Ten Years of Research on Fault Management in Grid Computing: a Systematic Mapping Study

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Abstract—
BACKGROUND: There is a large body of literature on research about fault management in grid computing. Despite being a well-established research area, there are no systematic studies focusing on characterizing the sorts of research that have been conducted, identifying well-explored topics as well as opportunities for further research.

OBJECTIVE: This study aims at surveying the existing research on fault management in grid computing in order to identify useful approaches and opportunities for future research.

METHOD: We conducted a systematic mapping study to collect, classify and analyze the research literature on fault management in grid computing indexed by the main search engines in the field.

RESULTS: Our study selected and classified 257 scientific papers and was able to answer five research questions regarding the distribution of the scientific production over the time and space.

CONCLUSIONS: The majority of the selected studies focus on fault tolerance, with very few efforts towards fault prevention, prediction and removal.

I. INTRODUCTION

Grid computing allows the integration and coordination of resource sharing, such as software, data and peripherals among dynamic collections of users and organizations, supporting dynamic and multi-institutional environments, named virtual organizations [1] [2].

Grids are more prone to failure than traditional computing platforms. In a grid environment there are potentially thousands of resources, services and applications that need to interact in order to make possible the use of the grid as an execution platform. Since these elements are extremely heterogeneous, there are many failure possibilities [3].

Over the years, several studies have described research efforts applied in fault management in computational grids. However, there are no records of studies focused on the systematic collection and classification of the previous works conducted in the area able to help in the identification of well-explored research topics and gaps that may represent new research opportunities. This work focus on solving this problem by conducting a systematic mapping study on fault management in grid computing.

A systematic mapping study is a secondary study that allows the researcher to have a consistent view of the scientific production on a given area, helping with the evaluation and interpretation of the selected primary studies [4]. This study methodology has been extensively used in evidence based medicine and just recently started to be used also in the information technology field, initially in the software engineering area [5].

This paper is organized as follows: Section 2 presents the research protocol used to conduct the study. Section 3 describes the execution of the systematic mapping study. Section 4 presents the results of our mapping study and answers the proposed research questions and section 5 concludes the paper with our final remarks.

II. RESEARCH PROTOCOL

Systematic mapping studies aim at providing an overview of a research area to assess the quantity and type of primary studies existing on a topic of interest [6]. The first step to start a systematic mapping study is the construction of the research protocol that will detail the methodology that must be followed in the research. We present now a research protocol that covers all the essential steps to conduct a systematic mapping study as pointed by Petersen et al. [5]: (i) definition of research questions, (ii) collection of the relevant primary studies, (iii) screening of collected papers, (iv) keywording of abstracts and (v) data extraction and mapping.

A. Research questions

Our main objective is to identify the distribution and characterization of the scientific literature on fault management in grid computing. In order to achieve this objective we proposed the following five RQ (research questions):

RQ1 How the publications about fault management in grid computing are distributed over the years?
RQ2 What are the main places to publish?
RQ3 What is the participation of industry and academia in the selected publications?
RQ4 Which research topics are most explored at the intersection of these two areas (grids and fault management)?
RQ5 What research methods are used in these studies?

B. Search strategy

The search strategy should reflect the research objectives in order to filter through a search string the studies indexed by search engines. The search engines used for this research were:

Table I shows the query string used to search for the primary studies on the selected search engines.

<table>
<thead>
<tr>
<th>TABLE I. SEARCH STRING</th>
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<tbody>
<tr>
<td>(&quot;error&quot; OR &quot;failure&quot; OR &quot;fail&quot; OR &quot;fault&quot;)</td>
</tr>
<tr>
<td>AND</td>
</tr>
<tr>
<td>(&quot;grid computing&quot; OR &quot;computing grid&quot; OR &quot;grid environment&quot; OR &quot;grid task&quot; OR &quot;grid application&quot; OR &quot;grid middleware&quot; OR &quot;grid fabric&quot; OR &quot;grid connectivity&quot; OR &quot;grid resource&quot; OR &quot;grid system&quot; OR &quot;grid service&quot; OR &quot;computational grid&quot; OR &quot;grid job&quot; OR &quot;grid collective&quot; OR &quot;grid toolkit&quot;)</td>
</tr>
</tbody>
</table>

C. Screening of the selected papers

Screening aims at determining which primary studies are relevant to answer our research questions [7]. We applied a set of exclusion criteria to each study. The EC (exclusion criteria) devised and applied were:

EC1 Works with irrelevant content in relation to the research area (each work must involve fault management and grid computing);
EC2 Duplicated works among the different search engines. The fist one found is included, the duplications are discarded;
EC3 Incomplete studies;
EC4 Works not written in English;
EC5 Works that are not primary studies.

D. Taxonomy

We present a taxonomy with different categories and subcategories that describes how we classify the selected works regarding its localization in the grid protocol stack, its research type, the objective of the work and the fault management strategy used to achieve this objective. Our taxonomy is based on the taxonomy defined by R. Wieringa et al. [8], A. Avizienis et al. [9] and the grid architecture defined by I. Foster [10].

Our taxonomy is divided into 4 parts, as shown in figure 1.

Fig. 1. Taxonomy to classify the studies

1) Grid architecture: The grid protocol stack defined by I. Foster [10] consists of 5 layers, however, after a short screening of the studies included in the research, we decided to summarize it in just 3 layers in order to facilitate the classification of works. The figure 2 shows our taxonomy compared with the grid protocol stack defined by I. Foster.

2) Research type: The research type defines what kind of research and results are described in the paper:

- Evaluation research: This is the investigation of a practical problem or implementation of a practical technique. Includes also works such as survey, case studies, etc.
- Proposal of solution: The paper proposes a novel solution technique or at least a significant improvement of an existing technique.
- Validation research: This paper investigates the properties of a solution proposal. Possible research methods are experiments, simulation, mathematical analysis, etc.
- Philosophical paper: The paper deals with a new conceptual solution or theory.
- Personal experience paper: The paper should contain a list of lessons learned by the author from his or her experience.

3) Attributes and functions: The terms used to classify the fault management refers to the definition of dependability, which is the ability to deliver service that can justifiably be trusted [9]. The attributes that support dependability are:

- Availability: readiness for correct service.
- Reliability: continuity of correct service.
- Integrity: absence of improper system alterations.
- Maintainability: ability to undergo modifications and repairs.

The functions to achieve dependability are:

- Fault prevention: means to prevent the occurrence or introduction of faults.
- Fault tolerance: means to avoid service failures in the presence of faults.
- Fault removal: means to reduce the number and severity of faults
- Fault forecasting: means to estimate the present number, the future incidence, and the likely consequences of faults.

III. RUNNING THE MAPPING STUDY

The selection and classification process was divided into three stages:
Stage 1: The title, abstract and keywords are used to identify the primary studies related to fault management in grid computing. In this stage we applied all exclusion criteria in order to remove duplicate and clearly irrelevant works returned by the search engines.

Stage 2: After the initial filtering in stage 1, the introduction and conclusion sections are used to identify those studies with great potential to be included in the research and to discard unrelated works.

Stage 3: After the elimination of works on stage 1 and 2, in this stage the remaining works are classified according to the proposed taxonomy.

During the selection process, the first two authors analyzed independently each of the selected works. The third author was involved only when there was a disagreement regarding the exclusion of a given paper, when he then acted as a tiebreaker. The total of studies analyzed in each stage is shows in figure 3.

Fig. 3. Stages of the selection process

IV. RESULTS

In this section we present the results achieved with the classification of the 257 scientific papers selected for the study. Each paper was classified according to the proposed taxonomy and this classification helped us to identify well-explored topics and gaps that may represent opportunities for future research.

Figures 4 and 5 present the source of the papers according to the search engines before and after the selection process. IEEExplore had the best recall, being responsible for almost 69% (179 in 257) of the selected papers. However, the ScienceDirect was the most precise search engine, with almost 17% of the returned papers (23 over 135) being included in the study. For comparison, the precision of the SpringerLink search engine was around 0.55% (25 over 4477).

A. RQ1 - How the publications about fault management in grid computing are distributed over the years?

In 2009 Dabrowski [11] published a study reporting that in recent years, the body of work on grid reliability produced by researchers and practitioners in academic and industry has increased steadily. Accord to figure 6, we observed that this growth reported by Dabrowski occurred until 2010, but in 2011 there was a large drop in the amount of papers focusing on grid reliability.

Fig. 6. Distribution of the research papers over the years

B. RQ2 - What are the main places to publish?

We observed that 198 (77%) of the selected studies were published in conferences, and just 59 (23%) in journals. Table III shows that the Future Generation Computer System journal was the place with the highest number of publications. Altogether, we identified 120 conferences and 28 journals.

TABLE II. TOP 13 OF MAIN PLACES OF PUBLICATION

<table>
<thead>
<tr>
<th>Description</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future Generation Computer Systems</td>
<td>12</td>
</tr>
<tr>
<td>International Symposium on Cluster Computing and the Grid</td>
<td>11</td>
</tr>
<tr>
<td>International Symposium on Parallel and Distributed Processing</td>
<td>11</td>
</tr>
<tr>
<td>International Conference on Grid and Cooperative Computing</td>
<td>9</td>
</tr>
<tr>
<td>Journal of Grid Computing</td>
<td>9</td>
</tr>
<tr>
<td>The Journal of Supercomputing</td>
<td>7</td>
</tr>
<tr>
<td>International Conference on e-Science and Grid Computing</td>
<td>6</td>
</tr>
<tr>
<td>International Symposium on High Performance Distributed Computing</td>
<td>6</td>
</tr>
<tr>
<td>International Conference on Parallel and Distributed Computing, Applications and Technologies</td>
<td>5</td>
</tr>
<tr>
<td>International Parallel and Distributed Processing Symposium</td>
<td>5</td>
</tr>
<tr>
<td>International Conference on Emerging Technologies</td>
<td>4</td>
</tr>
<tr>
<td>International Conference on Grid Computing</td>
<td>4</td>
</tr>
<tr>
<td>Journal of Parallel and Distributed Computing</td>
<td>4</td>
</tr>
</tbody>
</table>

These 13 journals and conferences were responsible for the publication of 33.76% of the selected papers.

C. RQ3 - What is the participation of industry and academia in the selected publications?

To answer this question we recorded the affiliations of the authors of the selected papers. According to figure 7, the academy demonstrates greater interest in fault management in grid computing.

A step further into the author’s affiliations showed that University of São Paulo in Brazil had the largest number of authors of the selected papers. The top 13 list is presented in table 4.
In the group of studies related to fault tolerance, we identified that the main techniques adopted in grid environments are: Checkpoint, Replication and Retrying. Few studies are related to Message Logging technique.

The study described in [13], assigned to Fault Tolerance and Personal Experience in our Functions and Type of Research facets, describes a flexible fault-tolerance mechanism implemented on the Integrate grid middleware that allows the customization and the combination of different fault tolerance techniques resulting in: retrying (without checkpoint or replication), checkpointing, replication (without checkpointing), and replication with checkpointing.

The vast majority of studies focused on fault forecasting used strategies based on the past occurrences of faults. One example of such strategy was the development of resource brokers that used the information about occurrences of faults on the available resources as a scheduling criteria, achieving a near optimal solution to decrease the probability of a fault [14].

Another study, published 2006, proposed a fault forecasting solution based on data-mining techniques [15].

Figure 8 shows several gaps related to fault prevention and fault removal and these functions may represent interesting opportunities for future research.

Figure 9 summarizes the amount of studies according to the Functions facet items.

Regarding the fault removal function, we found studies proposing to remove fault during the software development phase [16] and during the production phase [17], both based on the utilization of automated software.

In figure 10 we combine the Grid Architecture (y-axis) and Functions (x-axis) facets and showed the related dependability attribute inside the pie-charts.

We identified that 230 of the 257 studies targeted the grid middleware layer. We could also conclude that availability and reliability are two most explored dependability attributes.

Most studies focused on improving Availability used replication as a technique to tolerate faults. Despite being a known technique used also to improve integrity, only 14 studies have explored this possibility.

Among these 14 studies, we found [18], which proposed a solution named BonjourGrid. This solution was intended to create customized environments for each user based on a diversity of grid middleware and used replication to improve the reliability of the grid infrastructure.
V. CONCLUSION

This paper presented a systematic mapping study providing an overview of existing research on fault management in grid computing. We selected 257 scientific papers published on a ten-year window, from 2002 to 2012.

The classification of these scientific works helped us to identify how the scientific production is distributed over the years and to recognize what are the most used places for publication. We could also pinpoint well-explored topics and some gaps that may represent good opportunities for further research on fault management in grid computing.

We conclude that allow the grid to work even in the presence of faults was the main objective pursued by researchers over the last ten years. Fault tolerance techniques were vastly explored. On the other hand, very little effort have being put on techniques able to predict on prevent the occurrences of faults.

The next step of our research is intended to investigate the under represented research topics, seeking to understand the reasons for the lack of published work.

ACKNOWLEDGMENT

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VI. APPENDIX A

The table IV presents the studies listed by the facets shown in figure 8. The studies referenced in table IV are available at the public link: http://goo.gl/tW3GYP.
TABLE IV. REFERENCES LISTED BY TYPE STUDY AND FUNCTIONS FROM FIGURE 8

<table>
<thead>
<tr>
<th>Research Type versus Solution</th>
<th>1999-2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault tolerance</td>
<td>[1-113]</td>
</tr>
<tr>
<td>Fault forecasting</td>
<td>[7], [38], [46], [48], [58], [77], [93], [96], [114-120]</td>
</tr>
<tr>
<td>Fault prevention</td>
<td>[46], [47], [97], [99], [103], [110], [121-126]</td>
</tr>
<tr>
<td>Fault removal</td>
<td>[127-129]</td>
</tr>
</tbody>
</table>

TABLE V. REFERENCES LISTED BY ARCHITECTURE OF GRID AND FUNCTIONS

<table>
<thead>
<tr>
<th>Application layer</th>
<th>1999-2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault tolerance</td>
<td>[2], [5], [6], [9], [17], [23], [26], [28-31], [33], [35], [38], [40], [46], [50], [73], [79], [82], [89], [92], [99], [104], [109], [113], [140], [142-144], [151], [153], [157], [172], [182], [187], [213], [214], [224], [227], [231], [232], [239], [241], [244], [246], [247]</td>
</tr>
<tr>
<td>Fault forecasting</td>
<td>[38], [46], [120], [198]</td>
</tr>
<tr>
<td>Fault prevention</td>
<td>[46], [99], [140], [239]</td>
</tr>
<tr>
<td>Fault removal</td>
<td>[127219], [133], [206]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Middleware layer</th>
<th>1999-2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault tolerance</td>
<td>[1], [3], [4], [7-16], [18-21], [24-28], [33], [34], [37], [38], [40-68], [70-72], [74-78], [80], [81], [83-85], [88], [91], [93-98], [100-103], [105], [107-112], [131-141], [146-150], [152-156], [159-168], [170], [171], [174-186], [188], [189], [191], [210-212], [214-217], [219-227], [230], [232], [233], [235], [238], [240], [242], [243], [245], [247-256]</td>
</tr>
<tr>
<td>Fault forecasting</td>
<td>[7], [38], [46], [48], [58], [77], [93], [96], [114-116], [118-120], [159], [185], [195-198], [200], [243], [257]</td>
</tr>
<tr>
<td>Fault prevention</td>
<td>[46], [47], [97], [103], [110], [121-126], [140], [200], [201], [203], [205]</td>
</tr>
<tr>
<td>Fault removal</td>
<td>[133], [237]</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Fabric layer</th>
<th>1999-2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault tolerance</td>
<td>[22], [90], [211], [235]</td>
</tr>
</tbody>
</table>

REFERENCES


