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RESEARCH GAPS AND TRENDS IN CLOUD COMPUTING: A SYSTEMATIC MAPPING STUDY
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Abstract
Context: Since 2009 a large number of papers have been presented at IEEE International Conference on Cloud Computing (CLOUD). Studying these papers and identifying relevant research areas from them are both difficult and time consuming. Objective: To address this problem, we aim to provide a structure to the entire collection of full-length papers published in the proceedings of the past CLOUD conferences (from CLOUD 2009 to CLOUD 2014). Method: We undertake a Systematic Mapping study of these papers by categorizing them. Results: 523 relevant papers are selected and assessed in terms of their research topic, contribution and research type. Thematic and frequency analysis is then conducted to identify research gaps and trends. Conclusions: By research topic, technology oriented papers extensively outnumbered business oriented papers. By contribution, methods significantly outstripped other types of contribution whereas there is a desperate shortage of contribution from practical experience. By research type, empirical research papers have dominated the past six CLOUD conferences whereas theoretical research is close to none.
Keywords: Systematic Mapping, Systematic Review, Cloud Computing Research, CLOUD Conferences

1. INTRODUCTION
Emerged around 2006, cloud computing has been quickly embraced by businesses and governments as a new way to deliver IT services over the Internet. Through cloud services, people can access applications from anywhere in the world on demand (Buyya, Yeo, Venugopal, Broberg, & Brandic, 2009). For businesses and organizations, cloud computing offers immediate visible economic benefits, such as cost saving for IT infrastructure and operation, flexible service delivery and reduced carbon emission. Cloud computing is particularly attractive to small and medium-sized businesses, as it enables them to benefit from great computing power without needing to purchase expensive hardware. Since 2011 and for the fifth consecutive year, cloud computing has been constantly identified as one of the top 10 strategic technology trends by Gartner¹.

According to a literature review (Yang & Tate, 2012), first academic papers on cloud computing were published in 2008. Early that year, IEEE Transactions on Services Computing (TSC) added the term “cloud computing” to its body of knowledge areas (Zhang, 2008) and thus officially launched cloud computing as a research discipline within the services computing community. In the same year, IEEE International Conference on Services Computing (SCC 2008) delivered a keynote panel entitled “Business Cloud: Bridging The Power of SOA and Cloud Computing” and a keynote address called “Cloud Computing”. In September 2008, IEEE International Conference on Web Services (ICWS 2008) delivered a keynote on “Web Services: Software-as-a-Service (SaaS), Communication, and Beyond” and a panel on “Cloud Computing and IT as a Service: Opportunities and Challenges”. These events inspired the researchers and practitioners in the areas of service computing and web services to help define and shape the emerging field of cloud computing.

Driven by the industrial force, the first IEEE International Conference on Cloud Computing (CLOUD) was held in 2009. Since then CLOUD conference has become a fixture at annual IEEE World Congress on Services and established itself as the flagship conference in the field. Year by year, the conference has grown from strength to strength and the number of papers presented at this conference has also been increased, from tens to more than one hundred each year. At the last count, there were a total of 636 papers published from CLOUD 2009 to CLOUD 2014.

With the growing number of papers, it becomes important to review and organize these papers, so that they can be easily accessed and digested. Papers that review and organize other papers are called “literature reviews” or “secondary studies”, whereas papers that directly report research results are called “primary studies”. Most papers in the cloud computing field have been primary studies;

¹ http://www.gartner.com/technology/home.jsp
however, with the maturity of the field, it is imperative to produce more good quality secondary studies. Such studies are essential to any discipline, as they aid in “analyzing the past to prepare for the future (Webster & Watson, 2002).” More specifically, they help uncover weak areas where more research is needed, identify saturated areas where researchers should avoid and discover emerging trends for future research directions.

In this paper, we present a secondary study of the papers published at the past six CLOUD conferences (from CLOUD 2009 to CLOUD 2014). Since there are 636 papers, we have chosen to use a specific review methodology called “Systematic Mapping” for our study. Section 2 introduces this methodology, while Sections 3 and 4 present our study using this methodology. Section 5 summarizes the key findings from this study and Section 6 concludes the paper.

2. Systematic Mapping

Systematic Mapping is an evidence-based review methodology for secondary studies (i.e. literature reviews). This methodology uses categorization and thematic analysis to structure and summarize primary studies. It is particularly suitable for providing high-level overviews for large collections of primary studies. This methodology has come from medical research, where it has been used to establish medical evidence in clinical trials, experiments or diseases. It was first introduced to the software engineering field in 2007 (Kitchenham & al., 2007), to help identify evidence for research “clusters” and “deserts” (i.e., gaps) in software engineering research papers (Bailey et al., 2007; Petersen, Feldt, Mujtaba, & Mattsson, 2008).

Systematic Review is another evidence-based methodology frequently used in medical research reviews (Kitchenham & al., 2007). Systematic Mapping and Systematic Review are complementary in that they focus on different levels of granularity, with the former surveying the literature landscape from above and in breadth, the latter scrutinizing a specific area in depth. This complementarity makes these two methodologies good companions for literature review; which one to use depends on the scope and purpose of the review (Kitchenham & al., 2007). This also implies that Systematic Review is not suitable for surveying larger areas, as its attention to detail would require too big an effort to review a large quantity of studies.

Underlying the systematic mapping methodology is a fundamental process that consists of the following essential steps:

1. Defining research questions.
2. Identifying relevant primary studies.
3. Categorizing relevant primary studies.
4. Analyzing and synthesizing results obtained and answering research questions.

This process is supported by several techniques, including: a search strategy to guide literature search, inclusion and exclusion criteria for determining and selecting the relevant primary studies, and a classification method for categorizing the relevant studies.

Secondary studies based on Systematic Mapping are called “systematic mapping studies” (or “mapping studies” for short), whereas those based on Systematic Review are called “systematic reviews”.

Since cloud computing research is still a young area, only a small number of secondary studies have adopted these systematic methods (Carvalho, Neto, Garcia, Assad, & Durao, 2013; daSilva et al., 2013; daSilva, Neto, Garcia, Assad, & Trinta, 2012; González-Martínez, Bote-Lorenzo, Gómez-Sánchez, & Cano-Parra, 2015; Neto & Duarte, 2013; Pallis, 2010; Rimal, Choi, & Lumb, 2009; Yang & Tate, 2012). Given the rising importance of cloud computing and the fast growing number of publications in the field, it is the high time for cloud computing researchers to conduct more such secondary studies to help analyze and synthesize the existing literature, and to produce high quality literature reviews.

With this brief introduction, we can now present our mapping study.

3. A Mapping Study for Cloud Computing

3.1 Research Questions

The main goal of a mapping study is to provide an overview of a research area. Such an overview should identify the quantity and type of publications, show the frequencies and trends of publications over time, and reveal research deserts and clusters. This goal should be reflected in the study’s research questions, to guide the review process. Consequently, as noted in (Petersen et al., 2008), research questions for mapping studies are similar, as they are driven by similar goals. Our research questions are similar to research questions used in two mapping studies presented in (Bailey et al., 2007; Petersen et al., 2008):

RQ1: What topics have been most investigated in the papers published in the past six CLOUD proceedings and how have these changed over time?

RQ2: What types of contribution are most popular in these papers and how have these changed over time?

RQ3: What types of research are dominating these publications and how have these changed over time?

These questions have been used to direct and shape our mapping study and discussion.
3.2 Identifying Relevant Primary Studies

Our search strategy is to identify relevant primary studies from the six proceedings of the CLOUD conferences, from CLOUD 2009 to CLOUD 2014. We have searched these proceedings one by one within IEEE Xplore® Digital Library and obtained 636 papers. To determine and select the relevant studies from these results, we have applied the following inclusion and exclusion criteria:

- **Inclusion:** All full-length papers which report primary studies should be included.
- **Exclusion:** 1) All “Work in Process” papers should be excluded, for the obvious reason. 2) All secondary studies should be excluded.

After evaluating each of the 636 papers against these criteria, 523 papers have been selected as relevant and included in our study. Table 1 lists the search results and selected papers. We have downloaded all 523 papers and their bibliographic details into an EndNote library, from which our mapping study was conducted.

![Table 1. Search Results (N=636) and Relevant Papers (N=523) for CLOUD Proceedings](image)

<table>
<thead>
<tr>
<th>Proceedings</th>
<th>All Papers</th>
<th>Selected Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLOUD 2009</td>
<td>23</td>
<td>17</td>
</tr>
<tr>
<td>CLOUD 2010</td>
<td>77</td>
<td>65</td>
</tr>
<tr>
<td>CLOUD 2011</td>
<td>109</td>
<td>91</td>
</tr>
<tr>
<td>CLOUD 2012</td>
<td>135</td>
<td>116</td>
</tr>
<tr>
<td>CLOUD 2013</td>
<td>148</td>
<td>119</td>
</tr>
<tr>
<td>CLOUD 2014</td>
<td>143</td>
<td>115</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>636</strong></td>
<td><strong>523</strong></td>
</tr>
</tbody>
</table>

3.3 Developing a Classification Schema for Categorization

Categorization is a process of placing things in categories whose members bear some similarity to each other. Categorization can be performed in two ways: top-down and bottom-up. In the top-down approach, a set of categories are defined in a classification schema, so categorization is essentially a process of placing things in appropriate categories under this schema. In the bottom-up approach, categories are unknown to start with and only created during the process of categorization. The bottom-up approach usually uses the “Affinity Diagram” technique (Brassard, 1989) to create categories. The process of affinity works like this: It looks for things that seem to be related and places them into a new group; it then adds more related things to the group. When no more related things could be found, the process moves to create a new group. At the end of this process, each group becomes a category and is given a suitable name.

In our view, the bottom-up categorization approach suffers from a number of problems. First, it is random, as forming similarity groups is subjective and arbitrary. Second, there is no constraint on the number of the categories so we may end up with a large number of small categories, which cannot reveal anything meaningful. Third, the categories formed are individuals, rather than a whole, which defeats the purpose of mapping studies where thematic analysis of related studies is the key to achieve their goal.

The top-down categorization approach is not perfect either, as it tends to create a classification schema that is too general, as its categories are formed a priori, before papers have been studied.

In our study, we have applied both top-down and bottom-up approaches to categorization. From top-down, we have used a predefined classification schema to support a coarse-grained categorization. This schema allows each paper to be classified according to three facets, which are *Topic*, *Contribution* and *Research Type*. Each facet corresponds to a research question.

For each facet, papers are divided into different, mutually exclusive categories. This allows us to identify research clusters and research deserts in a meaningful way. The categories for each facet are formed as follows.

To determine the categories for the *Topic Facet*, we have studied the following publications: the NIST cloud computing standards roadmap (Hogan, Liu, Sokol, & Tong, 2011), the cloud computing open architecture (Zhang & Zhou, 2009), architectural requirements for cloud computing systems (Rimal, Jukan, Katsaros, & Goeleven, 2011), cloud computing taxonomies (Armbrust et al., 2010; Carvalho et al., 2013; daSilva et al., 2013; daSilva et al., 2012; Neto & Duarte, 2013; Pallis, 2010; Rimal et al., 2009; Yang & Tate, 2012), and requirements classification in software engineering (Sommerville, 2004). From these publications we have identified six broad cloud computing topics, concerning Functional Aspect, Non-Functional Aspect, Architectural Aspect, Resource Aspect, Adoption Aspect, and Domain Aspect.

We believe these aspects are high-level, general and comprehensive enough to cover major cloud computing topics; they are also easily separable, because they represent different aspects about the development of cloud computing systems. Most importantly for us, these aspects have equal status and the same level of detail.

For the *Contribution Facet*, we have adopted the categories from (Petersen et al., 2008), which are Method, System, Model, Formal Study, and Experience. We found that these contribution types can represent general contributions in software engineering research. A method can be a process, algorithm or technique. A model can be a conceptual model or design. A formal study can be a theory...
or metric. An experience is a unique contribution, which can be personal experience or lessons learned.

For the Research Type Facet, we have used an existing classification (Wieringa, Maiden, Mead, & Rolland, 2006), which divides research types into Evaluation Research, Validation Research, Solution Proposal, Experience Paper, Philosophical Paper, and Opinion Paper. Although these categories were originally developed to classify requirements engineering research papers (Wieringa et al., 2006), they are also appropriate for classifying research types in systematic mapping studies (Petersen et al., 2008).

This faceted classification schema is shown in Figure 1, and its categories are defined in Table 2.

To complement this top-down classification, we have applied a bottom-up approach to the Topic facet, to create a fine-grained classification of subcategories for each topic category. These subcategories (subtopics) are formed through the aforementioned “Affinity Diagram” technique. For example, subcategories of the Architectural Aspect category include Cloud Architecture and Design, Cloud Middleware, Virtual Machine, and Cloud Maturity Model.

### 3.4 Categorizing Relevant Primary Studies

This step involves sorting the relevant primary studies into different categories within the classification schema. The categories within each facet are mutually exclusive and non-overlapping. This means that each paper can only be classified into one and only one category within each facet. This requirement ensures that the total number of the relevant papers in each facet remains the same (N = 523).

To determine each paper’s category, we have employed the “keywording” technique (Petersen et al., 2008) to profile the paper. This involved reading each paper’s title, keywords, abstract, introduction, and conclusion to establish which category the paper should be placed for each facet. When we could not decide, we would briefly read other sections of the paper or discuss with each other. We carried out this step iteratively to ensure that our classification is as accurate as possible.

This step is also called “data extraction” or “mapping”. The results of this step are presented as “a systematic map”, which is a visual representation of the distributions and statistics of different categories and their relationships. Such a map serves as an overview of the mapping study. A mapping study normally produces multiple systematic maps, each showing a particular perspective of the mapping results.

The categories of the 523 papers obtained from this mapping study will be made available at the journal website. Our mapping results have been analyzed in multiple ways and presented in complementary visual representations, as follows:
<table>
<thead>
<tr>
<th>Facet</th>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topic</td>
<td>Functional Aspect</td>
<td>This topic deals with the functional aspect of Cloud Computing applications development, such as cloud services (IaaS, PaaS, SaaS, XaaS), cloud deployment (public, private, hybrid cloud), measurements, and application &amp; tool support.</td>
</tr>
<tr>
<td></td>
<td>Non-Functional Aspect</td>
<td>This topic addresses the non-functional or quality aspect of Cloud Computing systems development, including trust, security, privacy, data integrity &amp; protection, performance, reliability, availability, scalability, elasticity, fault-tolerance, and usability.</td>
</tr>
<tr>
<td></td>
<td>Architectural Aspect</td>
<td>This topic covers the architectural aspect of cloud systems, including cloud architectures &amp; design, programming language, virtual machine, virtualization, middleware, cloud compliancy &amp; standards, and cloud maturity model.</td>
</tr>
<tr>
<td></td>
<td>Resource Aspect</td>
<td>This topic concerns the resource aspect of cloud systems development, including managing, controlling and using cloud computing resources, such as resource utilization &amp; management, energy efficiency, job &amp; resource scheduling.</td>
</tr>
<tr>
<td></td>
<td>Adoption Aspect</td>
<td>This topic addresses the issues related to using, adopting Cloud Computing, and migrating to the cloud, including cloud adoption, cloud migration, cloud broker, contracts &amp; SLAs, cost, pricing, billing, accounting.</td>
</tr>
<tr>
<td></td>
<td>Domain Aspect</td>
<td>This topic addresses the development of domain-specific applications on Cloud Computing, including eScience, weather applications, mobile applications.</td>
</tr>
<tr>
<td></td>
<td>Contribution Type</td>
<td>Method</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Model</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Formal Study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experience</td>
</tr>
<tr>
<td>Research Type</td>
<td>Evaluation Research</td>
<td>This type of research investigates a practical problem and provides an implemented solution. It uses a sound research method (case study, field study, field experiment, survey, or mathematical proof/logic reasoning) to validate the knowledge claim. The paper presents sufficient discussion of related work and provides insights into lessons learned.</td>
</tr>
<tr>
<td></td>
<td>Validation Research</td>
<td>This type of research differs from evaluation research in that the techniques investigated are novel and have not yet been implemented in practice. The investigation uses a thorough, methodologically sound research setup. Possible research methods are experiments, simulation, prototyping, mathematical analysis, mathematical proof of properties, etc.</td>
</tr>
<tr>
<td></td>
<td>Solution Proposal</td>
<td>This type of research proposes a solution technique and argues for its relevance, without a full-blown validation. The technique must be novel, or at least a significant improvement of an existing technique. A proof-of-concept may be offered by means of a small example, a sound argument, or by some other means.</td>
</tr>
<tr>
<td></td>
<td>Experience Paper</td>
<td>This type of research reports personal experiences or case studies of one or more projects that have been completed and provides lessons learned. The experience reported must be original and relevant to practitioners.</td>
</tr>
<tr>
<td></td>
<td>Philosophical Paper</td>
<td>This type of research is philosophical in nature, and sketches a new way of looking at existing things by structuring the field in the form of a taxonomy or conceptual framework.</td>
</tr>
<tr>
<td></td>
<td>Opinion Paper</td>
<td>This type of research contains the author’s opinion about what is wrong or good about something, how we should do something, etc.</td>
</tr>
</tbody>
</table>
Systematic maps were used to show the number of papers for each category and the distributions of the papers across different years. Three systematic maps are provided, one for each facet of classification. These maps are represented as Matrix Bubble Charts\(^2\) (shown in Figures 2 – 4).

Tables were used to show the distributions of the papers across different categories within each facet and the percentages of these distributions (see Tables 3 – 5).

Charts were used to depict the trends of the papers over time (Figures 5 – 7).

In Section 4, we analyze our mapping results and answer our research questions.

## 4. Results

The results are presented in order of the research questions posed. For each question, we conduct a frequency and thematic analysis of the publications to reveal research gaps and trends.

### 4.1 Research Topics

**RQ1**: What topics have been most investigated in the papers published in the past six CLOUD proceedings and how have these changed over time?

To answer the first part of the question, we analyzed the distributions of papers by topics, as shown in Table 3. According to the table, the most investigated topic is “Functional Aspect” (197 papers, 38%), followed by “Non-Functional Aspect” (107 papers, 20%). The least investigated topic is “Domain Aspect” (21 papers, 4%), followed by “Adoption Aspect” (53 papers, 10%).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional Aspect</td>
<td>197</td>
<td>38%</td>
</tr>
<tr>
<td>Non-Functional Aspect</td>
<td>107</td>
<td>20%</td>
</tr>
<tr>
<td>Architectural Aspect</td>
<td>75</td>
<td>14%</td>
</tr>
<tr>
<td>Resource Aspect</td>
<td>69</td>
<td>13%</td>
</tr>
<tr>
<td>Adoption Aspect</td>
<td>53</td>
<td>10%</td>
</tr>
<tr>
<td>Domain Aspect</td>
<td>22</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>523</td>
<td>100%</td>
</tr>
</tbody>
</table>

Functional and non-functional aspects are related to Cloud Computing technologies and so are architectural (75

\(^2\) Our Matrix Bubble Charts are based on a template from: https://goo.gl/8EW0zD
papers, 14%), and resource aspects (69 papers, 13%). On the other hand, cloud adoption and domain applications are related to business issues of cloud computing. This suggests that the most heavily published papers at CLOUD conferences are in technological categories, whereas the least published papers are in business categories. One reason for this lopsided emphasis on the technology aspects might be that cloud computing is still a relatively new paradigm and hence still facing many technological challenges (Hogan et al., 2011; Pallis, 2010; Wei & Brian Blake, 2010; Q. Zhang, Cheng, & Boutaba, 2010).

However, a serious shortage of papers on business issues indicates a lack of business perspective in the field (Yang & Tate, 2012). Given that cloud computing has been widely viewed as “utility computing” (Buyya et al., 2009; Foster, Zhao, Raicu, & Lu, 2008), more research effort needs to be stepped up to reduce this rather worrying gap.

To answer the second part of the question, we analyzed the trends of papers over time. Figure 5 shows that since 2009 the number of papers on “Functional Aspect” has been growing rapidly, consistently and farther apart from papers in other categories. Figure 5 also shows that this growth trend will continue. By contrast, the number of papers on cloud adoption and domain applications has been consistently low over the past six years. Overall, the gap between the technology categories and the business categories has become even wider over the course of the past six years.

4.2 Contribution Types

RQ2: What types of contribution are most popular in these papers and how have these changed over time?

To answer the first part of the question, we analyzed the distributions of papers by contribution types, as shown in Table 4. According to this table, the most popular contribution type is “Method” (234 papers, 45%), followed by “System” (106, 20%). The least popular contribution type is “Experience” (6 papers, 1%).

We noted that the contributions on systems and models are predominately made by researchers from the industry (this information was obtained from the author affiliation of the papers). This finding is extremely positive, as it demonstrates that the CLOUD conferences have a strong industry engagement.

However, the shortage of papers in the “Experience” category indicates a lack of participation by practitioners in cloud computing research. This is a serious research gap in current CLOUD conferences.

To answer the second part of the question, we analyzed the trends of the papers by contribution type over time. Figure 6 shows that since 2011, papers in the “Method” and “System” categories have continuously outnumbered other types of paper, and by stark contrast, the number of papers in the “Experience” category has almost been negligible. No papers on “Formal Study” and “Experience” were published in 2009. Since 2011 there has been a healthy growth in the “Formal Study” category. The number of papers on “Model” was peaked in 2010 but has since been reduced gradually. An interesting observation is that the decrease in the “Model” papers correlates with the increase in the “System” papers and this might indicate that some of

Table 4. Distributions of Papers by Contribution Types

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>234</td>
<td>45%</td>
</tr>
<tr>
<td>System</td>
<td>106</td>
<td>20%</td>
</tr>
<tr>
<td>Model</td>
<td>99</td>
<td>19%</td>
</tr>
<tr>
<td>Formal Study</td>
<td>78</td>
<td>15%</td>
</tr>
<tr>
<td>Experience</td>
<td>6</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td>523</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure 5. Trends of papers for different topics.

Figure 6. Trends of papers for different contributions.
the proposed models have subsequently been implemented into systems.

4.3 Research Types

**RQ3: What types of research are dominating these publications and how have these changed over time?**

To answer the first part of the question, we analyzed the distributions of papers by research types, as shown in Table 5. According to the table, “Validation Research” dominates the publication population with 361 papers (69% of all publications), while at the other end of the scale there are only 10 “Philosophical” papers (2% of all publications) and 6 “Experience” papers (1% of all publications). There is no “Opinion Paper” – perhaps this type of research has not been accepted by the CLOUD conferences so far.

The lack of experience papers is directly linked to the gap in the “Experience” contribution type, as described in Section 4.2.

The shortage of philosophical papers indicates a lack of theory building work in cloud computing. Since “Validation Research”, “Evaluation Research” and “Solution Proposal” can be grouped into empirical research, our mapping results have identified a vast gap in theoretical research.

**Table 5. Distributions of Papers by Research Types**

<table>
<thead>
<tr>
<th>Research Type</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation Research</td>
<td>77</td>
<td>15%</td>
</tr>
<tr>
<td>Validation Research</td>
<td>361</td>
<td>69%</td>
</tr>
<tr>
<td>Solution Proposal</td>
<td>69</td>
<td>13%</td>
</tr>
<tr>
<td>Experience Paper</td>
<td>6</td>
<td>1%</td>
</tr>
<tr>
<td>Philosophical Paper</td>
<td>10</td>
<td>2%</td>
</tr>
<tr>
<td>Opinion Paper</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>523</td>
<td>100%</td>
</tr>
</tbody>
</table>

To answer the second part of the question, we analyzed the trends of the papers by research type over time. Figure 7 shows that since 2009, the use of “Validation Research” has risen sharply and grown further apart from other types of research. This trend seems to continue. The use of “Solution Proposal” type of research was peaked in 2011 (with 28 papers) and has since been declined. No “Experience” and Philosophical papers were published in 2009 and the both types of paper remain to be extremely scarce throughout the review period.

5. Discussion

In this section, we summarize our key findings and discuss validity concerns to our study.

5.1 Key Findings

The results of our mapping study indicate the following gaps in cloud computing:

1. **Gap between technology development and business uptake:** The purpose of the first research question (RQ1) is to understand the collection of publications in terms of their research topics. Our answer shows that 86% of the papers addresses technology aspects (Functional Aspect, Non-functional Aspect, Architectural Aspect, and Resource Aspect) whereas only 14% papers dealing with business aspects (Adoption Aspect and Domain Aspect). This enormous gap must be closed in order for cloud computing to have an impact on businesses.

2. **Gap between academic research and industrial practice:** The second research question (RQ2) is to understand the purposes of these selected papers through their contribution types. Our answer shows that among five types of contribution, the Method type draws 45% of the papers whereas at the other end of the scale the Experience type only attracts 1% of the papers. This serious shortage of the contribution from practical experience indicates a lack of participation from cloud computing practitioners at the CLOUD conferences. A potential danger of this is the isolation of cloud research from practice.

3. **Gap between theoretical research and solution proposals:** The third research question (RQ3) is to investigate the type of research conducted by these papers. Our answer shows that Validation Research alone pulls 69% of the papers and outstripped all
other types of research combined. Overall, 97% of the papers use empirical research methods.

It is interesting to note that our mapping results accord with the findings of Yang and Tate (Yang & Tate, 2012). This is very significant, at least statistically. Although these two mapping studies were conducted for different periods (theirs from 2008 to 2011 and ours from 2009 to 2014) and had different scopes (journal articles versus CLOUD conference papers), the agreement between the results of these two studies suggests that the landscape of cloud computing has remained more or less the same since 2008. It also suggests that our study, albeit being focused on a specific community, also reflects a general trend in cloud computing research.

5.2 Interesting Correlations
During our study we have observed some interesting correlations between contribution types and research types:

- **Between “Method” and “Validation Research”:** Method papers tend to use validation research.
- **Between “Formal Study” and “Validation Research”:** Formal study papers also tend to use validation research.
- **Between “System” and “Evaluation Research”:** System papers tend to use evaluation research.
- **Between “Model” and “Solution Proposal”:** Model papers tend to use solution proposal research.
- **Between “Experience” and “Experience Paper”:** Experience papers are indeed experience papers.

These relationships may be useful for researchers to design their research, as by choosing a particular type of contribution to make, researchers can predetermine the type of research validation that needs to be undertaken. These relationships may also be useful for paper reviewers, as by understanding the type of contribution a paper claims to make, reviewers can expect the type of research validation to be reported in the paper.

5.3 Validity Concerns
A common threat to the validity of systematic mapping studies is that the papers are not exactly what “it says on the tin”. According to (Mendes, 2005), 73% of the papers were designed incorrectly; for example, they promised an experiment but had no experiment. The same problem was also reported by other authors (Jorgensen & Shepperd, 2007), who found that the term “experiment” was not always used in line with the definition of controlled experiments. In our mapping study, we found that the term “framework” was used loosely to mean a range of different things, such as method, model, architecture, formal study, and application development framework. Similarly, the term “method” was not always used in line with the definition of methods. Consequently, as noted in (Petersen et al., 2008), systematic mapping studies, when not evaluating the papers in detail, may make judgmental errors and hence classify the papers into wrong categories.

In our study, we have mitigated this threat by conducting a more detailed evaluation to the papers that we could not establish their categories through keywording. In addition, we performed the categorization iteratively by double-checking or treble checking of the mapping results. Yet, as stated in (Petersen et al., 2008), this threat can only be minimized in systematic reviews because of their in-depth evaluation of the papers. Our mapping study has identified an extremely large number of papers for the Method type of contribution and an exceptionally high number of Validation Research papers, and future refinement could be to conduct systematic reviews in these two specific areas to gain a detailed insight into these papers.

6. Conclusions
This paper has made several contributions to cloud computing research. First, it has presented a major mapping study of the 532 papers published in the six previous CLOUD conference proceedings (from CLOUD 2009 to CLOUD 2014). To the best of our knowledge, this is the first study that covers the entire collection of full-length papers published in these proceedings. The mapping results obtained from this study, including research gaps, trends and themes (topics, contribution types and research types) can help the CLOUD community to shape its future research directions and to conduct further secondary studies.

Second, this paper has introduced Systematic Mapping to cloud computing research as a methodology for secondary studies and illustrated the process of this methodology step by step in our mapping study. The faceted classification schema developed for this study and the detailed analysis of the mapping results by means of different visual techniques are useful examples for cloud computing researchers to conduct future mapping studies.

Third, this paper has made a contribution to the development of a cloud computing taxonomy, by proposing a novel classification of cloud computing topics, based on different aspects of concerns, rather than specific technical issues. Such a classification is more natural and extensible.

Finally, the ultimate goal of this mapping study is to provide a basis for further research and for shaping research directions in cloud computing. For example, the topic categories and subcategories obtained from this mapping study can serve as a basis for many in-depth systematic reviews, with each review focusing on a particular category or subcategory; the gaps identified from this study can inform further primary research. We encourage our fellow researchers to use our mapping results for their research and together we can build a strong cumulative research culture for our field.
7. References


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