Cloud migration process—A survey, evaluation framework, and open challenges

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A B S T R A C T

Moving mission-oriented enterprise software applications to cloud environments is a crucial IT task and requires a systematic approach. The foci of this paper is to provide a detailed review of extant cloud migration approaches from the perspective of the process model. To this aim, an evaluation framework is proposed and used to appraise and compare existing approaches for highlighting their features, similarities, and key differences. The survey distills the status quo and makes a rich inventory of important activities, recommendations, techniques, and concerns that are common in a typical cloud migration process in one place. This enables both academia and practitioners in the cloud computing community to get an overarching view of the process of the legacy application migration to the cloud. Furthermore, the survey identifies a number challenges that have not been yet addressed by existing approaches, developing opportunities for further research endeavours.

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1. Introduction

Many enterprise software applications that support IT functions are characterized by the need for high computing capability, scalability, and resource consumption (Buyya et al., 2009; Armbrust et al., 2010). In recent years, cloud computing initiatives have received significant attention towards addressing these requirements through offering services in various forms such as SaaS (software as a service), PaaS (platform as a service), and IaaS (infrastructure as a service) which are universally accessible, acquirable, and releasable on the fly, and payable on the basis of service usage amount. Given these advantages, many IT-based organisations have been interested in moving their legacy assets to cloud environments. It is estimated that the global cloud computing market will grow from $40.7 billion in 2011 to $241 billion in 2020 (Ried and Kisker, 2011). So far, a significant collection of research has been devoted to this topic by both academia and practitioners ranging from pure technical-centric solutions related to the using of cloud services, to research around the social and non-technical impact of the cloud as a new emerging paradigm. However, studies that focus on designing approaches offering a process model (method-

ology) for the cloud migration have not yet received much attention. Several studies such as Mohagheghi et al. (2010), Chauhan and Babar (2012) and Jamshidi et al. (2013) suggest that a well-defined process model for supporting the migration (or development) and maintaining working legacy applications to the cloud is a key concern. A rigorous approach is particularly important when moving large scale and complex legacies which have been in operation and stored critical data over the years. Moving legacies to the cloud raises many concerns such as security, interoperability, and vendor lock-in.

Legacy applications often predate the cloud computing and thus have been developed without taking into account the characteristics of cloud environments. The complexity of migration is exacerbated by the fact that some legacy applications may have been developed without taking into account the unique requirements attributed to cloud environments such as elasticity, multi-tenancy, interoperability, and cloud service/platform selection. Such requirements raise new challenges that entail to improve conventional software (re-engineering) development methodologies or to choose ones that address these specific requirements towards making a legacy application cloud-enabled. Various projects and studies in the cloud computing community have been suggested in order to enable legacy applications to utilize cloud services. A well-structured methodology can aid developers to carry out an effective and safe application migration, instead of struggling to understand "what" and "how" to carry out such a transition in an ad-hoc

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manner which may latter result in poor and erroneous migration and maintenance overhead. A methodological approach can be acclaimed as promising mean for tackling the cloud migration complexities and move from an ad-hoc cloud migration to a structured and step by step quality methodology. In this spirit, Laszewski and Nauduri (2011), who are the designer of a methodology for moving Oracle legacy applications to the cloud, mention: *Like any software development project, migration projects require careful planning and good methodology to ensure successful execution.* A similar recommendation is stated in the final report of REMICS project, which is a three years research project supported by the European Commission and focuses on a methodological support for moving legacy applications to cloud platforms (Benguria et al., 2013). The above report mentions that *in the beginning it [legacy migration] was motivated by the lack of documentation, but in the last years it has been motivated by adaptation to new technologies. Each new technology has required new and renewed approaches and technologies to address the migration process in a more effective way.*

As will be elaborated in Section 2.3, there are several surveys in the literature each focuses on different aspects of cloud migration such as interoperability, techniques and tools for migration, and cloud architecture design. Although these surveys provide a partial understanding of certain aspects of the legacy to cloud migration, they do not provide a complete picture of how the cloud migration is to be carried out and organised from the perspective of the process model. There is not yet a rigorous analysis of the extant material on this aspect of the cloud computing. For this reason and regarding the fact that the interest for legacy application migration to the cloud grows, there is a need to contribute a survey that distills existing cloud migration approaches by identifying their common characteristics and varying motives, concomitant activities, and empirical findings. This survey will differ from existing related surveys (Section 2.3) by focusing on the process aspect of the cloud migration to understand what essential activities and concerns are involved during such a transition. By comprehensively reviewing existing cloud migration approaches, we thus position this survey as the newest reference point for the cloud computing research and practice. Accordingly, the current study will attempt to answer the following research questions:

- **RQ1.** What are the existing approaches proposing a migration model for moving legacy applications to cloud environments in the literature?
- **RQ2.** What is the current state of these approaches w.r.t. the proposed evaluation framework introduced in Section 3?
  RQ2.1. what generic criteria, as typically expected for a software development methodology, are supported by these approaches?
  RQ2.2. what cloud-specific criteria are supported by these approaches?

RQ1 is motivated by the need to describe the state of the art of cloud migration approaches. This gives readers an overall understanding of approaches' core idea, their objectives, and a concise description of them. RQ2 was formulated to characterise as well as highlight the focus of approaches with respect to two dimensions. (See Section 3). More specifically, RQ2 aims to answer two sub-research questions RQ2.1 and RQ2.1.

RQ2.1 assesses generic criteria that any process model would need to address regardless of its application genre. RQ2.2 is related to the evaluation of cloud-specific aspects of available migration approaches. This decomposition is a first step in the synthesis of the evaluation framework which we will later use to identify and highlight a rich collection of key activities and recommendations that existing approaches include. In summary, the contributions of this paper are the following:

- To provide a deep understanding of the current state of migration approaches proposed in the literature, understand insightful activities and recommendations to be learned,
- To help both researchers and practitioners in the cloud community if they want to capture key facets of existing approaches and select or discard one or collection of them that may suit their needs for a particular migration exercise, and
- To give a broad view of research challenges, specifically concerned with process models for the legacy to cloud migration that need to be investigated by researchers. Hence, a gateway to new research opportunities can be opened.

This paper is structured as follows: In Section 2, we give a general review of terms related to the cloud migration, key challenges that need to be addressed in a typical migration process, and the related work to this paper. Section 3 describes proposed evaluation framework designed for the purpose of this paper. Section 4 presents the research methodology that was adopted to conduct the current study. Section 5 reports the findings of the review after identifying the existing approaches from the literature. Section 6 discusses the remaining challenges and promising directions for future research. Section 7 presents the limitations of this survey. Finally, Section 8 concludes this paper.

2. Background and related work

As with all new areas of study, an etymological analysis is instructive. This is first undertaken in this section to give some clarity as to what a cloud migration and methodology mean in the context of cloud computing (Section 2.1). This section then identifies technical and organisational concerns of the legacy to cloud migration (Section 2.2) and provides a review of surveys related efforts (Section 2.3).

2.1. Etymology

- *Cloud migration and methodology*. In software engineering (SE) a software development methodology can be defined as a *systematic way of doing things in a particular discipline* (Gonzalez-Perez and Henderson-Sellers, 2008). Another definition can be borrowed from Avison and Fitzgerald (2003): *a recommended collection of phases, procedures, rules, techniques, tools, documentation, management and training used to develop a system.* A methodology organises the coordination of development team members, integration of project activities, and specifies when certain activities, which contains sequence and input/output artifacts, should be carried out.
  Migration of legacy applications to the cloud signifies that an organisation has already in place existing software applications earmarked to take advantages of cloud services. A common understanding of the term *cloud migration*, as offered by Chauhan and Babar (2012), is the reengineering process of legacy applications for becoming cloud-enabled. That is, migration to the cloud is a kind of software reengineering where the target application will be able to interact or become integrated with cloud services. Another definition, offered by Andrikopoulos, views the cloud migration process as a set of architectural adaptations/modifications required to ensure a legacy application becoming cloud-compliant (Andrikopoulos et al., 2013). Similarly, Kwon et al. pose the term *cloud refactoring* in which code transformation mechanisms are used to integrate legacy applications and cloud services (Kwon and Tilevich, 2014). Another yet broader and workable definition, which covers both technical and non-technical aspects of the cloud migration is suggested by Pahl et al. (2013) as: *A cloud migration process is a set of migration activities carried to support*