud Evaluation Experiment Methodology (CEEM) for Cloud services evaluation. Our effort into proposing CEEM mainly involved three aspects. Firstly, we borrowed the existing lessons from evaluating traditional computing systems [11], [13], [21]. Since Cloud Computing is an emerging computing paradigm [5], individual Cloud services can be viewed as concrete computing systems within such a paradigm. Thus, the traditional evaluation lessons would be also useful for evaluating Cloud services. Secondly, we referred to the guidelines for performing Design of Experiments (DOE) [20]. Although DOE is normally applied to agriculture, chemical, and process industries, considering the natural relationship between experiment and evaluation, we believe that the various DOE techniques of experimental design and statistical analysis can also benefit Cloud services evaluation. Thirdly, we summarized others' and our own experiences of evaluating Cloud services. Based on the existing evaluation experiences, we are able to supply more specific and practical suggestions in particular steps, for example pre-listing experimental factors and metrics [16], [17].

This paper introduces the proposed CEEM by briefly explaining its ten steps ranging from *Requirement Recognition* to *Conclusion and Reporting*. To preliminarily validate this proposed methodology, we replicated a study of performance evaluation of the Google AppEngine Python runtime, and then compared our study with the original one. The comparison shows that CEEM can lead to a systematic and complete approach to evaluating Cloud services. The contribution of our work is threefold. First, the generic steps of implementing Cloud services evaluation are summarized. Second, to

978-0-7695-5024-4/13 $26.00 © 2013 IEEE
DOI 10.1109/SERVICES.2013.73

the best of our knowledge, this is the first time DOE has been used in Cloud services evaluation. Third, by putting a series of efforts on gathering evaluation experiences, we finally make this proposed evaluation methodology more practical.

The remainder of this paper is organized as follows. Section II summarizes the existing work related to methodologies for Cloud services evaluation. Section III specifies the evaluation activities involved in CEEM one by one. A real case of evaluating Google AppEngine is replicated and compared with the original study in Section IV to preliminarily validate the proposed CEEM. Conclusions and some future work are discussed in Section V.

II. Related Work

It has been recognized that Cloud services evaluation belongs to the field of experimental computer science [27], which requires suitable evaluation methodology as a strategic role in directing experimental studies [3]. An evaluation methodology instructs complete evaluation implementations that may cover various aspects, for instance workload selection, experimental design, and result analysis [3]. Therefore, a concrete methodology adopted in Cloud services evaluation should have distinguished between detailed steps [18], [24], [28]. In particular, the study [27] extended the ASTAR method [26] and specifically suggested a five-step methodology (*Identify benchmark*, *Identify configuration*, *Run tests*, *Analyze*, and *Recommend*) for evaluating Cloud services. A more detailed evaluation methodology was specified in [14], which used the business process modeling notation to describe the general steps of developing, executing, and evaluating a Cloud benchmark suite.

However, according to our systematic literature review [19], most evaluators did not strictly define or specify their evaluation steps, not to mention using a sound methodology to guide Cloud services evaluation. Although the existing evaluation implementations must have followed particular approaches, different approaches described in different evaluation reports vary, and even with flawed considerations. For example, evaluation methodology has been treated as experimental setup and/or preparation of experimental environment [7]; some authors only focused on metrics [10], while some others only highlighted benchmarks [2] when specifying their evaluation approach; and an inappropriate concern was to separate evaluation metrics and experimental implementation from the corresponding methodology [12]. Furthermore, even in the studies with concrete Cloud services evaluation methodologies [14], [27], some important steps like the selection of metrics and experimental factors were missed out.

III. CEEM: The Methodology for Cloud Services Evaluation

As mentioned previously, by borrowing the lessons from evaluating traditional computing systems, referring to the guidelines for conducting DOE, and summarizing the existing experiences of evaluating Cloud services, we proposed a ten-step methodology for Cloud services evaluation, as illustrated in Figure 1. Note that here we only concern ourselves with experiment as the evaluation technique rather than other techniques like simulation or modeling. The individual evaluation steps are briefly explained in the following subsections.

1) **Requirement Recognition:** Recognize the problem, and state the purpose of a proposed evaluation.
2) **Service Feature Identification:** Identify Cloud services and their features to be evaluated.
3) **Metrics and Benchmarks Listing:** List all the metrics and benchmarks that may be used for the proposed evaluation.
4) **Metrics and Benchmarks Selection:** Select suitable metrics and benchmarks for the proposed evaluation.
5) **Experimental Factors Listing:** List all the factors that may be involved in the evaluation experiments.
6) **Experimental Factors Selection:** Select limited factors to study, and also choose levels/ranges of these factors.
7) **Experimental Design:** Design experiments based on the above work. Pilot experiments may also be done in advance to facilitate the experimental design.
8) **Experimental Implementation:** Prepare experimental environment and perform the designed experiments.
9) **Experimental Analysis:** Statistically analyze and interpret the experimental results.
10) **Conclusion and Reporting:** Draw conclusions and report the overall evaluation procudure and results.

Figure 1. The Cloud Evaluation Experiment Methodology (CEEM) for Cloud services evaluation.

A. Requirement Recognition

The recognition of an evaluation requirement is not only to understand a problem related to Cloud service evaluation, but also to achieve a clear statement of the evaluation purpose, which is an obvious while nontrivial task [20]. A clearly understood evaluation requirement can facilitate driving the remaining steps properly in an implementation of Cloud services evaluation. To help recognize a requirement, it has been suggested to prepare a set of specific questions to be addressed by potential evaluation experiments [20]. Moreover, it is normally helpful to replace one comprehensive question with a list of separated and easily answerable questions, so that we can conveniently define specific evaluation objectives, and then employ the strategy of sequential experiments to satisfy the overall evaluation requirement.

B. Service Feature Identification

Given the recognized evaluation requirement, evaluators can identify the relevant Cloud services and their features to be evaluated. Although it is hard to outline the scope of Cloud Computing [29], and various Cloud services are increasingly available in the market [18], it is still possible to list a suite of general service features in advance. By exploring the existing practices of Cloud services evaluation

[19], we show that three service features have been mainly of concern, namely Performance, Economics, and Security. In particular, the elements of the Performance feature can be divided into *Physical Properties* and *Capacities* [15], while the Economics feature covers *Cost* and *Elasticity* of using Cloud services. Although the Security feature has not been well evaluated yet [19], it may comprise numerous security concerns ranging from access control to prosecution [4], [8]. Thus, in most cases, we may conveniently identify relevant service features in the general feature list.

C. Metrics and Benchmarks Listing

It is natural that the choice of right metrics depends on the identified Cloud service features to be evaluated [11]. However, one service feature may be measured by different metrics with different benchmarks [17], and the selection of particular metrics and benchmarks may also have other constraints or tradeoffs (cf. Subsection III-D). To facilitate the metric/benchmark selection, it is helpful to first list all the candidate metrics and benchmarks for a proposed Cloud services evaluation. By using different Cloud service features as the retrieval keys, we have established a lookup capability for metrics and benchmarks when evaluating Cloud services [17].

D. Metrics and Benchmarks Selection

According to the rich research in the evaluation of traditional computer systems, the selection of metrics plays an essential role in evaluation implementations [21]. Furthermore, a suitable metric would play a *Response Variable* role [20] in applying DOE to Cloud services evaluation. Although traditional evaluation lessons treat metrics selection as one of the prerequisites of benchmark selection [11], we found that there were always tradeoffs between metrics and benchmarks selection when evaluating Cloud services. For example, only two metrics (*Benchmark Runtime* and *Benchmark FLOP Rate*) are available to respectively measure computation latency and transaction speed if adopting NAS Parallel Benchmarks to evaluate Cloud services [1]. Therefore, we suggest that metrics and benchmarks could be determined together within one step.

E. Experimental Factors Listing

Before evaluating a Cloud service feature, knowing all factors (also called parameters or variables) that affect the service feature is a tedious but necessary task [13]. Although listing a complete scope of experimental factors may not be easily achieved, at all times evaluators should keep the factor list as comprehensive as possible, for further analysis and decision making about the factor selection and data collection [11]. Similar to the effort described in Subsection III-C, we have proposed a framework to capture the state-of-the-practice of experimental factors that people currently take into account when evaluating Cloud services [16]. This factor framework can in turn help facilitate identifying suitable factors for designing evaluation experiments. Moreover, the factor framework offers a concrete and rational base for further discussion and factor listing by expert judgements.

F. Experimental Factors Selection

When applying DOE techniques, the determination of factors and their levels/ranges is the prerequisite of factor-based experimental design [20]. For an evaluation experiment, it is better to start with limited design factors distinguished from nuisance ones and those that are not of interest, and the factors that are expected to have high impacts should be preferably selected [11]. As mentioned above, we may refer to the existing evaluation experiences (the proposed factor framework [16]) to quickly lookup and identify design factors. Note that we suggest using the factor framework to supplement, but not replace, the expert judgement for experimental factor selection, which would be particularly helpful for Cloud services evaluation when there is a lack of experts.

G. Experimental Design

Given the selected input-process variables (experimental factors) and output-process responses (metrics), we can design Cloud service evaluation experiments by using suitable DOE techniques. In particular, three basic principles, namely **Randomization**, **Replication**, and **Blocking** [20], should be taken into account no matter what DOE technique is employed. Moreover, a small scale of pilot experiments can often benefit the relevant experimental design. For example, the trial runs of an evaluation experiment may help evaluators get familiar with the experimental environment, optimize the experimental sequence, and even decide the sample size – number of replicates (cf. the demonstration in Section IV).

H. Experimental Implementation

Implementing an experiment is to carry out a series of experimental actions ranging from preparing environment to running benchmarks. Since any error in the experimental procedure may spoil the validity of the experimental results, the implementation process should be monitored carefully to ensure every step of the experiments follows the design [20]. Note that we regard pilot experimental runs as the activities in *Experimental Design* instead of in this stage.

I. Experimental Analysis

In DOE, statistical methods are strongly suggested for experimental analysis [20]. Although such methods do not directly prove any factor's effect, the statistical analysis adds objectivity to drawing evaluation conclusions and potential decision-making process. Moreover, it has been particularly pointed out that visualizing experimental results by using various graphical tools may significantly facilitate data analysis and interpretation. According to our own experiences, in addition to those statistical techniques, we found that machine learning techniques like mining association rules are also useful for experimental analysis in some circumstances, for example the evaluation results involving many experimental factors.

J. Conclusion and Reporting

Drawing practical conclusions is significant after analyzing the experimental results [20]. In addition, it is worth paying more attention to reporting the whole Cloud services evaluation work. In fact, not only conclusions but also complete evaluation reports would be vital for other people to learn from or replicate/confirm previous evaluation practices. However, the quality of the existing Cloud services evaluation reports varies [19], which implies that there is also a lack of evaluation reporting guidelines. Therefore, we first suggest using these ten evaluation steps as a natural documentation structure. The validation work described in Section IV can be viewed as a sample of such a case. Considering the close relationship between Cloud services evaluation and experimental computer science [27], moreover, we can adapt the well-proposed structure for reporting generic experiments or case studies [23] to reporting Cloud services evaluation studies. The adaption suggestions are out of the scope of this paper, and they will be elaborated in our future work.

IV. Preliminary Validation

To preliminarily validate CEEM, we decided to replicate a straightforward study of evaluating Google AppEngine service [9], and then compare our practice with the original one. Here we report the detailed evaluation activities.

1) Requirement Recognition:

The overall objective of the original study is to evaluate the computation performance of the Google AppEngine Python runtime. We correspondingly started with three specific questions for the evaluation requirement recognition, as listed below.

- How fast does Google AppEngine run a particular computation task in the Python runtime environment?
- How variable is the computation performance of Google AppEngine during a particular period of time?
- Can we expect a stable mean of the computation performance of Google AppEngine at different time?

Given the recognized evaluation requirement, we tried to simulate the original study in the pre-experimental-design steps (Step *2)* to *6)* in Figure 1), to make two studies comparable as much as possible.

2) Service Feature Identification:

It is clear that the service feature to be evaluated in this case is performance. When it comes to the performance evaluation of Cloud services, our previous taxonomy work [15] can be used to facilitate exploring available performance properties. Following the original study, we directly identified the combination of the related performance properties as *Computation Latency* and also *Variability of Computation Latency*, as shown in Figure 2.

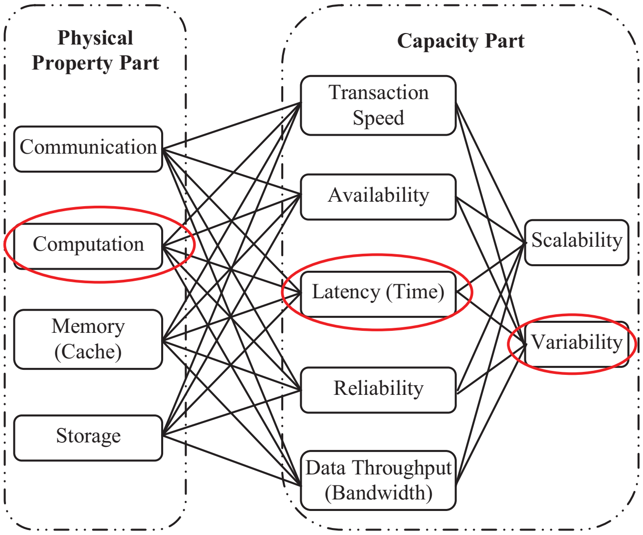

Figure 2. Performance properties for Cloud services evaluation (cf. [15]).

3) Metrics and Benchmarks Listing:

Candidate metrics and benchmarks can be conveniently listed by looking up a metrics catalogue [17], and the retrieval key is the pre-identified service feature. In this case, *Computation Latency* brings the only metric *Benchmark Runtime* and a set of benchmarks ranging from *Compiling Linux Kernel* to *NAS Parallel Benchmarks (NPB)*.

4) Metrics and Benchmarks Selection:

Naturally, we chose the metric *Benchmark Runtime* to measure the service feature *Computation Latency*. With regard to the benchmark, we decided to code a Python program to recursively calculate the 27th Fibonacci number. The function of Fibonacci calculation is shown below.

```
def fibo(n):
    if 1==n or 2==n:
        return 1
    else:
        return fibo(n-1) + fibo(n-2)
```

5) Experimental Factors Listing:

As explained in Subsection III-E, here we directly employed the experimental factor framework [16] to screen experimental factors. In large-scale cases of Cloud services evaluation, expert judgement may further be included to discuss candidate experimental factors.

6) Experimental Factors Selection:

Based on the experimental factor framework, we identified the only factor concerned in the original evaluation work, namely *Timing* (cf. Figure 3). As mentioned previously, although there are other potentially useful factors like *Workload Size*, we deliberately ignored them to make our study

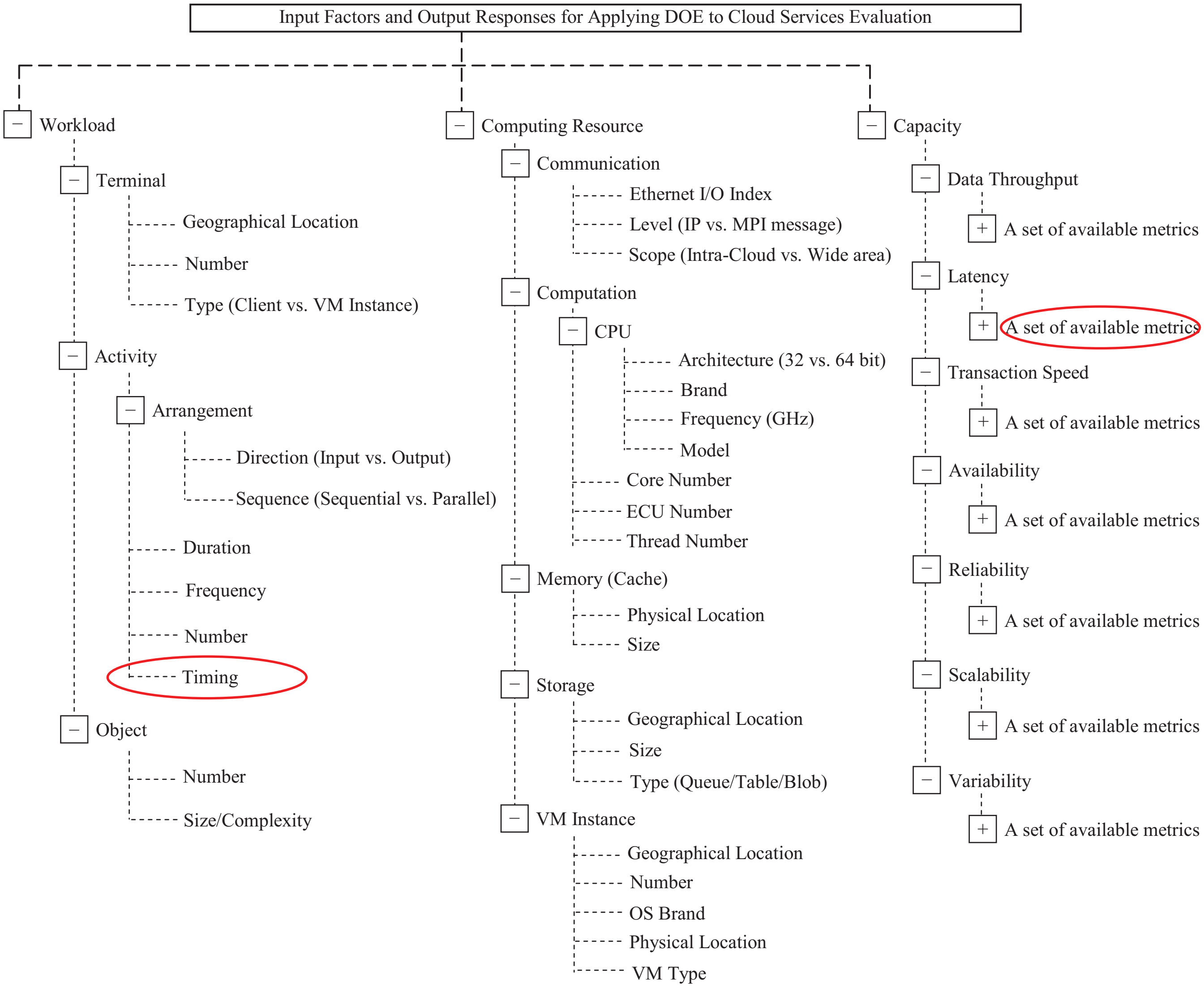

Figure 3. Experimental factor framework for applying DOE to Cloud services evaluation (cf. [16]).

comparable with the original one. Note that the metric *Benchmark Runtime* was also located as the response variable in the experimental factor framework [16] for applying DOE.

7) Experimental Design:

Recall that one of the evaluation questions requires observing Google AppEngine runtime for a period of time. There would be far more than two levels of the factor *Timing*. Therefore, in Step *7)* of the evaluation methodology, we naturally employed the technique of single-factor experimental design for variance analysis [20]. To simplify the demonstration of the preliminary validation, we decided to choose seven consecutive days as the experimental period. In other words, we treated different dates as different levels of the factor *Timing*. Thus, the third evaluation question can be viewed as testing the equality of seven computation performance means, as formally hypothesized in Equation (1), where μ_i refers to the Fibonacci calculation mean in the ith day.

$$\begin{aligned}&H_0 : \mu_1 = \mu_2 = \cdots = \mu_7\\&H_1 : \mu_i \neq \mu_j \quad \text{for at least one pair } (i, j)\\&(i \neq j \;\; \text{and} \;\; i, j = 1, 2, \cdots 7).\end{aligned} \tag{1}$$

Since determining sample size is critical in any experimental design problem [20], we performed a set of random and pilot Fibonacci calculations within Google AppEngine to estimate its performance standard deviation, and then used the Operating Characteristic (OC) Curves [20] to find a suitable number of replicates for everyday. To save space, here we do not specify the background knowledge and the detailed determining process. Our final decision was to run

Table I
EXPERIMENTAL RESULT OF THE 27TH FIBONACCI CALCULATION WITHIN GOOGLE APPENGINE PYTHON RUNTIME

Date	Average	Minimum	Maximum	Standard Deviation
Sept. 1	197.97ms	152.36ms	329.62ms	35.07ms
Sept. 2	194.65ms	151.65ms	311.38ms	30.43ms
Sept. 3	197.83ms	150.57ms	308.64ms	28.81ms
Sept. 4	199.95ms	151.13ms	329.29ms	34.82ms
Sept. 5	208.44ms	155.14ms	318.45ms	38.38ms
Sept. 6	226.39ms	153.91ms	313.66ms	45.48ms
Sept. 7	220.79ms	148.15ms	366.49ms	44.18ms
Total	206.58ms	148.15ms	366.49ms	38.84ms

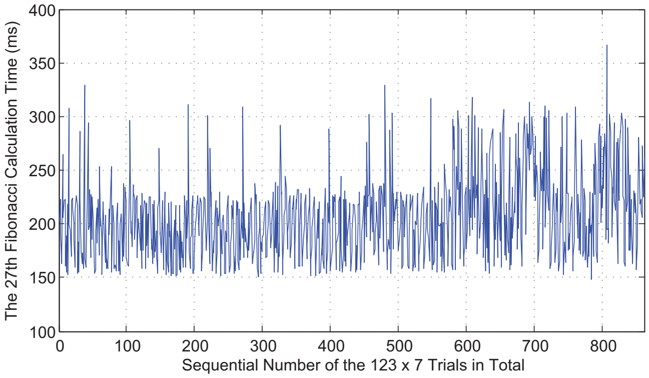

Figure 4. Google AppEngine computation performance during seven days.

123 replicates per day (or replicate once per 720 seconds) to satisfy a target power of at least 0.9.

8) Experimental Implementation:

Given the experimental design, the evaluation experiments were correspondingly deployed and implemented. Several typical indices of the experimental result are shown in Table I, which can be used to initially answer the first two evaluation questions.[1] Following the suggestions in Step *9)* of the evaluation methodology, we further visualized the experimental result to better answer those questions and also facilitate experimental analysis, as shown in Figure. 4. It can then be intuitively found that Google AppEngine takes $200 \pm 50ms$ in general to calculate the 27th Fibonacci number. To be more specific, we used Boxplot (cf. Figure. 5) to scale different quartiles of the runtime data. Note that the crosses in Figure. 5 indicate the outlier observations falling out of the 1.5 interquartile range (IQR). It is clearer that the computation performance peak of Google AppEngine is relatively stable (around $150ms$ for the 27th Fibonacci calculation) everyday, while the worst-case calculation time varies largely without considering the outliers.

9) Experimental Analysis:

However, it is still uncertain whether or not we can expect

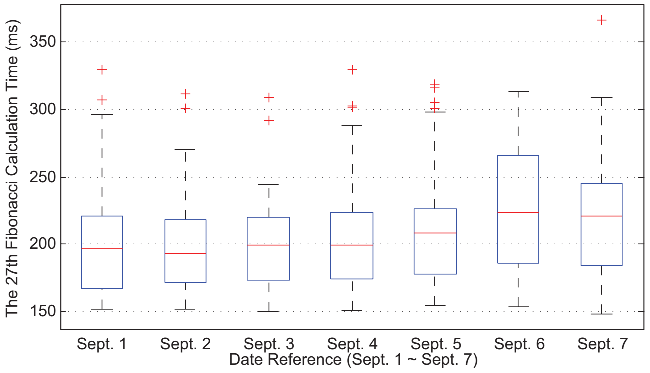

Figure 5. Google AppEngine computation performance shown in boxplot.

a stable mean of the computation performance of Google AppEngine, although the positive answer is suspicious due to the fluctuation in the last two days' experimental data. Recall that this evaluation question equals to the hypothesis testing of Equation (1). We employed Tukey's Test [20] to perform all pair-wise mean comparisons, as shown in Figure 6. It can be seen that the seven days' Fibonacci calculation means are divided into three groups, which statistically confirms that it is impossible to achieve a stable performance when using Google AppEngine at different period of time. However, interestingly, Group B can be viewed as a linkage between Group A and C. We thus claim that, although not absolutely stable, the performance mean of Google AppEngine may fluctuate mildly.

10) Conclusion and Reporting:

As the last step of evaluation activities, the conclusions are to be drawn to finally satisfy the evaluation requirement. Since the pre-recognized requirement was clarified into three questions in this case, we can conveniently respond the evaluation requirement by answering those specific questions, as listed below.

- How fast does Google AppEngine run a particular computation task in the Python runtime environment?
  – *The 27th Fibonacci calculation by using Google AppEngine may take time between 148.15ms and 366.49ms.*
- How variable is the computation performance of Google AppEngine during a particular period of time?
  – *The 27th Fibonacci calculation by using Google AppEngine may take 206.58ms averagely with the standard deviation 38.84ms.*
- Can we expect a stable mean of the computation performance of Google AppEngine at different time?
  – *The performance mean of Google AppEngine may not be absolutely stable, while the fluctuation could be mild.*

After finishing the evaluation work, the details of the evaluation procedure are worth being documented for the purpose of verification and experience sharing. In addition

[1] The specific experimental result can be found online: http://evaluation-experiments.appspot.com

```
One-way ANOVA: Runtime versus Date

Source   DF        SS     MS      F      P
Date      6    114934  19156  13.84  0.000
Error   854   1182327   1384
Total   860   1297261

S = 37.21   R-Sq = 8.86%   R-Sq(adj) = 8.22%


                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev
Level     N    Mean  StDev  ---+---------+---------+---------+-----
Sept. 1  123  197.97  35.07    (----*---)
Sept. 2  123  194.65  30.43  (---*----)
Sept. 3  123  197.83  28.81    (----*---)
Sept. 4  123  199.95  34.82      (----*---)
Sept. 5  123  208.44  38.38            (----*---)
Sept. 6  123  226.39  45.48                          (----*---)
Sept. 7  123  220.79  44.18                      (---*---)
                            ---+---------+---------+---------+-----
                              192       204       216       228

Pooled StDev = 37.21


Grouping Information Using Tukey Method

Date      N    Mean  Grouping
Sept. 6  123  226.39  A
Sept. 7  123  220.79  A B
Sept. 5  123  208.44    B C
Sept. 4  123  199.95      C
Sept. 1  123  197.97      C
Sept. 3  123  197.83      C
Sept. 2  123  194.65      C

Means that do not share a letter are significantly different.
```

Figure 6. Grouping information in Tukey's analysis result (by Minitab).

to the formal reporting guidelines [23], this proposed methodology also supplies a documentation structure for reporting the Cloud services evaluation implementations. Our practice described in this section can then be viewed as a sample of the structured evaluation report.

Overall, compared with the original study [9], the proposed methodology led to a systematic and complete approach to evaluation of Google AppEngine. Given specific evaluation questions, rigorous experimental design, and comprehensive data analysis, we can achieve more rational and convincing experimental results and conclusions. In fact, although this is a simplified evaluation study, the demonstration can be regarded as a further pilot experiment for determining sample size of a whole year's experiment.

V. Conclusions and Future Work

As Cloud Computing becomes one of the most promising computing paradigms in industry [5], numerous vendors have started to supply public Cloud infrastructures and services [22]. Unfortunately, the Cloud service indicators are usually insufficient for service selection with regard to specific application scenarios [14], while customers have little knowledge and control over public Cloud services except for those indicators [25]. As such, it would be necessary and significant to implement appropriate evaluation following a suitable methodology before employing particular Cloud services.

Given the lack of a sound methodology for Cloud services evaluation, we investigated the generic steps of evaluation implementations mainly through three types of sources: lessons from evaluating traditional computing systems, guidelines for performing DOE, and the existing Cloud services evaluation studies. Then, a ten-step methodology CEEM was developed and evaluated to guide future Cloud service evaluation experiments. By delivering generic suggestions and a pre-experimental knowledge base, we further made CEEM more practical particularly in the Cloud Computing domain. Compared to the existing studies of Cloud services evaluation, the validation study shows that CEEM would be able to help evaluators achieve more rational experimental results and draw more convincing conclusions. Moreover, we believe that the evaluation activities involved in CEEM can be conveniently adapted to suit other computing domains by collocating the domain-specific evaluation experiences correspondingly.

Our future work will be unfolded along two directions. On the one hand, CEEM's knowledge base of evaluating Cloud services will be continually enriched. For example, we are conducting a mapping between specific DOE techniques and detailed evaluation situations, to further facilitate applying DOE to Cloud services evaluation. On the other hand, in addition to employing CEEM in our own evaluation studies, we plan to introduce this work to other Cloud evaluators, and collect their feedback for further validation and improvement.

Acknowledgment

This project is supported by the Commonwealth of Australia under the Australia-China Science and Research Fund.

NICTA is funded by the Australian Government as represented by the Department of Broadband, Communications and the Digital Economy and the Australian Research Council through the ICT Centre of Excellence program.

References

[1] S. Akioka and Y. Muraoka, "HPC benchmarks on Amazon EC2," *Proc. 24th Int. IEEE Conf. Advanced Information Networking and Applications Workshops (WAINA 2010)*, IEEE Computer Society, Apr. 2010, pp. 1029-1034.

[2] M. Alhamad, T. Dillon, C. Wu, and E. Chang, "Response time for Cloud computing providers," *Proc. 12th Int. Conf. Information Integration and Web-based Applications & Services (iiWAS 2010)*, ACM Press, Nov. 2010, pp. 603–606.

[3] S. M. Blackburn, K. S. McKinley, R. Garner, C. Hoffmann, A. M. Khan, R. Bentzur, A. Diwan, D. Feinberg, D. Frampton, S. Z. Guyer, M. Hirzel, A. Hosking, M. Jump, H. Lee, J. E. B. Moss, A. Phansalkar, D. Stefanović, T. VanDrunen, D. von Dincklage, and B. Wiedermann, "Wake up and smell the coffee: Evaluation methodology for the 21st century," *Commun. ACM*, vol. 51, no. 8, Aug. 2008, pp. 83–89.

[4] P. A. Boampong and L.A. Wahsheh, "Different facets of security in the Cloud," *Proc. 15th Communications and Networking Simulation Symp. (CNS 2012)*, Society for Computer Simulation International, Mar. 2012, pp. 1–7.

[5] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, "Cloud Computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility," *Future Gener. Comp. Sy.*, vol. 25, no. 6, Jun. 2009, pp. 599-616.

[6] M. Cunha, N. Mendonça, and A. Sampaio, "Investigating the impact of development configuration and user demand on a social network application in the Amazon EC2 Cloud," *Proc. 3rd Int. Conf. Cloud Computing Technology and Science (CloudCom 2011)*, IEEE Computer Society, Nov. 2011, pp. 746–751.

[7] J. Dejun, G. Pierre, and C.-H. Chi, "EC2 Performance Analysis for Resource Provisioning of Service-Oriented Applications," *Proc. 2009 Int. Conf. Service-Oriented Computing (ICSOC/ServiceWave 2009)*, Springer-Verlag, Nov. 2009, pp. 197–207.

[8] I. Iankoulova and M. Daneva, "Cloud computing security requirements: A systematic review," *Proc. 6th Int. Conf. Research Challenges in Information Science (RCIS 2012)*, IEEE Computer Society, May 2012, pp. 1–7.

[9] A. Iosup, N. Yigitbasi, and D. Epema, "On the performance variability of production Cloud services," Delft Univ. Technol., Netherlands, Tech. Rep. PDS-2010-002, Jan. 2010.

[10] K. R. Jackson, L. Ramakrishnan, K. Muriki, S. Canon, S. Cholia, J. Shalf, H. J. Wasserman, and N. J. Wright, "Performance analysis of high performance computing applications on the Amazon Web services Cloud," *Proc. 2nd IEEE Int. Conf. Cloud Computing Technology and Science (CloudCom 2010)*, IEEE Computer Society, Nov.-Dec. 2010, pp. 159-168.

[11] R. K. Jain, *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling*. New York, NY: Wiley Computer Publishing, John Wiley & Sons, Inc., May 1991.

[12] D. Kossmann, T. Kraska, and S. Loesing, "An evaluation of alternative architectures for transaction processing in the Cloud," *Proc. 2010 ACM SIGMOD Int. Conf. Management of Data (SIGMOD 2010)*, ACM Press, Jun. 2010, pp. 579-590.

[13] J.-Y. Le Boudec, *Performance Evaluation of Computer and Communication Systems*. Lausanne, Switzerland: EFPL Press, Feb. 2011.

[14] A. Lenk, M. Menzel, J. Lipsky, S. Tai, and P. Offermann, "What are you paying for? Performance benchmarking for Infrastructure-as-a-Service offerings," *Proc. 4th Int. Conf. Cloud Computing (IEEE CLOUD 2011)*, IEEE Computer Society, Jul. 2011, pp. 484–491.

[15] Z. Li, L. O'Brien, R. Cai, and H. Zhang, "Towards a taxonomy of performance evaluation of commercial Cloud services," *Proc. 5th Int. Conf. Cloud Computing (IEEE CLOUD 2012)*, IEEE Computer Society, Jun. 2012, pp. 344–351.

[16] Z. Li, L. O'Brien, H. Zhang, and R. Cai, "A factor framework for experimental design for performance evaluation of commercial Cloud services," *Proc. 4th IEEE Int. Conf. Cloud Computing Technology and Science (CloudCom 2012)*, IEEE Computer Society, Dec. 2012, pp. 169–176.

[17] Z. Li, L. O'Brien, H. Zhang, and R. Cai, "On a catalogue of metrics for evaluating commercial Cloud services," *Proc. 13th ACM/IEEE Int. Conf. Grid Computing (Grid 2012)*, IEEE Computer Society, Sept. 2012, pp. 164–173.

[18] A. Li, X. Yang, S. Kandula, and M. Zhang, "CloudCmp: Comparing public Cloud providers," *Proc. 10th Annu. Conf. Internet Measurement (IMC 2010)*, ACM Press, Nov. 2010 pp. 1–14.

[19] Z. Li, H. Zhang, L. O'Brien, R. Cai, and S. Flint, "On evaluating commercial Cloud services: A systematic review," *J. Syst. Software*, in press.

[20] D. C. Montgomery, *Design and Analysis of Experiments*, 7th ed. Hoboken, NJ: John Wiley & Sons, Inc., Jan. 2009.

[21] M. S. Obaidat and N. A. Boudriga, *Fundamentals of Performance Evaluation of Computer and Telecommjnication Systems*. Hoboken, New Jersey: John Wiley & Sons, Inc., Jan. 2010.

[22] R. Prodan and S. Ostermann, "A survey and taxonomy of Infrastructure as a Service and Web hosting Cloud providers," *Proc. 10th IEEE/ACM Int. Conf. Grid Computing (GRID 2009)*, IEEE Computer Society, Oct. 2009, pp. 17–25.

[23] P. Runeson, M. Höst, "Guidelines for conducting and reporting case study research in software engineering," *Empir. Software Eng.*, vol. 14, no. 2, Apr. 2009, pp. 131-164.

[24] J. Schad, J. Dittrich, and J.-A. Quiané-Ruiz, "Runtime measurements in the Cloud: Observing, analyzing, and reducing variance," *VLDB Endowment*, vol. 3, no. 1-2, Sept. 2010, pp. 460-471.

[25] W. Sobel, S. Subramanyam, A. Sucharitakul, J. Nguyen, H. Wong, A. Klepchukov, S. Patil, A. Fox, and D. Patterson, "Cloudstone: Multiplatform, multi-language benchmark and measurement tools for Web 2.0," *Proc. 1st Workshop on Cloud Computing and Its Applications (CCA 2008)*, Oct. 2008, pp. 1–6.

[26] V. Stantchev and C. Schröpfer, "Techniques for service level enforcement in Web-services based systems," *Proc. 10th Int. Conf. Information Integration and Web-based Applications & Services (iiWAS 2008)*, ACM Press, Nov. 2008, pp. 7–14.

[27] V. Stantchev, "Performance evaluation of Cloud computing offerings," *Proc. 3rd Int. Conf. Advanced Engineering Computing and Applications in Sciences (ADVCOMP 2009)*, IEEE Computer Society, Oct. 2009, pp. 187–192.

[28] G. Wang and T. S. E. Ng, "The impact of virtualization on network performance of Amazon EC2 data center," *Proc. 29th Annu. IEEE Int. Conf. Computer Communications (IEEE INFOCOM 2010)*, IEEE Computer Society, Mar. 2010, pp. 1-9.

[29] Q. Zhang, L. Cheng, and R. Boutaba, "Cloud computing: State-of-the-art and research challenges," *J. Internet Serv. Appl.*, vol. 1, no. 1, May 2010, pp. 7-18.