Cloud Monitoring Data Challenges: A Systematic Review

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Abstract. Organizations need to continuously monitor, source and process large amount of operational data for optimizing the cloud computing environment. The research problem is: what are cloud monitoring data challenges – in particular virtual CPU monitoring data? This paper adopts a Systematic Literature Review (SLR) approach to identify and report cloud monitoring data challenges. SLR approach was applied to initially identify a large set of 1861 papers. Finally, 24 of 1861 relevant papers were selected and reviewed to identify the five major challenges of cloud monitoring data: monitoring technology, virtualization technology, energy, availability and performance. The results of this review are expected to help researchers and practitioners to understand cloud computing data challenges and develop innovative techniques and strategies to deal with these challenges.

Keywords: Big Data, Cloud Computing, Capacity Planning, Monitoring, and Virtual CPU

1 Introduction

Cloud computing is a virtual data-intensive environment, which runs multiple virtual machines in large scalable clusters [11]. Cloud computing is one such new modes that supports pay-as-you-go and on-demand services (e.g. software as a service, platform as a service, infrastructure as a service) to enable business agility and flexibility [10]. Cloud computing seems to offer lucrative benefits [3], however, organizations need to actively monitor and analyze the operational data about the quality of cloud services and utilization of underlying virtual resources such as CPU, memory, storage and network [6]. This is also important to verify and identify any service performance related issues including Service Level Agreement (SLA). Monitoring is also important to track and control the expenses associated with the cloud service resource utilization [4].

There are a number of tools (e.g. AWS Cloud Watch) that claim to support the data monitoring including data acquisition and processing [e.g. 9]. However, to effectively adopt or develop specific cloud monitoring data tools, organizations need to identify and understand the fundamental challenges of cloud monitoring data. The understanding of challenges will help organizations in making informed decisions

about the development and improvement of specific cloud monitoring data sourcing and processing tools for different types of cloud resources (e.g. CPU data, storage device data) at different levels (e.g. resource utilization data, health data). Cloud monitoring data is a broad topic. This paper mainly focuses on the monitoring challenges of virtual CPU utilization data within the overall context of cloud monitoring. Thus, the main research question is: what are cloud monitoring challenges – in particular virtual CPU utilization monitoring data?

This paper applied the well-known Systematic Literature Review (SLR) method [7] to systematically search, identify and synthesize the challenges of virtual CPU utilization monitoring data. This paper is organized as follows. Firstly, it discusses the research method. Secondly, it presents the research findings. Finally, it discusses the research findings and future research directions before concluding.

2 Research Method

This paper applied the SLR guidelines [7] for systematically searching, selecting, reviewing and synthesizing the cloud monitoring data challenges from relevant academic and industry publications (2011-2015). This study included the paper written in English language, which were selected from five well-known electronic databases (Table 3).

Table 1. Search keywords

Search Category	Keywords/Phrases
Monitoring of Virtual CPU (using advanced search interfaces)	Virtual Processor; Virtual CPU; Monitoring Tool; Monitoring Technique; Cloud Computing; Virtual Machine; SaaS Monitoring Technology.
Monitoring of Virtual CPU (using advance command search)	(("virtual processor") OR ("virtual CPU")) AND (("monitoring tool*") OR ("monitoring technique*")) and (("cloud computing*")) (("*virtual processor*") OR ("*virtual CPU*")) AND (("*monitoring tool*") OR ("*monitoring technique*")) and (("*cloud computing*"))

Table 1 presents the keyword or terms that were used during the first attempt to search the topic. All of the terms from the search category field “Monitoring of Virtual CPU” were also joined using the “AND” or “OR” operator to examine different combinations. In addition to this, search history features were used to combine different returned searched results to narrow down to the desired topics. Table 2 presents the paper selection criteria stages, which were applied to systematically identify the relevant papers for this study.

Table 2. Paper selection criteria

Filtration stage	Method	Assessment Criteria
First Search Filtration	Explore the title	Title = **search keyword (s)** Yes = accepted No = rejected
Second Search Filtration	Explore the abstract	Abstract = **CPU OR Virtual CPU OR VCPU** Yes = accepted No = rejected
Final Search Filtration	Explore the content	1. Address **Virtual CPU OR Monitoring Tool OR Cloud Computing** 2. Well-referenced 3. Objective is clearly defined 4. Well-presented argument and justified 5. Clearly stated findings (Yes= accepted, No = rejected)

Table 3. Search results

Database	1st Search Filtration	2nd Filtration	Final Count
Web of Science	462	40	3
IEEE	913	30	10
Google Scholar	67	16	7
Gartner	12	6	2
Scopus	407	5	2
Total	**1861**	**97**	**24**

Initial search of keywords and filtration (based on title) across five selected databases resulted in a large number of 1861 papers. Second filtration resulted in 97 papers (based on the review of abstract), and finally, third filtration stage (based on the exploration of paper contents) resulted in 24 relevant papers for this review (Table 3). Please note that for the first and second search filtration stages, the items such as news, eBooks and tutorials were excluded as the contents were not suitable for this academic study. Finally, only those papers were selected that satisfied the five Assessment Criteria – Final Search Filtration (Table 2).

3 Findings

The selected 24 papers were analyzed and interpreted in order to answer the research question in hand. The detailed review of the selected papers resulted in five major challenge categories as shown in table 4. These challenge categories are: monitoring technology, virtualization technology, energy, availability and performance. These categories were extracted after the careful review of the papers by using the analysis techniques from the well-known Grounded Theory [2], which is useful for identifying

the relevant concepts and categories from a large volume of qualitative data or text [1]. Table 4 presents the identified major challenge categories and corresponding literature sources (see Appendix for selected literature sources S1-S24).

Table 4. Findings – data monitoring challenges categories

Challenge Categories	**Sources**	**Frequency (number of studies)**	**Percentage**
C1. Monitoring Technology	S14, S15, S16, S17, S18, S19, S20, S21	8	**34%**
C2. Virtualization Technology	S1, S2, S3, S4, S5, S6	6	**25%**
C3. Energy	S10, S11, S12, S13	4	**17%**
C4. Availability	S7, S8, S9	3	**13%**
C5. Performance	S22, S23, S24	3	**13%**

3.1. Monitoring Technology

Monitoring of a specific remote virtual CPU resource is a challenge in the complex distributed cloud environment. Monitoring technology category is heavily referenced in the literature (e.g. 34% of the selected studies) and can help to resolve this challenge. (Table 4). This challenge category has identified three key underlying monitoring technology data challenges: (1) lack of data standardization, (2) live resource monitoring data, and (3) interoperability of data. Lack of monitoring data standards (e.g. templates, format) hinder the ability to integrate disparate monitoring tools and different types of virtual CPU data [e.g. S14]. The accurate monitoring data of a live virtual CPU resource in a cluster, which can be dynamically added, updated or removed, is challenging [e.g. S16]. Finally, third challenge is about the inability of the monitoring technology to support the interoperability of monitoring data across different cloud platforms [e.g. S18].

3.2. Virtualization Technology

Monitoring of the virtualized CPU resource data can also be impacted by the hypervisor, which is used to virtualize the physical CPU resource [5]. Interaction between the monitoring tool and hypervisor is important for collecting the utilization data. This is the second highly referenced category (25% of the selected studies) (Table 4). This challenge category has identified two key underlying challenges: (1) dual monitoring data and (2) heterogeneous virtual environment data. Hypervisor and virtualized CPU share physical resources and the challenge is that both need to be monitored for collecting the correct utilization data. Thus, this dual monitoring challenge needs to be addressed to accurately collect the utilization data [e.g. S1].

Heterogeneous virtual environment, containing different types of hypervisors and virtual CPUs, poses the challenge of dealing with different hypervisors' APIs and monitoring tools' APIs for monitoring, collecting and processing large amount of data in different formats [e.g. S2].

3.3. Energy

This is the third referenced category (17% of the selected studies) (Table 4). This challenge category has identified two key underlying energy related challenges: (1) energy utilization data and (2) energy efficiency. Virtualized cloud environments claim to offer low energy utilization. These challenges draws our attention to the challenge of collecting and processing large amount of monitoring data using minimal energy or power. Energy utilization data needs to be monitored and optimized for energy efficiency [e.g. S10 and S11].

3.4. Availability

It is not about the CPU resource monitoring data. The monitoring should also provide the capability to collect and provide the virtual CPU availability data [e.g. S8]. This is the fourth referenced category (13% of the selected studies) (Table 4). This challenge category has identified two key underlying availability related challenges: (1) SLA verification data, and (2) detecting and alerting data. The availability, in the context of virtual CPU utilization, is important and draws our attention to the challenge of monitoring availability SLAs, and then processing it for detecting and alerting any related issues or breaches [e.g. S7 and S8].

3.5 Performance

Finally, this category draws our attention to the computational performance challenge of both the virtual machines and monitoring. This is the fifth referenced category (13% of the selected studies) (Table 4). This challenge category has identified two key challenges: (1) performance identification, and (2) detecting and alerting. The monitoring should provide the capability to collect and provide the data about the performance of the virtual CPU resource and monitoring technology to help detecting and alerting any performance issues [e.g. S24]. Based on the performance results, we can dynamically adjust the utilization and control the number of virtual CPUs assigned to a physical CPU [e.g. S24]. Further, performance results can lead to the consolidation and de-consolidation of the virtual CPUs and underlying physical resources [e.g. S22 and S23].

4 Discussion

The effective utilization of cloud requires monitoring the hypervisors and the virtual environments. Monitoring data growth and velocity are increasing, and different monitoring standards, architectures, tools, and APIs are required to monitor the resource usage and capture a large amount of operational data [8]. However, the monitoring of cloud, in particular virtual CPUs hosted on a heterogeneous environment, poses several challenges. This paper addresses this research problem and systematically identify the five key challenges categories and underlying challenges.

Firstly, our findings highlighted that monitoring (34%) and virtualization (24%) technology were the most important challenge categories with respect to virtual CPU monitoring data collection and processing. Thus, we can classify these two as core challenge categories. Other challenge categories such as energy (17%), availability (13%), and performance (13%) were classified as secondary. This is because they were not heavily reported, although, they could impact the monitoring (Table 4).

Secondly, our findings highlighted that the effective monitoring of the heterogeneous environment requires monitoring standards and frameworks for monitoring data integration and interoperability across different cloud platforms. This is important to facilitate the effective adoption of cloud.

Thirdly, our findings highlighted that the capturing and processing of the monitoring data are not enough. Monitoring capability should also support detecting any issues and alerting or taking corrective actions or adjustments. This leads to the identification of whole new area of research about smart data-driven and analytics-enabled adaptive monitoring. Monitoring of large and complex environment generates huge amount of data, which draws our attention to another area of research about BigData analytics for cloud monitoring data.

Similar to any other SLR studies, this paper has some limitations. One limitation could be the use of finite number of selected literature databases and studies. This paper included studies from well-known databases, and we have full confidence that the selected databases and studies provided us with the relevant and recent literature to address the research question in hand. One may argue about the possible bias in the selection of studies and inaccuracy of analysis. To mitigate this risk, we developed and applied relevant search string and keywords, systematic study selection criteria (Tables 1-2) and analysis techniques from well-known Grounded Theory [2]. This was done to ensure that the relevant studies were not omitted.

Despite possible limitations, this paper provided useful insights for both practitioners and researchers interested in the area of cloud monitoring data capturing and processing. For instance, practitioners may be interested in developing new tools, formats and standards for exchanging monitoring data across different cloud platforms. Researchers may be interested in developing new frameworks for BigData analytics enabled smart and adaptive monitoring.

5 Conclusion

This paper presented a SLR of virtual CPU utilization monitoring data challenges. This paper systematically searched, identified and reviewed a set of twenty-four relevant papers. The detailed review of selected papers provided us with the five major challenge categories. This study provided a knowledge-base of monitoring data challenges to practitioners and researchers who have interest in cloud computing. The findings of this paper can be further used in developing monitoring data sharing and processing standards, formats and tools to facilitate the effective cloud monitoring data management. The findings of this paper will provide necessary inputs to further research and develop the BigData analytics enabled framework for smart and adaptive cloud monitoring data.

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Appendix: Selected papers included in this review

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