A SYSTEMATIC MAPPING STUDY OF HIGH PERFORMANCE COMPUTING AND THE CLOUD

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ABSTRACT

Cloud computing is a paradigm that provides resources in an almost limitless way to users. High Performance Computing (HPC) involves performing computationally intense processes rapidly. Cloud computing being scalable and comparatively cheaper has the capacity to offer such processing speed, hence HPC are often deployed in the Cloud. However, determining a focus of research in a particular field of study is sometimes challenging especially in the area of HPC and the cloud. A systematic mapping study examines the various research work carried out in given area, summarizes these work and provides a visual representation of the results in form of maps. The method utilized in this study involved analysis on three categories namely, topics, research and contribution facets. Topics were extracted from primary studies, while research type such as evaluation and contribution such as tool were utilized in the analysis. The objective of this paper therefore was to conduct a systematic mapping study of HPC and the Cloud. The results showed that there were more publications in terms of performances in the aspect of metric with 2.88%, and more publications on applications relating to tool, model and method with 26.73%, 18.27% and 12.5% respectively. Furthermore, there were more publications on optimization in terms of process with 5.77%. In addition, there were more articles on applications based on evaluation and validation research with 18.1% and 6.9% respectively. Publications on optimization in terms of solution research accounted for 6.9%, while articles on design and implementation that relates to philosophical research were 3.45%. The outcome of this study identified several gaps that will be of benefit to researchers, practitioners and providers.

Keywords: cloud computing, cloud services, high performance computing, parallel processing, systematic mapping.

1. INTRODUCTION

The cloud is a parallel and distributed computing system consisting of a collection of interconnected and often virtualized computers, which are dynamically provisioned and presented to its users as a single computing resource based on pre-agreed service levels between the Cloud Service Providers (CSPs) and the Cloud users (Buyya, Broberg & Goscinski, 2011). There are three Cloud services which are Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS) and Infrastructure-as-a-Service (IaaS). These services are offered to clients in one of four models, namely private, public, community and hybrid (Mell, & Grance, 2011). CSPs have very large data centres with infrastructure capable of high performance computing. Beyond these, applications and services are also offered to users on-demand and in an elastic manner. This means that the resources being utilized by users have the ability to "grow" or "shrink" to meet changing demand (Hamdaqa, & Tahvildari, 2012). Cloud computing is becoming very effective and services are improving, and expanding on a regular basis because of the sound underlying architecture and applications running on the cloud (Odun-Ayo, Ananya, Agono, & Goddy-Worlu, 2018; Odun-Ayo, Odede, & Ahuja, 2018). Although the CSPs are striving to provide very efficient and reliable services on the cloud, there issues of trust (Odun-Ayo, Omoregbe, Odusami, & Ajayi, 2017)

High Performance Computing (HPC) can be defined as an aggregation of interconnected computing workstations, working together to solve complex problems (Maxey, 2016). It is essentially a cluster of high end computers, linked by very fast networks and collectively working on specific set of problems. Though similar, HPC and Cloud Computing are different concepts. A comprehensive comparisons of both technologies was done in Goscinski, Brock, and Church (2012) with some of the key differences being that Cloud relies on virtualization, supports on-demand utility-like computing and elasticity, all of which are not required for HPC and might even have adverse side-effects on HPC. However, due to the process of virtualization and multitenancy on the cloud, there are concerns of security (Odun-Ayo, Misra, Abayomi-Alli, & Ajayi, 2017; Odun-Ayo, *et al.*, 2017). These notwithstanding, some CSPs now offer specialized form of HPC services known as HPC-Clouds. HPC-Cloud refers to the use of Cloud resources to run HPC applications (Samimi, & Patel, 2011). Cloud technologies such as MapReduce discussed in Dean, and Ghemawat (2008) and Dryad in Isard, Mihai, Yuan, Birrell, and Fetterly (2007) have created new trends in parallel programming, support for handling large data sets, and make the Cloud relevant in solving large scale, compute intensive problems typically associated with HPC (Goscinski, *et al.*, 2012). Besides HPC applications need certain requirements such as scalability, performance and flexibility in handling workloads, which the Cloud provides (Hamdaqa, & Tahvildari, 2012). It is however important to note that these apply mainly to single threaded applications (Bismitriu, & Matei, 2015). Applications with multiple threaded or parallel processing might struggle in the Cloud. This however has not deterred Amazon Web Services (AWS) for instance, which offers HPC on its Cloud platform with reduced cost for customers by providing cluster compute or cluster GPU servers on demand without large capital investment (Al-Roomi, Al-Ebrahim, Buqrais, & Ahmed, 2013).

From literature, there are an increasing number of research work relating to HPC and the Cloud, but, many of these are skewed towards certain directions and do not cover the concepts in their entirety. In writing an article or embarking on research in general, a researcher must consider a technical area of interest. This involves a lot of studies in an attempt to understand the topic. This usually entails searching several conference proceedings, journals and even books. In addition, determining an area of interest may also require a lot of search on digital libraries, attending workshops, seminars and conferences. Through the process of conducting research, as well as the long hours that are spent reviewing other people's research, researchers can often stumble onto new and often unanticipated research ideas. Also, many researchers become interested in particular research in a specific observed phenomenon serving as impetus for a great amount of research in all fields of study. From the foregoing, it is obvious that the process of determining a research topic is sometimes usually cumbersome. This necessitates a summary and overview of research in this area. A systematic mapping study allows the categorization of reports using a unique structure and scheme to provide insight into these research work (Peterssen, Feldt, Mujtaba, & Mattsson, 2008). Such insights relating to frequency of publications are then visually reported using a bubble map. Three facets were employed in this study namely; the topic, contribution and research facets. The topic facet is used to extract core issues that relates to HPC and Cloud computing. The research facet focuses on the type of research carried out, while the contribution facet is concerned with the method, model or metric used. The purpose of the paper therefore, is to conduct a systematic mapping study of HPC and the Cloud. The rest of this paper is organized as follows: Section 2 examines related work. Section 3 materials and methods. Section 4 presents the obtained results and discussion. Finally, the paper is concluded and further studies suggested in section 5.

2. RELATED WORK

In Barros-Justo, Cravero-Leal, Benitti, and Capilla-Sevilla (2017), the planning phase of a systematic mapping study was explored. The work identifies the software patterns as evident during the requirement engineering phase of projects, seeking for a comprehension of the roles played by these patterns based on basic parameters required in the development process. A protocol was developed for the study with basic steps to replicate such a work in the research community for a confirmation of the validity of the research. The digital libraries used for the work are ACM DL, IEEExplore, Scopus, and Web of Science. The guidelines laid down in Petersen *et al* (2015) were adhered to for this work.

The work of Kosar, Bohra, and Mernik (2016) dwells on the description of the protocol for a systematic mapping study as it relates to domain-specific languages (DSL). The work is channeled towards an enhanced comprehension of the DSL domain of research with a focus on research trend and future direction. This work covers the period July 2013 to October 2014, and it leverages on three guidelines for performing systematic review, namely; planning, conducting the review, and reporting such.

The Systematic Mapping Study in Santos, Souza, Felizardo, and Vijaykumar (2017) is based on the analysis of the use of concept maps in Computer Science. This work delivers the result of an SMS that centers on collection and evaluation of existing research on concept maps in Computer Science. Five electronic databases were employed for the work. Backward snowballing and manual approaches were used in the searching process. The work shows massive interest and a rich investigation of concept maps, due to learning and teaching supports in that direction. The search strings of the work were applied on SCOPUS, ScienceDirect, Compedex, ACM Digital Library, and IEEExplore.

In Souza, Veado, Moreira, Figueiredo, and Costa (2018), a systematic mapping study was used to study how game related techniques have been employed in software engineering education and how these techniques support specific software engineering knowledge domains, with research gaps, and future direction identified. The primary studies of the work anchored on the use, evaluation of games, and their elements on software engineering education. A total of 156 primary studies were identified in this study based on publications from 1974 to June 2016. The mapping process of the work was done in tandem with Petersen *et al* (2015).

The work in Fernandez-Blanco, *et al*., (2017) did a mapping of power system model based on the provision of an overview of power system models and their applications used by European organizations; analysis of their modeling features and identification of modeling gaps. There were 228 surveys sent out to power experts for information elicitation, but only 82 questionnaires were completed and the knowledge mapping was done accordingly.

In Mernik (2017), a systematic mapping study of domain-specific languages was done with basic interest in type of contribution, type of research, and the focus area. The work features a search from reputable sources from 2006 to 2012 with the systematic mapping study done based on defining research questions, conducting the search, screening, classifying, and the data extraction. The research materials for the work includes: opinion papers, experience papers, philosophical or conceptual papers, solution proposal, and validation research materials.

Griffo, Almeida, and Guizzardi (2015) did a systematic mapping of the literature on legal core ontologies. The work based its search more on "legal theory" and "legal concepts". Also, the selected studies were categorized based on contribution as reflected in language, tool, method, and model. The other steps include identification of the used legal theories in legal core ontologies building process, identification of focus with a clear recommendation to use the two ontologies, and finally the analysis of every chosen research for cogent deductions about legal and ontological research.

In Petersen *et al* (2015) a systematic mapping study in software engineering was conducted, the work is a foundation to many systematic mapping studies. It provides guidelines for the conduct of systematic mapping studies and a comparison of systematic maps and reviews based on the analysis of existing systematic reviews. The work reveals that systematic maps and reviews are not the same, based on goals, breadth, validity measures, and implications and employ different analysis methods.

The work of Ahmad, Brereton, and Andras (2017) is a systematic mapping study that gives an overview of empirical research in software cloud-based testing in the process of building a classification scheme. Functional and non-functional testing methods were investigated; also the applications of the methods and their peculiarities. The work utilized 69 primary studies as discovered in 75 research publications. Only a fraction of the studies bring together rigorous statistical analysis with quantitative results. Majority of the studies employed a singular experiment for the evaluation of their proposed solution. From literature, there has been no work focused specifically on systematic mapping study of HPC and the Cloud. From literature, there has been no work focused specifically on systematic mapping study of HPC and the Cloud.

3. MATERIALS AND METHODS

A systematic mapping study employs a visual representation process to grant insight into materials published in a field of study. This systematic mapping study of HPC and the Cloud was carried out using the formal guidelines for a systematic mapping study in Petersen *et al* (2015) and Kitchenham and Charters (2007). It is defined as a repeatable process for extracting and interpreting available materials related to a research objective Muhammed and Muhammed (2014). There are essential steps required to accomplish a successful review as shown in Figure-1. The first step is the definition of research questions in which the scope of the study is outlined. Thereafter, a search is conducted for primary studies in the proposed field of study. The papers sought are screened to determine their relevance to the study. The next step is the key wording process. It involves using the abstracts of the paper to design a classification scheme. The last step is the process of data extraction, which takes place with a view to creating the systematic map. At every stage there is an outcome which services as input to the next stage and ultimately leads to creating the systematic map. These steps were rigorously followed in this paper.

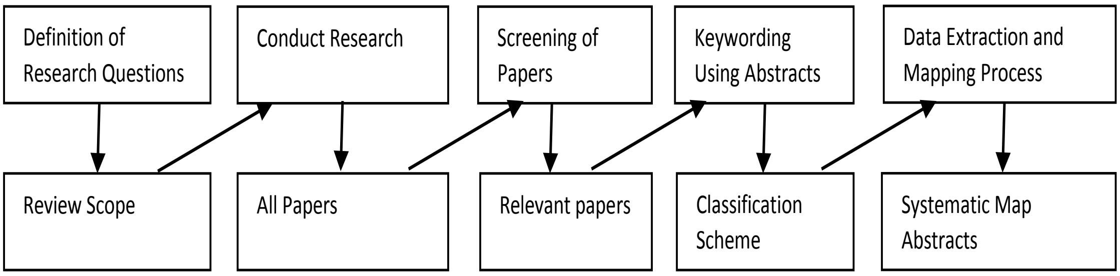

Figure-1. The systematic mapping process (Petersen *et al*., 2015).

3.1 Definition of research questions

The purpose of a systematic map is to have a synopsis of the quantity and type of research that has been done in a particular field of study. It may also be necessary to know the places that the research has been published. These issues inform the relevant questions to be utilized for the study. In this particular study, the research questions are as follows:

RQ1: What areas of High Performance Computing are addressed on the Cloud, and how many articles covered the different areas?
RQ2: What types of papers are published in the area and what particular evaluation and novelty did they constitute?

3.2 Conduct of search for primary studies (All papers)

A review is only possible when there are materials to examine; hence a search for primary studies is the starting point of any study. Typically this search for papers usually involves exploring major digital libraries. However, it can also be accomplished by manually searching through books, printed conference proceedings and journals. For this study, only papers available in major online databases were considered, thus excluding book and printed resources. All the papers selected for the primary studies are in the domain of cloud computing hence all the facets dealt with issues relating to cloud computing. The core concept of a systematic mapping study is key wording which is usually done on the abstract of peer-reviewed articles. Therefore, articles from newspapers, social networks and other sources are not suitable for conducting systematic studies, hence the need to utilize appropriate digital libraries. The search utilized four major digital libraries with high impact factor. The databases used for this study are summarized on Table-1.

Table-1. Digital libraries used for the systematic mapping study.

Electronic database	URL
ACM [a]	https://dl.acm.org/
IEEE [b]	http://ieeexplore.ieee.org /xplore
Science Direct	http://www.sciencedirect .com/
Springer	https://link.springer.com/

[a]ACM = Association for computing machinery
[b]IEEE = Institute of electrical and electronics engineers

The search string for this study was designed in terms of outcome, population, comparison and intervention. The keywords used in the search string were drawn from the title of the study. For this study on High Performance Computing and the Cloud, the search string used on the four digital libraries is:

(TITLE (''HPC") OR TITLE (''High Performance Computing")) AND (TITLE (Cloud))

The searches on the electronic databases were performed by running search string on documents' metadata. This ensured that relevant publications were not omitted. In perspective of our paper choice criteria described by the requirement of the study's objective and research questions a total of 116 papers were considered relevant to this study, out of an initial set comprising of 1, 125 papers from 2014 to 2018. These 116 selected studies are listed at the Appendix.

3.3 Screening of papers for inclusion and exclusion (Relevant papers)

The goal of the selection process is to find and include all papers relevant to the review. The inclusion and exclusion criteria was used to eliminate articles that are were not relevant to this study; as well as those not relevant to the research questions. Abstracts play a major role here, as they provide concise yet sufficiently detailed information about the main focus of a paper. However, some abstracts simply discuss the main focus without sufficient secondary details, such abstract were not utilized. Also because most papers on editorials, summaries, tutorials, presentation slides, panel discussions and prefaces do not always contain abstracts; these were also excluded from this study. The inclusion and exclusion criteria used for this study are shown on Table-2.

Table-2. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
The included abstract explicitly discusses High Performance Computing as it relates to the Cloud.	The paper lies outside the sphere of Cloud computing or does not mention High Performance Computing.

3.4 Key wording of abstracts (Classification scheme)

Key wording of abstracts is a core activity in the systematic mapping process. The systematic process is used to design the classification scheme. Key wording is essential in reducing the time needed to design a classification scheme for HPC and the Cloud. In addition, it ensures that the scheme considers all the relevant papers. For this study, the process involved studying the abstracts to extract concepts and keywords relating to the study. Thereafter, keywords from different papers relating to the study were combined to provide sufficient insight into the kind and contribution of the various research works. These were then used to determine the set of categories to be considered for the study. It was also necessary to examine the introduction and conclusion to ensure a comprehensive key wording for the study.

3.5 Research type facet with categories and description

In this study and in line with Petersen *et al* (2015), three main facets were utilized. The first focused on topics in terms HPC and the Cloud; the second, the types of contribution made to the research in terms of models, methods, processes and metrics, while the third involved classification of research approaches. The categories and description of research works as listed in Wieringa, Maiden, Mead, and Rolland (2006) are as following:

a) **Validation research:** Papers that confirm previously obtained results. In essence reports on experiments conducted in a lab.

b) **Evaluation research:** Papers showcasing the techniques for implementation and evaluation. The outcomes in terms of pros and cons are also presented.

c) **Solution proposals:** These papers present unique solution(s) to specified problem(s). The benefits and applications of such solutions might also be highlights.

d) **Philosophical papers:** These offer new ways to examine a problem in terms of concepts and framework.

e) **Experience paper:** These papers detail the personal experiences of the author(s). It indicates how something was done.

f) **Opinion paper:** These does not rely on known methodology or conducted experiments. They simply relates the opinion of the author(s).

These categories were considered sufficient and adequate for use in the classification scheme of this study. The papers included in this study were checked based on the various research categories in the classification of research approaches, and used to represent the research facet.

3.6 Data extraction and mapping of studies (Systematic map)

During the classification process, relevant papers were sorted into groups. This step allowed for data extraction from various papers that were included in this study. During this extraction process new categories were added, similar ones were be merged, while others not considered sufficiently relevant were removed. This process resulted in a total of 116 shortlisted papers. The process of data extraction was done using Microsoft Excel. The Excel table contained each category of the classification scheme. The frequencies of publications in each category were combined into tables containing either "topic/contribution category" or "topic /research type". The analysis focused on presenting the frequencies of publications based on the results obtained from the Microsoft Excel tables.

The purpose of this was to identify which aspect of HPC and Cloud computing were given more emphasis within the various research publications. Consequently, enabling the identification of gaps and providing avenues for further research.

Based on the results obtained from the analysis tables, a bubble plot was generated and used to present these frequencies. The map is a two axes (x and y) scatter plot, with bubbles at the intersection of the various categories. The intersection have bubble sizes proportional to the number of articles in each category in the various intersections It is made up of two halves, with each half offering a visual map based and the intersection of the topic category with either the contribution or research type category. Hence, making it easy to visualize both halves and the different facets simultaneously. Additionally, summary statistics were added to the bubbles, which offered at a glance a holistic overview of articles on the field of study as shown in Figure-2. Table-3 and Table-4 shows the selected primary studies as it relates to the topics, the contribution facet and the research facet. Table-3 and Table-4 treats the literature that fits within each class with a view to substantiating the percentages presented.

Table-3. Topic and contribution facet primary studies.

Contribution Facet / Topic	Metric	Tool	Model	Method	Process
Architecture	PS44	PS18, PS23	PS14, PS16, PS24, PS25, PS26, PS36, PS51		
Virtualization	PS93, PS113,		PS1, PS13, PS76, PS77, PS78, PS81	PS55, PS53, PS56	PS52, PS61, PS74, PS75
Application		PS19, PS21, PS28, PS29, PS96, PS99, PS108, PS109	PS4, PS8, PS12, PS17, PS30, PS33, PS39, PS71, PS83, PS84, PS85, PS86, PS87, PS89, PS90, PS94, PS95, PS102, PS105	PS42, PS43, PS49, PS65, PS68, PS69, PS72, PS73, PS79, PS80, PS82, PS91	
Optimization	PS59		PS34, PS50, PS57	PS35, PS41	PS34, PS63, PS45, PS46, PS47, PS64
Design and Implementation		PS62, PS70, PS98	PS5, PS6, PS10, PS37, PS58, PS111, PS112, PS114, PS115, PS116	PS66, PS67, PS104, PS106	PS88, PS92, PS97, PS107, PS110
Performance	PS2, PS3, PS38,	PS7, PS27			PS15, PS32
Percentage	6.37%	12.50%	43.27%	21.15%	16.35%

4. RESULTS AND DISCUSSIONS

The analysis of the results focuses on presenting the frequencies of publications for each category. This made it possible to identify which categories have been emphasized in past research and to report gaps for future work. The main focus of this systematic study is on HPC and the Cloud and this served as the metric used for analysis. The following subsections discuss the result of the study.

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4.1 Topics category and contribution facet

The topics that were extracted from the abstracts during the classification scheme of HPC and the Cloud are as follows:

a) Architecture.

b) Virtualization.

c) Application.

d) Optimization.

e) Design and Implementation.

f) Performances.

The list of primary studies used for checking the topics against the types of contributions is at Table-3. The systematic maps HPC and the Cloud is at Figure-2. On the x-axis of the left quadrant of Figure-2 is the result of the contribution facet. The contribution facet showed the types of inputs in the field of study. The result indicated that publication that discussed tool in term of mobiles and energy–efficient use of Cloud was 32.5% out of 120 papers in this category. Similarly, metric had 6.67%, model had 30%, method had 15.83% and process had 15%.

From the figure, model discussion contributed 43.27% of all the papers reviewed. Of this 43.27%, 6.73% were model discussions relating to architecture, 5.77% focused on virtualization, 18.27% on applications, 2.88% on optimization, 9.62% on design and implementation and none on performances.

4.2 Topic facet and research category

The list of primary studies used for examining the topics against the types of research is at Table-4. Depicted on the right half on Figure-2 are the results of the various type of researches conducted on the HPC and Cloud. The results showed 38.79% of the surveyed papers were solution proposals, while 15.52% were validation research publications. In addition, 21.55% were validation based, 7.76% were philosophical, 10.34% were experience papers and 6.03% were opinion papers.

In the figure, evaluation research discussions contributed 38.79% of the papers reviewed. Of these 38.79%, 5.17% were evaluating research discussion on architecture, 1.72% focused on virtualization, 18.10% on applications, 2.59% were on optimization, 7.76% focused on design and implementation and 3.45% were on performances.

Table-4. Topic and research facet primary studies.

Research facet / Topic	Evaluation	Validation	Solution	Philosophical	Experience	Opinion
Architecture	PS14, PS16, PS18, PS23, PS24, PS25		PS26, PS36, PS44			PS51
Virtualization	PS93, PS113,		PS1, PS13, PS76, PS77, PS78, PS81	PS52, PS74	PS54, PS55, PS53, PS56	PS61, PS75
Application	PS4, PS8, PS12, PS17, PS19, PS21, PS28, PS29, PS42, PS43, PS49, PS65, PS68, PS69, PS72, PS73, PS91, PS96, PS99, PS108, PS109	PS30, PS33, PS39, PS83, PS84, PS85, PS102, PS105	PS86, PS87, PS89, PS90	PS94, PS95	PS79, PS80, PS82	PS71
Optimization	PS34, PS63, PS64,		PS35, PS41, PS45, PS46, PS47, PS50, PS57, PS59	PS60		PS40
Design and Implementation	PS5, PS6, PS10, PS37, PS111, PS112, PS114, PS115, PS116	PS58, PS62, PS66, PS67, PS70, PS98	PS88, PS92, PS97,	PS104, PS106, PS107, PS110,	, PS100, PS101, PS103,	
Performance	PS2, PS3, PS38, PS48,	PS7, PS20, PS22, PS27	PS31		PS15, PS32	PS9, PS11
Percentage	38.79%	15.52%	21.55%	7.76%	10.34%	6.03%

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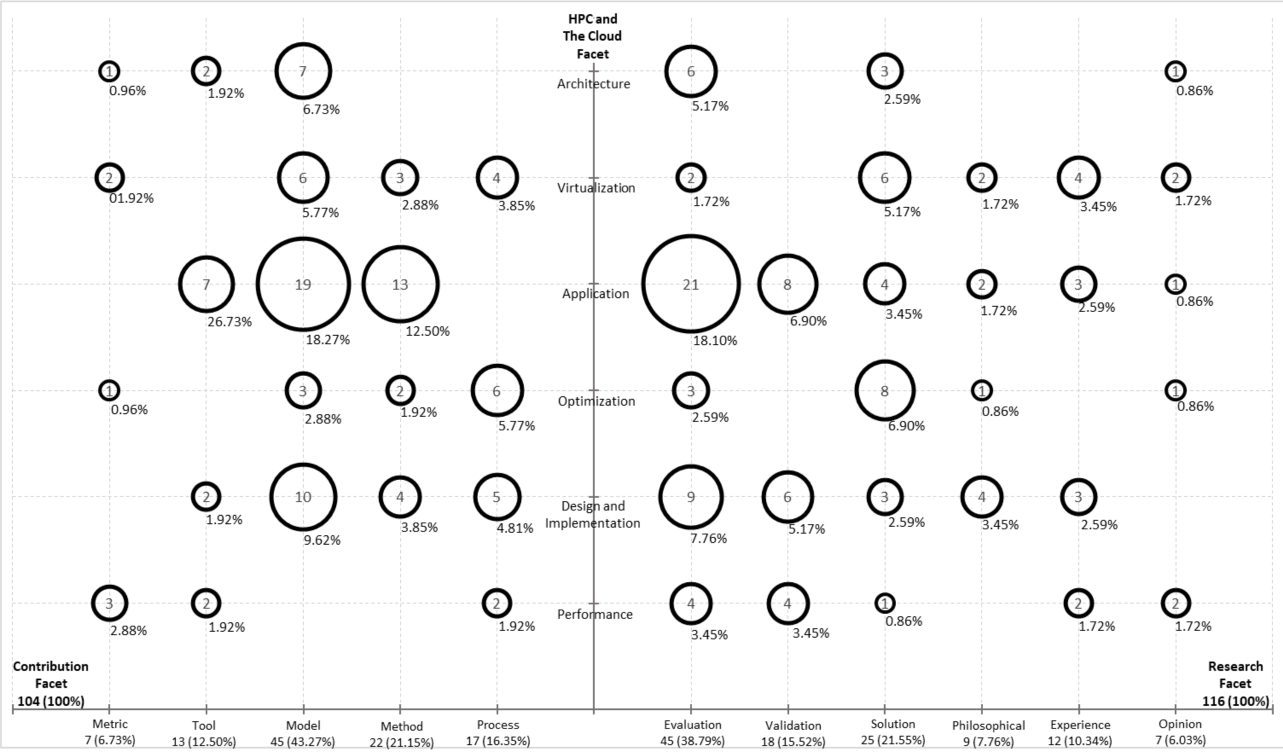

Figure-2. A systematic map on high performance computing and the cloud.

4.3 Systematic map of HPC and the cloud

The result of the analysis carried out and presented on Figure-2, makes it easy to identify which areas had more emphasis based on the frequencies of publications. From the figure, the left half shows a scatter chart with bubbles at the intersection of the topic and contribution facets; while the right half displays the intersection of the topic and research facets. The left half indicated that there were some publications in terms of performances in the aspect of metric with 2.88%, and much more publications on applications relating to tool, model and method with 26.73%, 18.27% and 12.5% respectively. Furthermore, there were more publications on optimization in terms of process with 5.77%.

Similarly, on the second half, there were more articles on application based on evaluation and validation research with 18.1% and 6.9% respectively. Publications on optimization in terms of solution research accounted for 6.9%, while articles on design and implementation that relates to philosophical research were 3.45%. The same percentage was observed for articles on virtualization in terms of experience papers.

On the other hand, there were no articles on the topic of architecture in terms of processes and methods. Similarly, there were also no articles on virtualization in relation to tools, and none for applications in terms of processes and metrics. There were also no articles on design and implementation in the area of metrics and no publications on performances in terms of models and methods.

On the right half of Figure-2, there were no publications on architecture that discussed validation, philosophical and experience research. Also, there were no articles on optimization in relation to validation and experience research. There were also no articles on design and implementation in terms of opinion, and none for performances in terms of philosophical. Overall, the highest frequencies of publication were in the area of evaluation research and models contribution. Articles relating to optimization in terms of metric, model and method are the least with 0.96%, 2.88% and 1.92% respectively. Publications on virtualization in terms of evaluation research were at 1.72%, while articles on performances in terms of solution research were 0.88%. Generally, there were more publications on applications considering the two halves of Figure-2 collectively.

Clearly, this presentation of the systematic map would stir up interest because the visual appeal of the map helps to summarize and provide results to researchers. There is no doubt that the bubble plot results will be quite useful. Suffice to mention, a systematic map without a systematic literate review has a unique value in itself, as it clearly helps to identify research gaps for further studies. This paper has created a systematic map pointing to areas lacking in studies in terms of systematic mapping study of HPC and the Cloud. The relevance of this is that researchers at all levels and industries practitioners can use this as a starting point to conduct further studies. This study provided six classes of studies in the areas of architecture, virtualization, application, optimization, design and implementation, and performances in relation to the focus of study. In addition, the six classes of study can be discussed either in terms of tool, model, method, metric and process or in terms of evaluation, validation, solution, philosophical and opinion research. These areas amongst others are therefore recommended for future research. The list of included references will also assist intending researchers. The important lessons learnt in this study is that research work is a continuum and it is inexhaustible.

5. CONCLUSIONS

The Cloud is a pay-per-use computing paradigm that is producing an ever increasing avenue for use and research. Cloud computing utilization is increasing both in terms of usage by individuals and organizations. The evolving nature of Cloud computing is also leading to numerous research studies especially in the area of High Performance Computing and the Cloud. Despite the volume of research being conducted in this field, there are still shortages of publications in particular topic areas. The results from this study is based on gaps identified in terms of tool, model, method, metric and process in relation to HPC and the Cloud. In addition, the paper identified gaps in the area evaluation, validation, solution, philosophical and opinion research on HPC and the Cloud. Furthermore, the topics of architecture, virtualization, application, optimization, design and implementation, and performances were extracted on HPC and the Cloud. To the best of the authors' knowledge there were no articles on the topic of architecture in terms of process and method. Similarly, there were also no articles on virtualization in relation to tool, and none for applications in terms of process and metric. There were also no articles on design and implementation in the area of metric and no publications on performances in terms of model and method. Furthermore, there were no publications on architecture that discussed validation, philosophical and experience research. Also, there were no articles on optimization in relation to validation and experience research. There were also no articles on design and implementation in terms of opinion, and none for performances in terms of philosophical. This shows that research works are unevenly distributed amongst the various areas. This systematic mapping study has been able to identify some areas where there is less emphasis in terms HPC and the Cloud based on the categories used in the analysis. This paper has therefore contributed to knowledge by indicating different aspects of the study where there are gaps on HPC and the Cloud. The gaps that have been identified are recommended for further studies. It is expected that it will serve as a broad guide into topics that can be researched on in the area of HPC and the Cloud. Further research could also be carried out to validate this study or resolve contradictory issues.

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Appendix: List of Primary Studies

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