Containers in Software Development: A Systematic Mapping Study

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Abstract. Over the past decade, continuous software development has become a common place in the field of software engineering. Containers like Docker are a lightweight solution that developers can use to deploy and manage applications. Containers are used to build both component-based architectures and microservice architectures. Still, practitioners often view containers only as way to lower resource requirements compared to virtual machines. In this paper, we conducted a systematic mapping study to find information on what is known of how containers are used in software development**.** 56 primary studies were selected into this paper and they were categorized and mapped to identify the gaps in the current research. Based on the results containers are most often discussed in the context of cloud computing, performance and DevOps. We find that what is currently missing is more deeply focused research.

Keywords: Containers, Software Engineering, Systematic Mapping Studies

1 Introduction

Over the past decade, continuous software development has become a common place in the field of software engineering. New toolchains have emerged to manage the complexity in continuous deployment activity. Containers are a lightweight solution that developers can use to deploy and manage applications [1]. Containers are often seen as a more light-weight alternative to Virtual Machines (VMs) [2]. Virtual Machines include the operating system where containers don't, allowing the containers to provide system resource usage advantages when compared against VMs [3].

The usefulness of containers is not limited to them being a more lightweight version of Virtual Machines. One interesting feature of the containers is that they provide portability [1] and thus modularity, making them suitable for working as software components [4] or as autonomous microservices [5]. When software systems grow, they encounter three problems:

1. Maintaining the software becomes harder
2. Adding new features to the system slows down
3. The resource requirements for the software grow

One option to address these problems is to make systems modular [6]. In modular systems software is split into smaller modules and the full software systems are built by combining different modules [7]. Component-based software architecture and microservice architecture allow developers to build more modular software [7, 8]. In component-based architecture systems are created by connecting different software components [9]. Components are required when the system is compiled, and they are loaded when the system starts. Because of this, component-based systems don't help with the growing resource requirements, but it makes maintaining the software easier.

Similar to components, microservices are autonomous services that together fulfill a business requirement [5]. Also, like component-based architecture, each microservice is required for the system to be fully functional. Since containers are not compiled as part of the software system, they could be used as way to build plug-in based architecture where containers-based plugins could provide new functionality into existing software and they could be added and removed runtime [10-12]. Based on our observation, containers are used to build both component-based architectures and microservice architectures [1, 5]. Still, containers are often viewed as way to lower resource requirements compared to Virtual Machines [3].

As using containers in software development is a new research area, the need for a systematic mapping study is crucial in order to summarize the progress so far and identify the gaps and requirements for future studies. In this paper we present a systematic mapping study of how containers are used in software development. In this research, we conducted a systematic mapping study to find information for the key question: What is currently known of **how containers are used in software development.** This paper is the first part of a larger study. The aim of this study is to learn if containers are used mainly as a lightweight replacement for the virtual machines or if their portability and low resource usage is used to build container-based software components. Next parts of this study will include a multi-vocal study [13] and a case-study [14].

The rest of this paper is structured as follows. Section 2 introduces the research methodology. Section 3 presents our key results. Section 4 provides discussion based on the results. Section 5 presents threats to validity of this research. Section 6 draws conclusions.

2 Research Methodology

Systematic Mapping Study (SMS) [15] is used in this paper to identify the gaps in the literature and identify where new or better primary studies are needed for using containers. This paper follows systematic mapping guidelines provided by [15-18].

The process of systematic mapping study can be split into multiple phases:

1. Defining the research questions
2. Conducting search
3. Study selection (Screening the papers)
4. Defining the classification scheme
5. Data extraction

6. Systematic mapping of the data using the classification scheme

The following figure 1 illustrates the process of this systematic mapping study:

Fig. 1. Systematic Mapping Study Process

The following sections are used to describe SMS from this study's perspective.

2.1 Definition of research questions

First task was the definition of research question (RQ). The research questions are listed in Table 1.

Table 1. Research questions

RQ number	Question	Motivation
RQ 1	How Containers are used in Software Development?	The question allows us to get the what is known of how containers are used in software development. What technologies are used and what software development problems are containers used to tackle.
RQ 1.1	Are containers used to modularize software system, either through component-based architecture or through microservices architecture?	Based on our observation, containers could be used to architecture software systems. Still, the practitioners mostly seem to discuss containers as a technology for handling software's infrastructure.
RQ 1.2	Are containers used to provide plugin-support for software systems?	Based on our observation, containers could be used to extend existing plugin-architecture based software systems.

2.2 Conduct Search

After defining the research questions relevant search terms and data sources were defined.

Search terms. Without correct search terms correct literature and research cannot be found. Table 2 lists the search terms used in this study. The following steps were used to create the search terms, as defined in [19]:

- Derive major terms from the questions by identifying the population, intervention and outcome.
- Identify alternative spellings and synonyms for major terms.
- Check the keywords in any relevant papers we already have.
- Use the Boolean OR to incorporate alternative spellings and synonyms.
- Use the Boolean AND to link the major terms from population, intervention, and outcome.

Table 2. Search terms

"container" OR "containers" OR "docker" OR "Kubernetes"
AND
"software engineering" OR "software design"

Data sources and search criteria. For this research only formal data sources were considered. These included papers and journals from the four digital libraries: IEEExplorer, ScienceDirect, SpringerLink and ACM Digital Library. The reason for selecting these sources is that they are important sources of computer science related research. Search terms were matched against title, keywords and abstract.

The search was performed between 22th of May and 5th of June in 2019. In total 3504 results were found. Results were exported into bibtex-format and loaded into reference manager.

Table 3. Results before study selection process

Library	Results
IEEEXplorer	120
ScienceDirect	1095
SpringerLink	889
ACM Digital Library	1400

Study Selection. After finding the initial results, the next phase of the SMS was study selection. The main goal of the study selection is to find select relevant studies that properly address the research questions. As displayed in Table 4, in this study 5 inclusion criteria and 7 exclusion criteria were used.

Table 4. Study selection criteria

Inclusion criteria	Exclusion criteria
• Studies that are presented as full paper. • Studies that focus on using modern containers in software development.	• Studies that are duplicate • Studies that are presented as short paper. • Studies that do not provide abstract

• Studies that compare containers and virtualization. • Studies that are related to Docker. • Studies that are related to Kubernetes	• Studies that are not peer-reviewed • Studies that are not written in English • Studies that are not related to the software engineering. • Studies that are not related to modern Docker-style containers. For example, articles related to Java containers or Inversion of Control Containers.

Of the 3504 results, 60 were removed as duplicates. Two-step selection process was used to filter out the irrelevant studies for this paper. First of each study the title was reviewed using inclusion and exclusion criteria. Each excluded study was marked as such. After this step, 3308 studies were filtered out and the second step was applied to the remaining 136 studies. In this step of each study abstract was skimmed through. In this second step, 80 studies were excluded.

In total, 56 studies [20-75] were selected as the primary studies of this paper.

Classification schema. The selected primary studies and the research questions were used to create the classification scheme for this study. Based on a qualitative assessment, research classification approach from [76] was used to classify the papers. The classifications are listed in more detail in table 5.

Table 5. Research type facet adapted from [76]

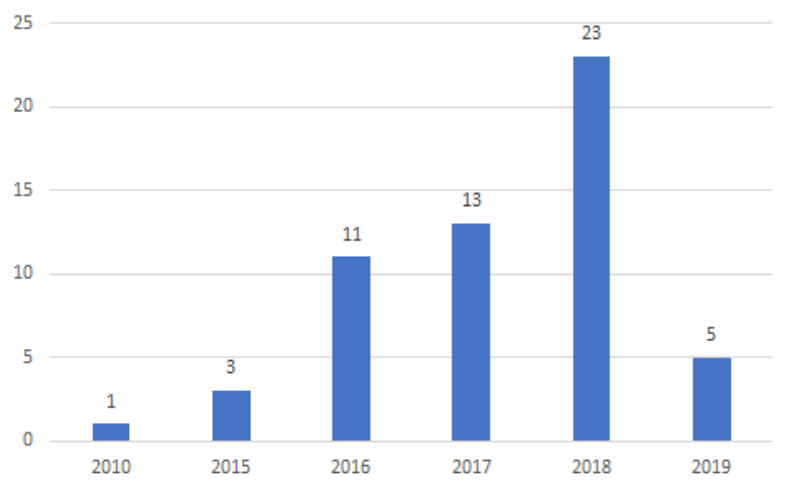
Research type	Description
Evaluation research	Type of paper which investigates a problem in practice.
Solution proposal	A paper which presents a solution for a problem. Benefits of the solution are described.
Validation research	Paper which investigates the properties of a solution that has not yet been implemented.
Experience report	Paper based on work done in practice. Describes what and how something has been done personally by the author.
Opinion	Paper based on the opinion of the author. Opinion articles do not rely on research methodology.

Data extraction. After using the primary studies and the research questions to create the classification schema, relevant data was extracted from the studies based on the classification schema. Title, author (first), year of publication, keywords, abstract and research type were extracted from each paper.

3 Results

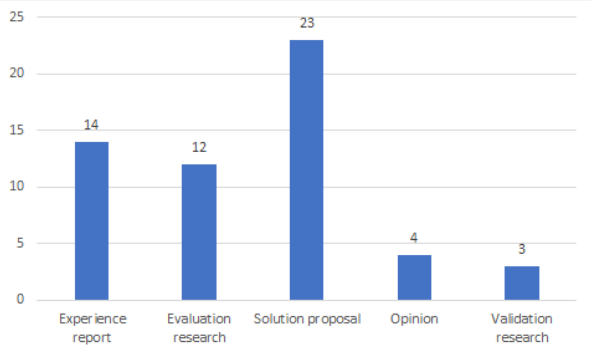
In this section the results are presented found in this mapping study are presented. Of the initial amount of 3504 papers, 56 were selected as the primary papers for this study.

Fig. 2. Articles by year



Papers were mapped into the classification schema presented earlier in this study. The results presented in Figure 3 of this mapping indicate that solution proposal is the most common paper when containers are discussed.

Fig. 3. Paper research types



Experience reports and evaluation research complete the top 3 of research types. Also, few validation research and opinion papers were found. Next, results are validated against the research questions.

3.1 RQ 1 How are Containers used in Software Development?

First research question was set to assess how containers are used in software development. The initial opinion of this study was that containers are often used as a lightweight alternative to virtual machines.

Keywords were extracted from each article's title and abstract. These keywords were then grouped together into different categories which were identified by generalizing the keywords. Table 6 presents the list of generalized categories. Each study belongs to one or more categories.

Table 6. Categories

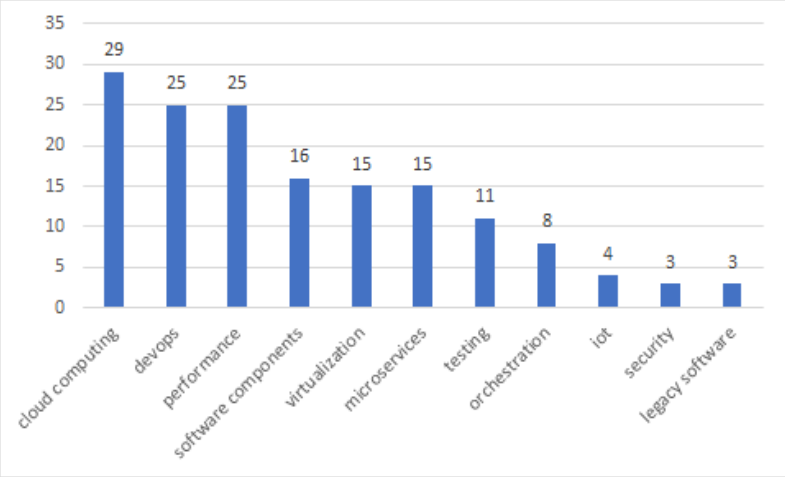
Focus	Keywords
Software Components	Modules, Packages, Artifacts, Bundle, Component
Cloud Computing	Cloud, PaaS, SaaS, Cloud Infrastructure, Cloud environment, Cloud platforms
DevOps	DevOps, CI, CD
Performance	Scalability, I/O, CPU, Scaling, Replication, resources, GPU, Resource contention, performance
Security	Security, Password, Secure
Microservices	Microservice-architecture, Microservices, Micro-service
Legacy Software	Modernization, Legacy
Orchestration	Orchestration, Docker Swarm, Kubernetes
Testing	Testing, Benchmark, Software Quality
IoT	IoT, Internet of Things
Plugin	Plugins, Addon, Extensions
Virtualization	Virtualization, Virtual Machine, VM

Based on the results, containers are most often discussed in relation to cloud computing, performance and devops (Figure 4). More than 50% of the papers discussed containers in context of cloud computing. Performance related aspects and devops discussed in 45% of the papers. Most of the papers do not focus on a single category. Instead, only 13 papers belong to a single category as shown in Table 7.

Table 7. Number of categories and number of papers

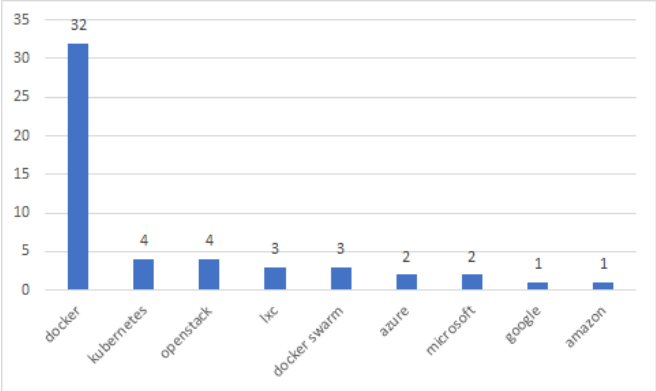
# of categories	# of papers
2	14
3	14
1	13
4	8
6	4
5	3

Fig. 4. Articles by categories



If we look at specific technologies (Figure 5) and companies discussed in the papers, we can see that Docker dominates the field. More than 57% of articles mention Docker in their abstract or in their title.

Fig. 5. Articles by Container Technology or Organization



3.2 RQ 1.1 Are containers used to modularize software system, either through component-based architecture or through microservices architecture?

The motivation of the first sub research question was to find out if containers are discussed in relation of software architecture. 16 of the 56 papers discuss containers from software component's point of view. Also, microservices are discussed in 15 papers (Figure 4). This clearly indicates that containers used to modularize software

system, either through component-based architecture or through microservices architecture.

3.3 RQ 1.2 Are containers used to provide plugin-support for software systems?

The motivation of the second sub research question was based on our observation that containers could be used to extend existing plugin-architecture based software systems. Even though 20% of the articles mentioned software components, we didn't find any indications that containers are used to create plugin-based software architecture.

4 Discussion

The implications of this systematic mapping study are described in the following sub sections.

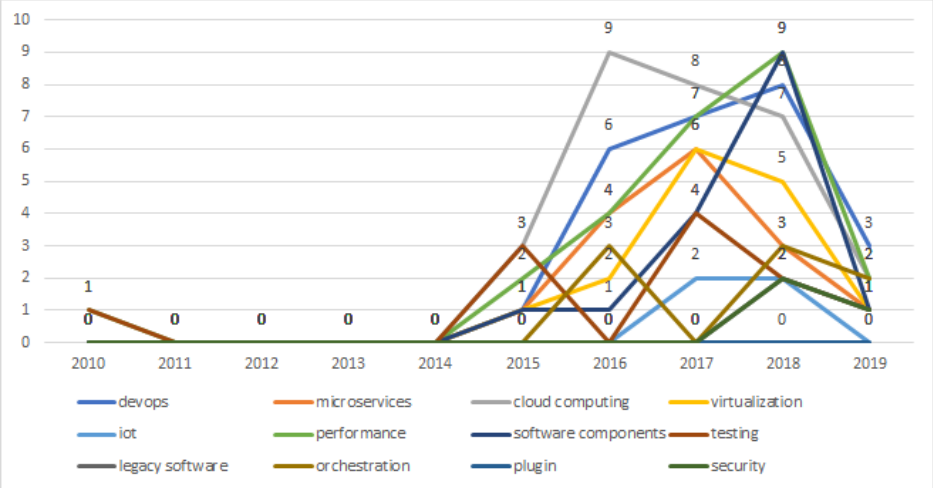
4.1 Research in using containers in software development

Results indicate that the number of container related articles is growing (Figure 2). 70% of the studies have been released between 2017 and 2019. There are multiple indicators that research on using containers in software development is a new research area:

1. First primary study found for this research is from 2010.
2. Number of research papers is rapidly growing.
3. Current research often covers multiple software development categories instead of focusing into a single category.
4. Research papers often start by describing what software containers are. This is an indication that the technology is seen as new by researchers and an introduction to the technology is required.
5. Most of the research focuses on a single container technology, Docker.

In summary it can be said that containers are a new research area. The amount of research has been growing steadily and there's no indication that in 2019 research related to containers is going to slow down.

Fig. 6. Trends of using containers in software development



4.2 More focused research

Only 13 of the selected 56 primary studies focus their research on one category. 52% of the primary studies are related to three or more categories. It's clear that there is room for more focused research. Many of the categories are large topics and instead of research covering multiple large categories, research could focus on a single category like container security, container performance and using containers for devops.

4.3 Potential research avenues

As seen in Figure 4, cloud computing, devops and performance related discussion are most common in current container research. There are multiple gaps or less-researched categories which provide potential research avenues:

- Container security
- Legacy applications and containers
- Container-based plugin technologies

Solution proposals, experience reports and evaluation research are currently the most popular research types. Together they make 88% of the primary studies selected for this research. This may indicate that containers are currently used to solve existing problems related to software development. The lack of validation research supports this as validation research could be used to test new ideas.

Figure 5 shows that Docker is the dominant technology used in research. Even though there are studies like [74] which compare Docker to other container technologies, there's room for more research. Best practices-based papers are helpful for the

industry: they help those organization who are already using containers and those who are just starting to use them. Only [35] provides best practices of using containers.

5 Threats to validity

In this section the threats of validity of this research are discussed. Also selected mitigation strategies are discussed. Three potential threats of validity were identified:

Search. This study is based on the search results provided by research databases and their search engines. Because of this, the results are subject to the limitations of the search engines. We mitigated this by using four different research databases.

The keywords selected for this study are subject to search term bias. Two different container related technologies were named in the search terms and this may have affected search results, causing these two technologies to be more prevalent in the search results. Search term bias was mitigated by including generic search terms.

Identification of the primary studies. The selected inclusion and exclusion criteria listed in Table 4 may have affected the identification of the primary studies. For example, only papers written in English were selected. Also, not all the studies related to containers in software development are available from the used research databases. Risk of excluding primary studies was mitigated by using multiple research databases.

Data extraction. Categories in chapter 7 were selected by the researcher after keywords were extracted. Researcher acknowledges that if there are errors in keyword extraction, this may invalidate the categorization of the keywords. To mitigate the keyword extraction and categorization, keywords were extracted multiple times and the selected categories were identified only after keyword extraction.

6 Conclusion

This paper is a part of larger study. The aim of the study is to learn if containers are used mainly as a lightweight replacement for the virtual machines or if their portability and low resource usage is used to build container-based software components. In this paper a systematic mapping was performed to examine what is known of how containers are used in software development. The next part of this research is a multivocal study. The research will conclude with a case study.

Four research databases were used to locate 3504 papers of which 56 were selected as the primary studies. The results indicate that cloud computing, devops and performance are the driving forces of container related discussion. Of the 56 primary studies 52% discussed cloud computing, 48% performance and 45% devops. Docker is currently the leading technology in container-based software development. 57% of the papers mentioned Docker in their title or in their abstract. Other container related technologies were mentioned at most in 7% of the papers.

As an answer to RQ 1.1, 55% of the primary studies mentioned software components or microservices. This clearly indicates that containers are used to modularize software system, either through component-based architecture or through microservices architecture. As the examination of RQ 1.2 indicated, no papers discussing the usage of containers for plugin-based architectures were found.

The findings of this paper indicate that using containers in software development is a new research area. Most of the studies don't focus on a single software development category. Instead, they often present introduction on what containers are, clearly indicating that software containers are seen as a new technology. Also, best practices-based research is not yet widely available.

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