A Model-Driven Approach to Reengineering Processes in Cloud Computing

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Context. The reengineering process of large data-intensive legacy software applications (legacy applications for brevity) to cloud platforms involves different interrelated activities. These activities are related to planning, architecture design, re-hosting/lift-shift, code refactoring, and other related ones. The cloud computing literature has seen the emergence of different methods with a disparate point of view of the same underlying legacy application reengineering process to cloud platforms. As such, effective interoperability and tailoring of these methods become problematic due to the lack of integrated and consistent standard models.

Objective. We introduce a novel framework called *MLSAC (Migration of Legacy Software Applications to the Cloud)* that aims at the facilitation of sharing and tailoring reengineering methods within software teams using a set of coherent, common recurring, and empirically tested cloud-specific method fragments grounded in the literature. This set, which is organized into a generic method along with instantiation guidelines, can be further reused to create and maintain bespoke reengineering methods for a given reengineering scenario to cloud platforms.

Approach. MLSAC is underpinned by a metamodeling approach that acts as a representational layer to express reengineering methods for migrating legacy applications to cloud platforms. The design and evaluation of MLSAC are conducted based on the guidelines in the design science research approach.

Results. Our framework is an accessible guide of what legacy-to-cloud reengineering methods can look like. The efficacy of the framework is demonstrated by modeling real-world reengineering scenarios and obtaining user feedback. Our findings show that the framework provides a fully-fledged domain-specific, yet platform-independent, foundation for the semi-automated representation, maintenance, share, and tailor of reengineering methods. MLSAC contributes to the state of the art of cloud computing and model-driven software engineering literature through (a) enabling a basis for the benefit of reengineering methods and processes within the cloud computing community and (b) providing a collection of mainstream method fragments to incorporate into various reengineering scenarios.

Keywords. Metamodeling, Model-driven software engineering, Reengineering process, Method engineering, Cloud computing

1 Introduction

The reengineering processes used for making legacy applications cloud-enabled involve various interacting elements such as tasks, procedures, people, resources, and many more [1],[2]. A variety of facets and concepts of those elements transpire such as legacy application code refactoring, interoperability across multiple cloud platforms, architecture design, optimized distribution of application components over cloud servers to name a few [3]. On the other hand, in practice, method engineers who oversee such processes need to know many of these concepts but, in practice, they apply only a subset appropriate to an on-going reengineering project [4],[5],[6]. If method engineers are newcomers to the cloud computing field, it may not always be clear what exact tasks and responsibilities should be performed before, during, and after migrating legacy applications to the cloud. The complexity of the transition to cloud platforms and accounts of breakdowns in cloud migration have been highlighted in many examples [7],[8]. Indeed, some IT-based organizations have even been unfortunate and forced to move back their cloud-enabled applications to on premises, i.e., de-migrated, after they failed to attain anticipated goals [9]. Among others, failures are often rooted in the lack of timely expertise, inapplicability, and negligibility of past reengineering experience. Former cloud migration experiences are sometimes deemed general, limited to legacy application type/domain, specific to a cloud platform provider, e.g., Amazon, IBM, Cisco, and confined to a particular type of service delivery model, e.g. IaaS (Infrastructure as Service), PaaS (Platform as a Service), and SaaS (Software as a Service). Moreover, the requirements of a migration context itself may be quite project-specific and heterogeneous in terms of the choice of service delivery model, security, and scalability. Naturally, method engineers may find off-the-shelf reengineering methods, individually, incomplete in supporting the overall reengineering process or they may encounter the issue of nonconformity among these methods due to competing requirements and different viewpoints to reengineering processes.

We refute the suggestion that the extant reengineering methods (e.g., [3], [10]) for the cloud migration are not suitable or individually selectable but we use their benefits via a synergistic combination of these methods. Instead of creating a comprehensive and universal reengineering approach applicable to all reengineering scenarios, which is likely infeasible [11],[12],[10], we advocate the development of a foundational middle knowledge layer that pulls together various dispersed and ad-hoc models describing reengineering processes to cloud platforms. As we will discuss, this view looks outward and claims that cloud-specific reengineering processes exhibit similar underlying concepts, development tasks, and axiomatic commonalities, though they vary in execution details such as the choice of cloud platforms and expressed terminologies. However, such conceptual links have not yet been exposed nor fully exploited to enable extensible and tailorable methods for a legacy to cloud migration, despite the need shown by the earlier research [3],[13].

Against this backdrop, we leverage the model-driven software engineering (MDSE) approach [14]. We use *metamodeling* [15],[16], a particular component of MDSE [17], that is used to model, integrate, and maintain the different blueprints of congruent and consistent software engineering methods (or methodologies) [15],[18],[19]. This has been an encouraging factor for this research to cumulatively build on prior metamodeling research [20] and to develop a new metamodel specific to legacy application reengineering to the cloud. Our proposed framework is called *Migration of Legacy Software Application to the Cloud* (MLSAC). It provides a unified viewed of reengineering methods with the following benefits:

(i) providing a collection of pre-made and reusable method fragments (or process fragments), organized into generic models, that allow creating cloud-specific bespoke reengineering methods or at least changes to existing methods; and

(ii) facilitating communication among software teams and the consistent maintenance and interoperability of evolving reengineering methods.

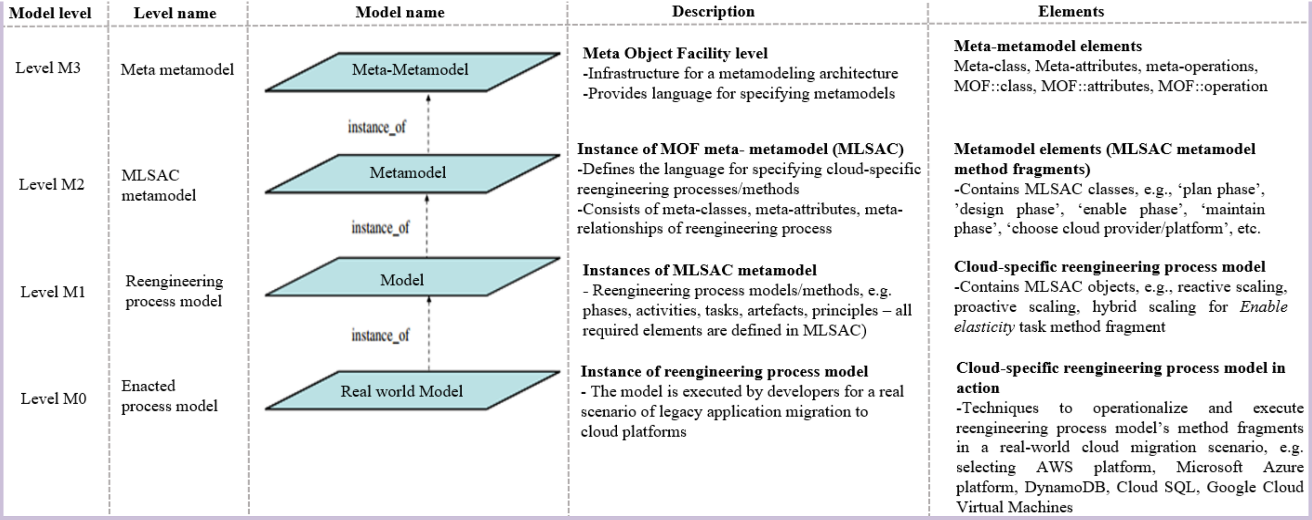
MLSAC idea, which is in line with the *separation of concerns design principle* [21] in the software engineering discipline, is cloud platform agnostic. It enables method engineers to concentrate on the method design and leave the method operationalization and variations for a particular scenario open to the software team's decision [15],[22].

We applied the Design Science Research (DSR) approach [23], [24] to conduct this research. Through DSR approach, we show the expressive power of the proposed MLSAC as a language infrastructure in different real-world reengineering scenarios such as EclipseSCADA in Australia and Hackystat SensorBase service in the US. Additionally, we discuss the application of MLSAC in a range of reengineering scenarios by our industry partners in Australia. The evaluation results confirm the merits of our framework in a practical context. These also highlighted further research opportunities.

In Section 2, we present a reengineering scenario that shows the key motivation of this research. This is followed by a discussion on the background of MDSE and metamodeling underpinning the theoretical foundation for the proposed framework in Section 3. Section 4 presents the framework design in line with the guidelines to conduct a DSR approach. The application of MLSAC framework in a three-step evaluation is discussed in Section 5. Related works are discussed in Section 6. Finally, this paper ends in Section 7.

2 Motivating Scenario

Consider an exemplar scenario of a cloud migration project EclipseSCADA [25], a supervisory control and data acquisition legacy application that was moved to a private IaaS cloud named NeCTAR in Melbourne. EclipseSCADA is a class of Internet of Things (IoT) based systems [26],[27] allowing administrators to monitor an industrial system remotely via sensors and actuators. The cost of application maintenance was relatively high as it was running on dedicated in-house infrastructure. The top-level management was interested in moving EclipseSCADA workload from in-house hosted servers to flexible and cheaper models offered by cloud services in the marketplace. EclipseSCADA's components were planned to be deployed across Melbourne



Model level	Level name	Model name	Description	Elements
Level M3	Meta metamodel	Meta-Metamodel	**Meta Object Facility level** -Infrastructure for a metamodeling architecture -Provides language for specifying metamodels	**Meta-metamodel elements** Meta-class, Meta-attributes, meta-operations, MOF::class, MOF::attributes, MOF::operation
Level M2	MLSAC metamodel	Metamodel	**Instance of MOF meta- metamodel (MLSAC)** -Defines the language for specifying cloud-specific reengineering processes/methods -Consists of meta-classes, meta-attributes, meta-relationships of reengineering process	**Metamodel elements (MLSAC metamodel method fragments)** -Contains MLSAC classes, e.g., 'plan phase', 'design phase', 'enable phase', 'maintain phase', 'choose cloud provider/platform', etc.
Level M1	Reengineering process model	Model	**Instances of MLSAC metamodel** - Reengineering process models/methods, e.g. phases, activities, tasks, artefacts, principles – all required elements are defined in MLSAC)	**Cloud-specific reengineering process model** -Contains MLSAC objects, e.g., reactive scaling, proactive scaling, hybrid scaling for *Enable elasticity* task method fragment
Level M0	Enacted process model	Real world Model	**Instance of reengineering process model** - The model is executed by developers for a real scenario of legacy application migration to cloud platforms	**Cloud-specific reengineering process model in action** -Techniques to operationalize and execute reengineering process model's method fragments in a real-world cloud migration scenario, e.g. selecting AWS platform, Microsoft Azure platform, DynamoDB, Cloud SQL, Google Cloud Virtual Machines

Figure 1. OMG four abstraction levels of hierarchy

and Tasmania NeCTAR cloud regions, i.e., hardware components such as sensors deployed in Tasmania servers and software components were hosted in Melbourne servers. A method engineer took the responsibility to rule out a base method for the software team as the guideline for refactoring and re-hosting EclipseSCADA components. Such a method could ensure the consistency of reengineering tasks and the team's outputs. The method could be enacted by the software team to enable EclipseSCADA to utilize NeCTAR cloud services. The developers could enact the method, though it was up to them to choose tools, development libraries, and implementation techniques to operationalize the method. The design of such a base method that could ensure a safe EclipseSCADA reengineering over multiple iterations was a challenging exercise due to issues such as:

Challenge 1. The design of an overall base reengineering method would need knowledge about several aspects such as understanding legacy application architecture, creating a new architecture model based on NeCTAR cloud, resource scaling, code refactoring according to NeCTAR, and so on. Unfortunately, the domain knowledge about the cloud migration is dispersed in the (multi-vocal) literature and, in some cases, it was~~thewere~~ incompatible or specific to particular cloud platforms;

Challenge 2. The *one-size-fits-all* assumption to design a super engineering method was not a realistic option. Rather, a tailorable reengineering method ~~evolvable regarding~~to the upcoming requirements of EclipseSCADA project would be needed and updated if new requirements arise.

It is difficult to assess the merits and demerits of existing reengineering methods and choose one that is superior; however, the method engineer believes pragmatically selected fragments of these methods can reduce defects and deliver quality cloud migration within schedule. Towards addressing these challenges, we offer MLSAC framework that provides a metamodel comprising of necessary elements of different reengineering methods and enables tailoring and extending this metamodel to the variant of migration types such as re-hosting (lift and shift), moving from an existing cloud platform to another platform, or de-migration from the cloud to in-house infrastructure.

3 Research Background

A key underlying principle of MDSE approach is the *abstraction*, making a separation between different essential and non-essential aspects of a software system during its design, development, and maintenance [14]. One solution to reach abstraction is to use models. A *model* is a high-level representation of a domain [28]. It is used to manage the complexity of representation and facilitate understanding of the domain. Models express the structure and behaviour of the concepts in a domain. Towards this, models may include a set of implying statements and constraints about the concepts and their relationships [29]. Concepts characterise the domain entities and relationships describe links among these concepts. In MDSE, the term *metamodel* is, evidently, a qualified variant of models. The *metamodeling*, is the act of creating a metamodel, which is, in other words, a unified view of a fairly related set of variant models [15].

Consequently~~In this spirit~~, ~~a~~ msodel of reengineering methods or processes that specifies *what* phases, tasks, and other elements are sequenced to perform~~-~~, instead of *how* ~~this model is implemented via tools and platforms~~ [28] – are required. Such models, ~~s with~~ conforming to rules and a defined syntax, would ~~–~~allow method engineers to represent and maintain reengineering methods. In creating these models, a metamodeling effort, among others, is required to identify reengineering method fragments ~~through w~~which can facilitate further reengineering of new methods~~ can be expressed~~. A *method fragment* is a structured, atomic, and re-usable piece of software development processes/methods [30]. Our ~~M~~method fragments are stored in MLSAC repository, combined to create a new method or augment ~~an~~ existing ones, ~~and matched~~ as ~~varying~~ reengineering contexts vary and demand.

Model transformation enables the instantiation of the metamodel to describe various method fragments of a development method [31],[32]. In MLSAC, these are also required to enable unified access to reengineering methods and to communicate the knowledge across different cloud migration scenarios. Our MLSAC framework has a metamodel as a ~~language~~ foundation to express reengineering methods. MLSAC is an extension to the ~~initial~~ preliminary model presented in [33]. ~~We addressed the deficiencies in [33] by providing~~It provides a new set of method fragments related to the maintenance and model transformation rules to instantiate and tailor the metamodel. We leverage the metamodeling foundation proposed by Object Management Group (OMG) [28]. As shown in Figure 1, these layers, which have been used to develop core technologies (e.g. unified modeling language (UML)), define an instance-of-relationship as follow [28]:

(i) M3-level (the meta-metamodel layer or meta-object facility layer) is used to describe basic modeling constructs and their relationships;

(ii) M2-level (metamodel layer) defines concepts and relationships that are instances of concepts from M3 and they define a modeling language to enable model creation/edition at M1;

(iii) M1-level (model layer) instances of M2-level concepts that are used to describe a domain and provides an abstraction of M0-level user data; and

(iv) M0-level is an instance of M1-level, which describes actual user data in a domain model instance.

Each level of OMG hierarchy (Figure 1) provides a language to express abstractions and relations of concepts at the lower level. The derivation of a model, including concepts and relations, from its upper level is referred to as *instantiation* [34]. Based on this modeling hierarchy, MLSAC is placed at M2-level (Figure 1), i.e., metamodel level aiming at the representation of reengineering methods situated at M1-level. The methods that are enacted by software teams in reengineering scenarios are called method instance, a.k.a. endeavor, and are positioned at M0-level. The relationship between MLSAC metamodel and method model are defined via model transformations which convert one model to another model [35].

4 Design Science Research Approach

We employed the DSR approach [23], [24] for the design and evaluation of MLSAC. DSR aims at developing new IT artefacts such as constructs, models, methods, frameworks, and instantiations to address a problem of high significance for research and practice. It is both ~~-~~rigorous~~ly~~ and systematic~~ally~~. Our In this paper, the IT artefact in focus of the DSR approach ~~focuses on the development of an IT artefact, i.e.~~is the MLSAC framework, ~~which intends~~intended to support method engineers in creating and reusing project-specific reengineering methods for ~~for legacy to~~ cloud migration. To organize this research effort, ~~W~~we use ~~conducted~~ the typical DSR phases of *design* (subsection 4.1,4.2,4.3,4.4) and *evaluation* (Section 5) [23] as described next.

4.1 Modeling quality factors and requirements

~~Following the DSR approach, any novel IT artifact should be designed and evaluated with respect to its pursuit goals.~~ In line with challenges 1 and 2 listed in Section 2, we used three quality factors (or design principles), namely *semantic quality*, *tailorability*, and *pragmatic quality* to design and evaluate MLSAC as delineated below.

(i) Semantic quality is the extent to which a model is sound and complete in capturing domain concepts [36]. Through the identification of frequently used concepts in a domain, it will be likely that the resultant model is generic and inclusive. Defining a threshold for model completeness depends on the application context and modeling purpose. We leveraged the highlighted challenges in migrating legacy applications to cloud platforms (e.g., [1],[4]), as a yardstick to derive an initial set of method fragments along with their relationships. The challenges are related, for instance, to resource elasticity, multi-tenancy, interoperability and migration over multiple cloud platforms, application licensing, dynamicity and unpredictability, and legal issues. The semantic quality is primarily associated with challenge 1.

(ii) Tailorability quality is the extent to which a model can

be specialized to the fit requirements of a particular domain modeling [36]. Undoubtedly, different reengineering scenarios entail different methods. For example, necessary method fragments that are needed for incorporation into a reengineering process of moving large and distributed workloads from on-premises data centres to public IaaS may vary compared to a reengineering process to enable a legacy application serving as a SaaS. MLSAC needs to be bottom-up tailorable by combining method fragments to meet various requirements of reengineering scenarios. The tailorability factor addresses challenge 2.

(iii) Pragmatic quality is the extent to which a model is perceived to be applicable by its audience [36] in terms of properties such as clear and unambiguous diagrams, notations, visualization of relationships, layout, etc. This quality factor concomitantly addresses both *challenges 1* and *2*.

4.2 Metamodeling

Our metamodel derivation is~~deployed~~ a mixture of top-down and bottom-up steps~~approaches~~. We used top-down steps to review the general cloud migration literature to get a broad view of legacy application reengineering processes to cloud platforms. We also used bottom-up steps for analyzing, reconciling, and abstracting frequently occurring method fragments from the literature. The metamodeling endeavor, the main concern in [33], was iterative and it consisted of the following steps:

(i) Preparing knowledge source. This step identified the knowledge source as the input for the metamodeling effort. We utilized the cloud computing literature as the main knowledge source. ~~A major role in this step was played by~~ Kitchenham et al. guidelines for conducting Systematic Literature Review (SLR) [37] of the cloud migration research were followed. The criteria included (a) time filter selecting papers between 2007 and 2019, (b) papers scope restricted to those properly describing the adaptation of legacy applications to cloud platforms, (c) focus forum restricted to international Software Engineering or Information Systems related journals/conferences or multi-vocal literature published by leading companies such as Oracle, IBM, and Amazon. The main keywords for the search of mainstream scientific digital libraries such as Google Scholar, IEEE Explore, ACM Digital Library, Elsevier, SpringerLink, and ScienceDirect were *Cloud*, *Cloud Migration*, *Legacy Application, Reengineering, Method*, and *Process Models*. Different search strings were defined using logical operators OR to cover synonyms for each search string as well as the logical operator AND to link together each set of synonyms. We selected studies from the literature that contained well-described validation such as case study, exemplar scenario, purposeful interview, questionnaire survey of domain experts, simulation, comparative analysis, and theoretical evaluation [37], [38]. Based on this criterion, theory, opinions, white, and short papers with any sort of validation were excluded from the identified studies. The choice of this criterion, as it strived to benefit from the empirical knowledge of cloud migration, could contribute to the reliability of the derived metamodel from the literature. This step identified 74 (seventy-four) studies as listed in Appendix A. We refer to them as the knowledgebase throughout this paper. Each study has a unique index (from [1..74]).

(ii) Identifying method fragments. As discussed in [33], we reviewed each paper and extracted the relevant text segments that could be considered as a *task.* A task is a discrete and small unit of migration work that developers may execute. A task execution achieves one or more specified goals and it produces a tangible *work-product.* A work-product can be used in the execution of other tasks according to a *principle*, i.e. a consideration that should be taken into account during the design of cloud-based architecture. A *phase* is a logical way to manage and classify tasks and work-product based on their relatedness. Text segments were labeled as candidate method fragments. We had a tendency in the selection of method fragments that were frequently underlined in the identified studies, sufficiently cloud-platform independent, and relatively application to a variety of reengineering scenarios. Method fragments that were too general or belonged to the general software reengineering such as governance and umbrella activities, risk management were omitted as they could make the metamodel too large and change the scope of this research.

(iii) Harmonizing method fragments. The variant definitions of the same method fragments were reconciled. Among several definitions of an overarching method fragment, a hybrid one encompassing all variant definitions was chosen. For example, in studies [S4],[S9],[S32] (Appendix A) the choice of cloud computing platform has been defined in three ways, though underlying the same logic: "*this step will select the best supplier based on value, sustainability, and quality*" [S4]; as *identify a set of potential cloud computing platforms based on a project's nature, data confidentiality and sensitivity requirements, budget constraints and long-term organizational objectives*" [S9]; and as *selecting appropriate technology for the modernized system and technology that can run alongside and communicate with the legacy system*" [S32]. A hybrid definition that could cover all these interpretations was chosen for the method fragment *Choose cloud*

platform/provider as "*Define a set of suitability criteria that characterize desirable features of cloud platforms. The criteria include provider profile (pricing model, constraints, offered QoS, electricity costs, power, and cooling costs), organization migration characteristics (migration goals, available budget), and application requirements. Based on the criteria identify and select suitable cloud providers*".

(iv) Organizing method fragments into phases. Reconciled method fragments in the previous step were grouped into one of

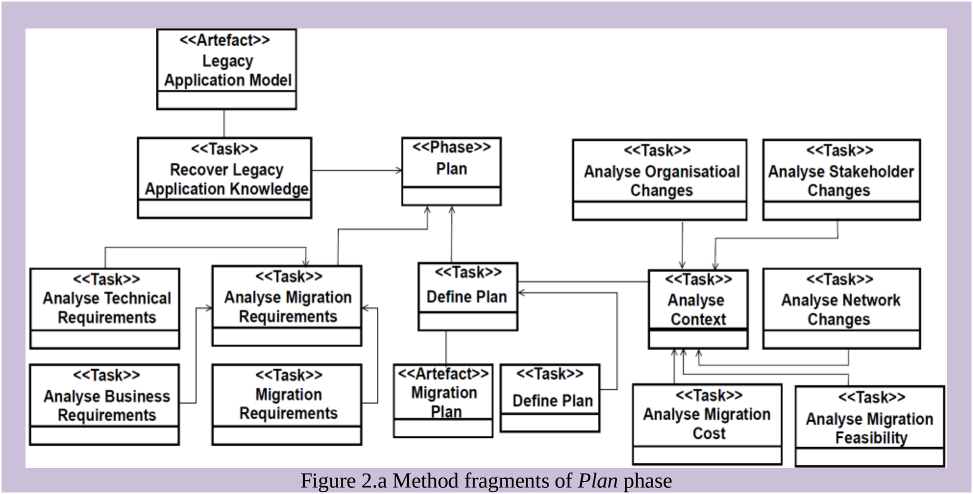


Figure 2.a Method fragments of *Plan* phase

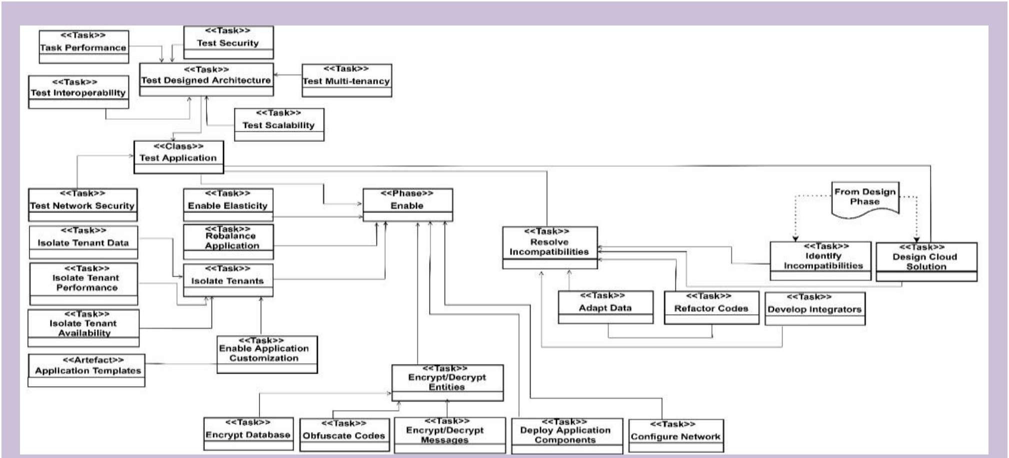


Figure 2.b Method fragments of *Design* phase

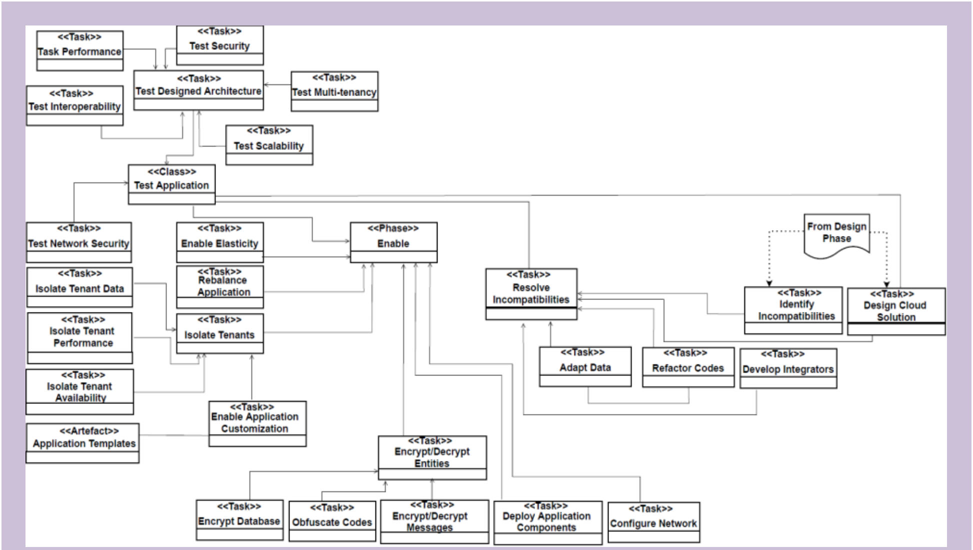


Figure 2.c Method fragments of *Enable* phase

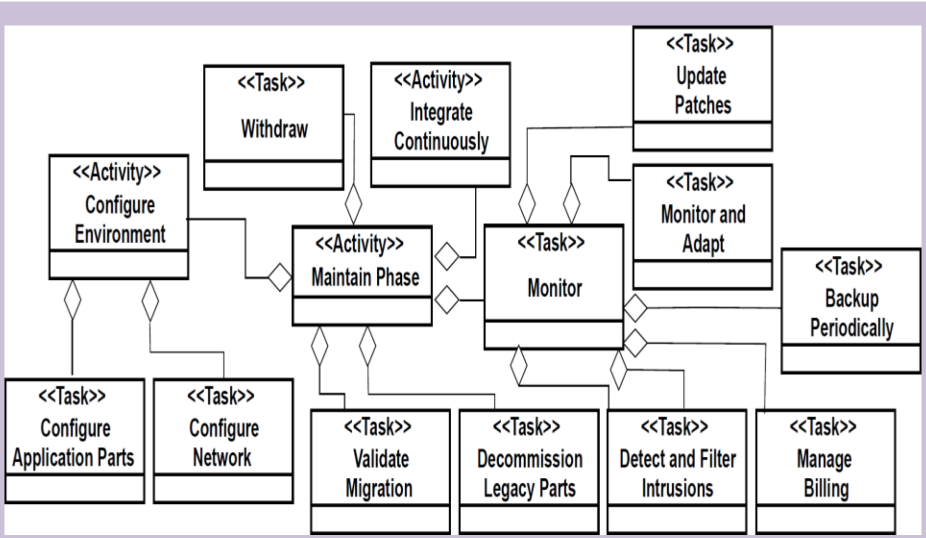


Figure 2.d Method fragments of *Maintain* phase

Table 1. An excerpt of transformation rules for instantiation of MLSAC method fragments to a reengineering process

Rule id	Rule name	Rule meaning	Rule syntax
R00	*ResolveIncompatibilities* method fragment of MLSAC	ResolveIncompatibilities::=(< ResolveIncompatibilities MethodFragmentClass>)	$C_M(\mu MLSAC)$
R01	Instance model of MLSAC	The set of all MLSAC metamodel instances, i.e., methods, conforming to MLSAC metamodel, $\mu MLSAC$	$\top(\mu MLSAC)$:={: ($\mu MLSAC$) |≡ $\mu MLSAC$ }8
R01.1	MLSAC metamodel fragment	MLSAC metamodel method fragment is consisting of name and relationships with other method fragments such as sequence, association, specialization, and aggregation	$C_M(\mu MLSAC) ::= MLSAC\_MethodFragment$); MLSAC_MethodFragment ::=(<MethodFragmentName> AND <MethodFragmentRelationship>)
R04	Method fragment subset MLSAC metamodel	All method fragments defined in each class of phases are a subset of MLSAC metamodel	$C_M(\mu MLSAC\_PlanPhase) \wedge C_M(\mu MLSAC\_DesignPhase) \wedge C_M(\mu MLSAC)\_EnablePhase \wedge C_M(\mu MLSAC\_MaintainPhase)$
R04.3	*Plan phase* M1 method	*Plan phase* of a method that contain method fragments and their relations from Plan phase class of MLSAC metamodel is a part of method designed	$(C_M(\mu MLSAC\_PlanPhase) \wedge \mathrm{r}(\mu MLSAC\_PlanPhase)) \in : \top(\mu MLSAC\_PlanPhase)$
R05.1	Relationships of method fragments	Relationships of all method fragments defined in each class of phases are a subset of MLSAC metamodel	$(r(C_M(\mu MLSAC_{PlanPhase})) \wedge r(C_M(\mu MLSAC\_DesignPhase)) \wedge r(C_M(\mu MLSAC)\_EnablePhase)) \wedge r(C_M(\mu MLSAC_{MaintainPhase})) \subset \mu MLSAC)$

the generic reengineering phases: *Plan*, *Design*, *Enable*, and *Maintain*. The *Plan* phase, is to understand the organizational context in which legacy applications operate. The *Design* phase defines a new cloud-enabled architecture for the legacy applications wherein *Enable phase* lists the tasks such as incompatibility resolutions and network configuration are carried out. The *maintain* phase deploys and monitors the performance of application components running over cloud platforms.

(v) Conceptual representation. Our metamodeling effort resulted in a few UML object models shown in figures 2.a, 2.b, 2.c, and 2.d including relationships, associations' cardinalities, and stereotypes such as phase, task, and work-product. They constitute a set of commonly occurring method fragments for incorporating into a typical reengineering method. The operationalization of the method fragments is deferred to implementation time and subjected to developers' choice of techniques and tools. For example, whilst method fragment *Develop Integrator* (Figure 2.b) informs developers of incorporating mechanisms to address the interoperability and portability of applications, a Docker container, i.e., a form of virtualization technology, can be used to realize this method fragment.

4.3 Model transformation rules

The model transformation rules instantiate MLSAC metamodel at M2-level to generate new specific method instances at M1-level according to MOF framework (Fig. 1). This instantiation is a vertical transformation from the higher level of abstraction, i.e., MLSAC metamodel, to the lower-level model, i.e., MLSAC metamodel instance [34]. We defined the transformation rules based on our knowledge source (Appendix A). These rules act as guidelines and semantic for the transformation of the metamodel to a specific reengineering method instance. They guarantee a consistent transformation from the metamodel (M2-level) to a model (M1-level) [32]. The transformation rules are implemented as a distinct module in MLSAC architecture using database tables describing relationships among method fragments. The transformation rules, like semi-MOF transformation notations [39], $C_M(\mu MLSAC)$ indicate a set of method fragments ∈ MLSAC metamodel. Table 1 shows a sample of rules. For example, Rule R00 formalizes the instance creation of *Plan* phase in MLSAC to a specific process model where:

> *Transformation rule*: Rule R00 (Plan phase):
> *Rule syntax*: $C_M(\mu MLSACplanphase)$
> *Rule meaning*: The set of tasks defined in MLSAC Plan phase are instantiated to Plan phase of a new method
> *Rule construct*: <*PlanPhaseClass*> :: = (*Analyze business requirements* Class AND *Analyze migration cost* Class AND *Analyze migration feasibility* Class AND Analyze network change Class AND *Analyze organizational changes* Class AND *Analyze stakeholders change* Class AND *Analyze technical requirements* Class AND *Define Plan* Class AND *Recover legacy application knowledge* Class)

Table 2. An excerpt of relationships matrix for selection of method fragments based on migration types (√: Mandatory, (√): Situational, × Unnecessary)

Method fragment	Migration type*					Situation
	I	II	III	IV	V	
Adapt data	×	(√)	(√)	(√)	(√)	The incorporation of this fragment for the migration types II, III, IV, V depends on the choice of a cloud platform.
Analyze business requirements	√	√	√	√	√	Mandatory
Choose cloud platform/provider	√	√	√	√	√	Mandatory
Cloud solution architecture	√	√	√	√	√	Mandatory
Decouple application components	(√)	(√)	(√)	(√)	(√)	The incorporation of this principle depends on the definition of architecture model and the distribution of application components in the cloud.
Develop integrators	(√)	(√)	(√)	(√)	(√)	The incorporation of this fragment depends on the choice of a cloud platform and required effort to refactor/modify legacy codes. If the code refactoring, as supported by refactor codes, is costly, then developing integrators/adaptors can be served as an alternative solution to hide incompatibilities.
Enable elasticity	(√)	(√)	×	×	(√)	The incorporation of this fragment in the migration types I, II, and V depends on a need for the application elasticity.
Encrypt/decrypt database	×	(√)	(√)	(√)	(√)	The incorporation of this fragment in the migration types depends on the security requirement.
Handle transient Fault	√	√	√	√	√	Mandatory
Identify incompatibilities	√	√	×	√	√	Mandatory
Isolate tenant availability	×	√	×	×	×	This is a mandatory fragment for migration type II but it is not required to be incorporated in other migration types.

*Migration type I: deploying business logic of a legacy application on cloud via IaaS service delivery model, type II: replacing or reengineering legacy components with SaaS delivery model, type III: deploying legacy database components on a cloud data storage, type IV: converting a legacy database to a cloud database solution, and type V: deploying whole legacy application stack on cloud via IaaS service delivery model

Each cloud migration type, such as I, II, III, IV, and V [3], entails specific tasks. The relationship matrix is used to classify method fragments and to guide the metamodel instantiation. As such, the method engineer is informed of method fragments that are required for inclusion into a reengineering method instance. Table 2 shows a sample of situations in which fragments are to be incorporated into the reengineering method with respect to a given migration type. These relationships are based on the knowledge source and are coded as transformation rules in MLSAC. For example, according to the knowledge source, reflected in studies [S41] and [S42], deploying legacy application components from a local organization network to a cloud server via IaaS service delivery model, i.e., migration type V, requires a new architecture model specifying a topology of migrated components and their communication with in-house ones. Hence, *Design cloud solution* method fragment is mandatory for inclusion in a newly created reengineering method in all migration types. To ensure this, *Rule R01* is defined:

Transformation rule: Rule R01 (Plan, Design, Enable, Maintain phases):
Rule syntax: $C_M(\mu MLSACplanphase) \wedge C_M(\mu MLSACdesignphase) \wedge C_M(\mu MLSACdesign\ phase) \wedge C_M(\mu MLSACmaintainphase)$
Rule meaning: The set of mandatory task method fragments defined in MLSAC *Plan* phase is instantiated to all phases of a new reengineering process

Rule syntax: <PlanPhaseClass> :: = (*Plan phase* Class AND *Design phase* Class AND *Enable phase* Class AND *Maintain phase* Class AND *Analyze business requirements* Class AND Analyze migration cost Class AND *Analyze migration feasibility* Class AND *Analyze network change* Class AND *Analyze organizational changes* Class AND *Analyze stakeholders change* Class AND *Analyze technical requirements* Class AND *Choose cloud provider* Class AND *Cloud solution architecture model* Class AND *Define plan* Class AND *Deploy application components* Class AND *Handle transient fault* Class AND *Legacy application architecture* Class AND *Migration plan* Class AND *Migration requirements* Class AND *Synchronize application components* Class AND *Test network connectivity* Class AND Test security Class)

The relationships between method fragments such as *follows*, *association*, *specialization* and, *aggregation*, respectively, are represented by notations (−), (—▷) and (—◇). They have been defined in MLSAC based on the knowledge source and metamodeling steps. They are stored in MLSAC repository and are used during MLSAC metamodel instantiation and tailoring. For example, *follows relation* means that the default execution sequence of method fragments in a typical migration scenario. As shown in Table 3, the relation between the method fragments *Identify incompatibilities* and *Choose cloud platform* signifies that once a cloud platform is chosen, examining potential incompatibilities between legacy application components and this platform should be the next task. The evidence to this, based on the knowledge source, is:

> "*An application is analyzed to assess its compatibility with the potential cloud computing environment. For example, it may be the case that a target PaaS cloud does not support frameworks or specific technologies being used by an application. If such issues are identified, then these need to be resolved first*" [S36].

Table 3. Sample relationships between the method fragments in the metamodel (L: cloud computing literature, M: during metamodeling steps)

Relationship Type	Relationship Name	Method fragment 1		Method fragment 2		Source
		Name	Type	Name	Type	
Association	Uses	Analyze migration requirements	Task	Choose cloud provider	Task	L
Association	Uses	Design cloud solution	Task	Plan migration	Task	L
Association	Follows	Choose cloud provider	Task	Identify incompatibilities	Task	L
Association	Produces	Design cloud solution	Task	Cloud solution architecture model	Work-Product	L
Aggregation	IsAGroupOf	Analyze context	Task	Initialize migration	Task	M
Specialization	isAKindOf	Re-factor codes	Task	Resolve incompatibilities	Task	M
Specialization	isAKindO'	Develop integrators	Task	Resolve incompatibilities	Task	M
Specialization	isAKindOf	Migrate data	Task	Resolve incompatibilities	Task	M

To save space, the full list of these relationships is publically available at GitHub [40]. Arguably, the execution order of method fragments is context-dependent and confined to each individual reengineering scenario. Thus, it is not feasible to capture all possible flows in MLSAC. Moreover, method engineers are not restricted to follow the predefined sequences in MLSAC when creating a new method for their own reengineering scenario.

4.4 Architecture overview

We implemented a MLSAC prototype version using technologies Microsoft .Net Framework 2015, C# programming language, and Microsoft Access Database. Feedback collected from our partners helped us test and improve MLSAC which is now publically available at GitHub [40] and briefly described below. Figure 3 depicts a snapshot of MLSAC's three-layer architecture.

The user interface layer has 19 interactive forms enabling a method engineer to create, update, and import/export the metamodel and method instances. The business logic layer operationalizes vertical model transformations from MLSAC metamodel. Since we used the object-oriented paradigm to design MLSAC architecture; three levels of MOF, i.e., *metamodel*, *method model*, and *method model instance* were mapped to the notion of *class*, each with its properties and operations in the business logic layer. The main classes in this layer are *method_fragment*, *metamodel*, *method model (reengineering process model)*, *method_instance*, *modeling component*, and *tailoring* (Figure 3). For example, the *method_fragment* class has the following fields: identifier, type, name, definition, relationships, and migration type. An excerpt of that is:

> MethodFragmentClaas::= <Method_fragment_Id, Method_fragment_name, Method_fragment_type, Method_fragment_definition, Method_fragment_relation, Method_fragment_ migration_type>

where:

> *Method_fragment_Id* represents the identifier of the method fragment
>
> *Method_fragment_name* refers to the name of the method fragment
>
> *Method_fragment_type* indicates whether the method fragment is phase, activity, task, work-product, or principle.
>
> *Method_fragment_definition* explains the steps to execute and aspects related to the method fragment
>
> *Method_fragment_relation* specifies the relation to other fragments such as being precedence and successors
>
> *Method_fragment_migration_type* defines the situations for which the method fragment is recommended to be sequenced in the reengineering process.

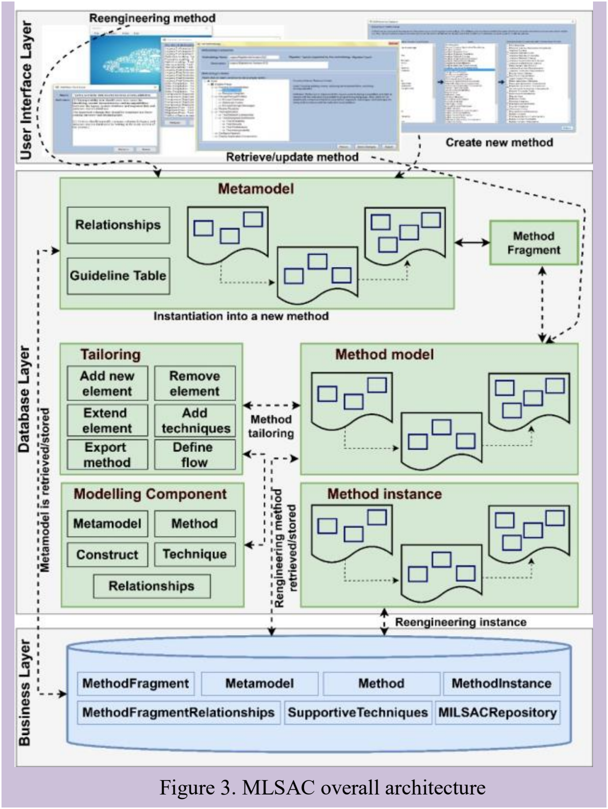


Figure 3. MLSAC overall architecture

The layer also defines a *modeling component* providing functions for deriving new bespoke methods from the metamodel. The *tailoring* class implements functions for creating methods. The method engineer can refine a method fragment from M2-level to M0 level through associating it with operationalization techniques as defined by the *technique* method fragments.

MLSAC is built using the relational database management system (RDBMS). A collection of relational tables is used to keep and update method modeling. Regarding MOF framework, a method fragment is stored at three levels of M0, M1, and M2 (Figure 1). That is, MLSAC metamodel, itself, is expressed as a collection of method fragments and stored in *Metamodel* table. It makes statements to describe reengineering processes. Instances of MLSAC metamodel, positioned at M1-level, and enacted instances, positioned at M0-level, are, respectively, stored in *Method* and *MethodInstance* tables. Moreover, information about operationalization of method fragments, i.e. supportive techniques, positioned at M0-level, is stored in *SupportiveTechniques* table.

5 Framework Evaluation

We iteratively evaluated and revisited MLSAC in the view of quality factors, as described in Section 4.1, as shown in Table 4 and discussed in what follows.

Table 4. MLSAC evaluation

Evaluation scenario	Quality factor		
	Semantic	Tailorability	Pragmatic
EclipseSCADA case (section 5.1)	-	√	-
Hackystat case (section 5.2)	-	√	-
User evaluation (section 5.3)	√	√	√

5.1 Maintaining reengineering processes

This evaluation focused on the *tailorability* factor of MLSAC. In EclipseSCADA exemplar scenario stated in Section 2, the developers aimed at deploying the application stack on the NeCTAR to reach flexible fees based on required computing resources.

Evaluation procedure. The method engineer performs the following tailoring procedure to instantiate the metamodel into EclipseSCADA reengineering method.

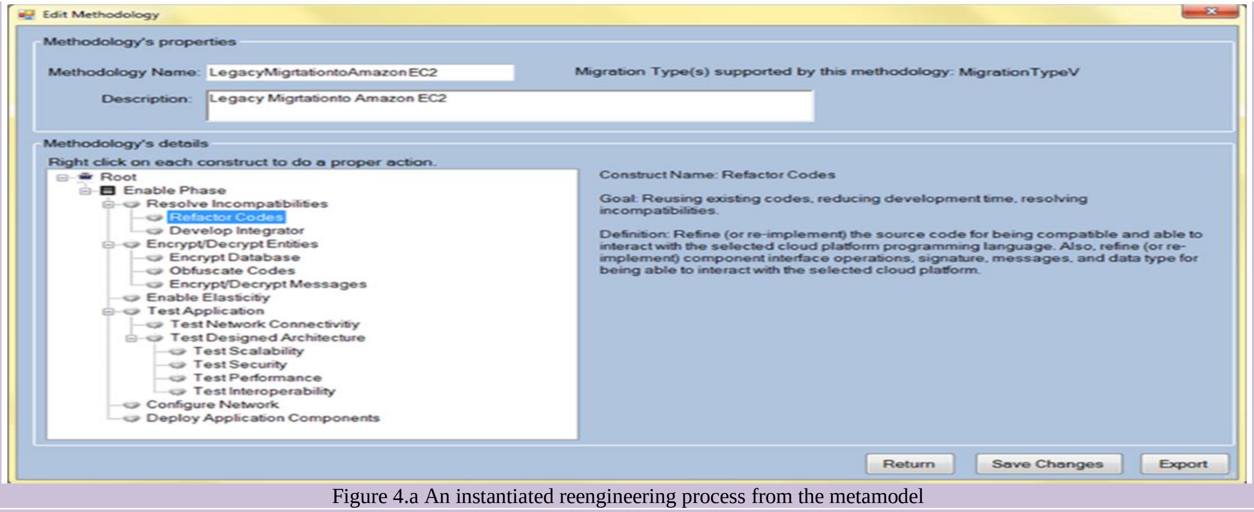
Step i. Three input parameters to MLSAC are method name/description, the choice of migration types, and phases. This scenario is subsumed under the migration type V, i.e. a virtual-machine-based application migration to the NeCTAR cloud IaaS model [3]. The method engineer merely focuses on the *Plan* phase and skips other phases.

Step ii. Input parameters are used to inform a vertical transformation from MLSAC's metamodel – as the source model at M2-level – to a new reengineering method instance at M1-level. Relevant method fragments associated with the selected migration type V and the *Plan* phase are retrieved from MLSAC repository according to the transformation guidelines for inclusion in the new method instance. These fragments are suggestive by MLSAC repository for inclusion in the base reengineering method model instance: *Analyze context*, *Recover legacy application knowledge*, *Analyze migration requirements*, *Define plan*. This derivation can be codified using the following pseudo-code (if-then expression):

```
Model_Instance Function MetamodelInstantiation (mt, p)
  {
    QUERY_STRING ← {};//query string to retrieve method fragments from the repository
    MIGRATION_TYPE ← mt; //the choice of migration type
    PHASE ← p; //the choice of phase
    if (MIGRATION_TYPE == Type I) then
    QUERY_STRING ← "TYPE I"
    else if (MIGRATION_TYPE == Type II) then
    QUERY_STRING ← "TYPE II"
    else if (MIGRATION_TYPE == Type III) then
    QUERY_STRING ← "TYPE III"
    else if (MIGRATION_TYPE == Type IV) then
    QUERY_STRING ← "TYPE IV"
    else if (MIGRATION_TYPE == Type V) then
    QUERY_STRING ← "TYPE V"
    if (PHASE == Plan_Phase then
    QUERY_STRING ← + "Plan_Phase"
    if (PHASE == Design_Phase then
    QUERY_STRING ← + "Design_Phase"
    if (PHASE == Enable_Phase then
    QUERY_STRING ← + "Enable_Phase"
    if (PHASE == Maintain_Phase then
    QUERY_STRING ← + "Maintain_Phase"
    PROCESS_INSTANCE←retrieve (QUERY_STRING)
    return PROCESS_INSTANCE
```

}

This instance method model containing the set of method fragments and their definitions that are reused from the metamodel is shown in Figure 4.a. The graphical user interface in Figure 4 has three main sections. The upper section has the general description of the



Methodology Name: LegacyMigrtationtoAmazonEC2

Migration Type(s) supported by this methodology: MigrationTypeV

Description: Legacy Migrtationto Amazon EC2

Right click on each construct to do a proper action.

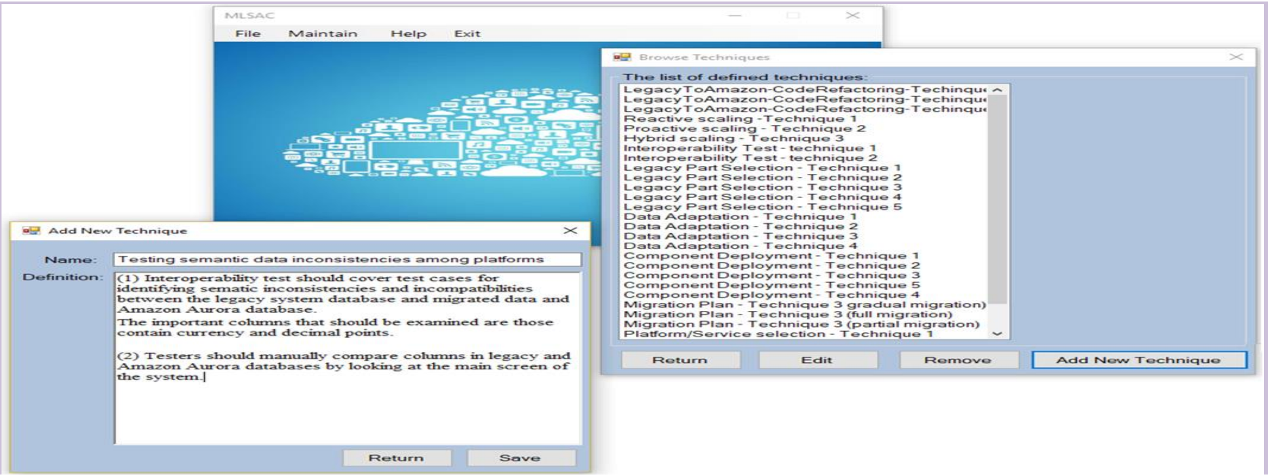
- Root
  - Enable Phase
    - Resolve Incompatibilities
      - Refactor Codes
      - Develop Integrator
    - Encrypt/Decrypt Entities
      - Encrypt Database
      - Obfuscate Codes
      - Encrypt/Decrypt Messages
    - Enable Elasticitiy
    - Test Application
      - Test Network Connectivitiy
      - Test Designed Architecture
        - Test Scalability
        - Test Security
        - Test Performance
        - Test Interoperability
    - Configure Network
    - Deploy Application Components

Construct Name: Refactor Codes

Goal: Reusing existing codes, reducing development time, resolving incompatibilities.

Definition: Refine (or re-implement) the source code for being compatible and able to interact with the selected cloud platform programming language. Also, refine (or re-implement) component interface operations, signature, messages, and data type for being able to interact with the selected cloud platform.

Figure 4.a An instantiated reengineering process from the metamodel



The list of defined techniques:

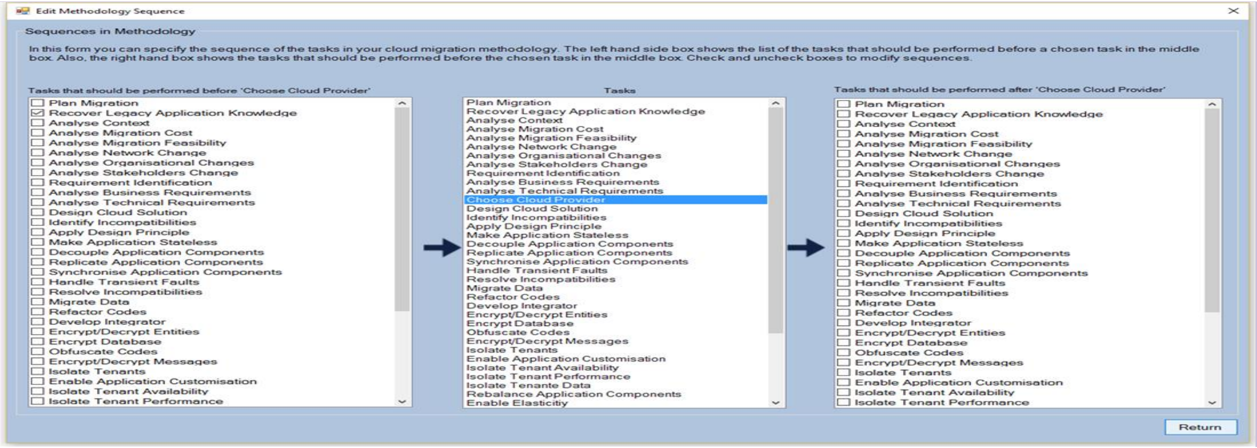
LegacyToAmazon-CodeRefactoring-Techinqu
LegacyToAmazon-CodeRefactoring-Techinqu
LegacyToAmazon-CodeRefactoring-Techinqu
Reactive scaling -Technique 1
Proactive scaling - Technique 2
Hybrid scaling - Technique 3
Interoperability Test - technique 1
Interoperability Test - technique 2
Legacy Part Selection - Technique 1
Legacy Part Selection - Technique 2
Legacy Part Selection - Technique 3
Legacy Part Selection - Technique 4
Legacy Part Selection - Technique 5
Data Adaptation - Technique 1
Data Adaptation - Technique 2
Data Adaptation - Technique 3
Data Adaptation - Technique 4
Component Deployment - Technique 1
Component Deployment - Technique 2
Component Deployment - Technique 3
Component Deployment - Technique 5
Component Deployment - Technique 4
Migration Plan - Technique 3 gradual migration)
Migration Plan - Technique 3 (full migration)
Migration Plan - Technique 3 (partial migration)
Platform/Service selection - Technique 1

Name: Testing semantic data inconsistencies among platforms

Definition: (1) Interoperability test should cover test cases for identifying sematic inconsistencies and incompatibilities between the legacy system database and migrated data and Amazon Aurora database.
The important columns that should be examined are those contain currency and decimal points.

(2) Testers should manually compare columns in legacy and Amazon Aurora databases by looking at the main screen of the system.

Figure 4.b Defining an implementing technique for *Test interoperability* task method fragment



In this form you can specify the sequence of the tasks in your cloud migration methodology. The left hand side box shows the list of the tasks that should be performed before a chosen task in the middle box. Also, the right hand box shows the tasks that should be performed before the chosen task in the middle box. Check and uncheck boxes to modify sequences.

Tasks that should be performed before 'Choose Cloud Provider'

☐ Plan Migration
☑ Recover Legacy Application Knowledge
☐ Analyse Context
☐ Analyse Migration Cost
☐ Analyse Migration Feasibility
☐ Analyse Network Change
☐ Analyse Organisational Changes
☐ Analyse Stakeholders Change
☐ Requirement Identification
☐ Analyse Business Requirements
☐ Analyse Technical Requirements
☐ Design Cloud Solution
☐ Identify Incompatibilities
☐ Apply Design Principle
☐ Make Application Stateless
☐ Decouple Application Components
☐ Replicate Application Components
☐ Synchronise Application Components
☐ Handle Transient Faults
☐ Resolve Incompatibilities
☐ Migrate Data
☐ Refactor Codes
☐ Develop Integrator
☐ Encrypt/Decrypt Entities
☐ Encrypt Database
☐ Obfuscate Codes
☐ Encrypt/Decrypt Messages
☐ Isolate Tenants
☐ Enable Application Customisation
☐ Isolate Tenant Availability
☐ Isolate Tenant Performance

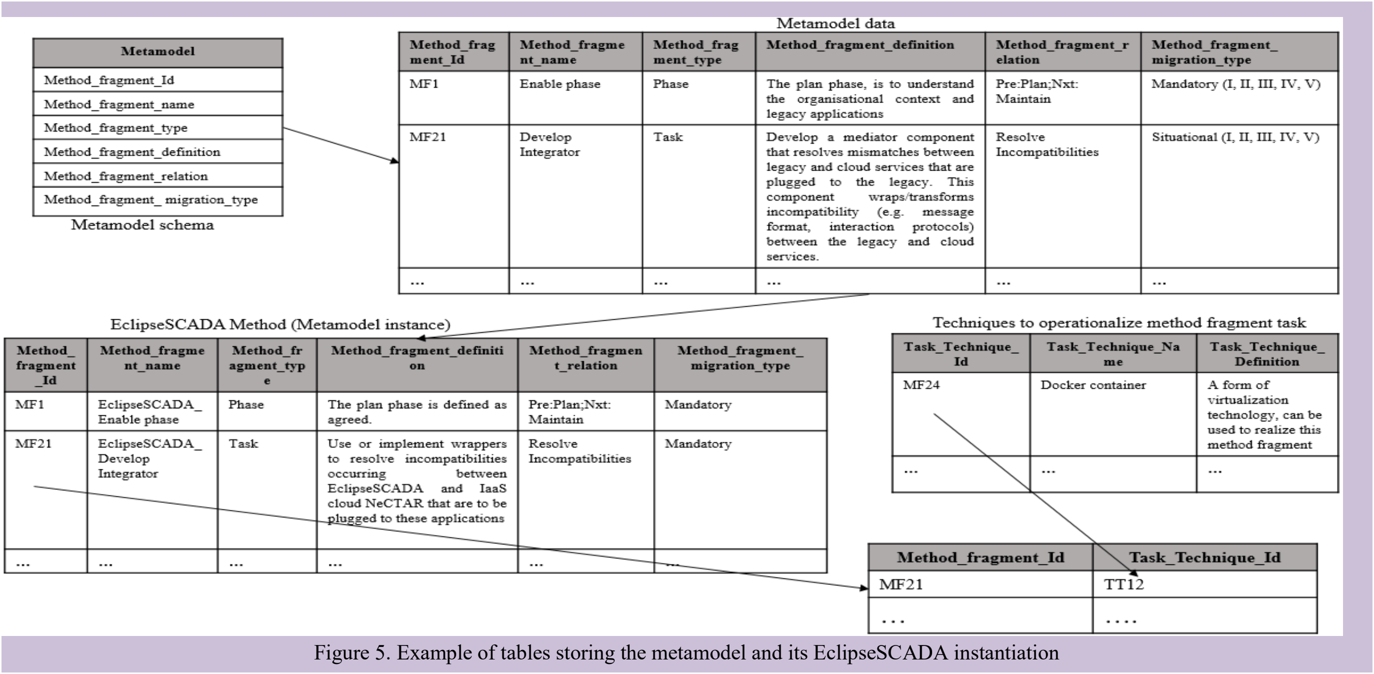
Tasks

Plan Migration
Recover Legacy Application Knowledge
Analyse Context
Analyse Migration Cost
Analyse Migration Feasibility
Analyse Network Change
Analyse Organisational Changes
Analyse Stakeholders Change
Requirement Identification
Analyse Business Requirements
Analyse Technical Requirements
Choose Cloud Provider
Design Cloud Solution
Identify Incompatibilities
Apply Design Principle
Make Application Stateless
Decouple Application Components
Replicate Application Components
Synchronise Application Components
Handle Transient Faults
Resolve Incompatibilities
Migrate Data
Refactor Codes
Develop Integrator
Encrypt/Decrypt Entities
Encrypt Database
Obfuscate Codes
Encrypt/Decrypt Messages
Isolate Tenants
Enable Application Customisation
Isolate Tenant Availability
Isolate Tenant Performance
Isolate Tenante Data
Rebalance Application Components
Enable Elasticitiy

Tasks that should be performed after 'Choose Cloud Provider'

☐ Plan Migration
☐ Recover Legacy Application Knowledge
☐ Analyse Context
☐ Analyse Migration Cost
☐ Analyse Migration Feasibility
☐ Analyse Network Change
☐ Analyse Organisational Changes
☐ Analyse Stakeholders Change
☐ Requirement Identification
☐ Analyse Business Requirements
☐ Analyse Technical Requirements
☐ Design Cloud Solution
☐ Identify Incompatibilities
☐ Apply Design Principle
☐ Make Application Stateless
☐ Decouple Application Components
☐ Replicate Application Components
☐ Synchronise Application Components
☐ Handle Transient Faults
☐ Resolve Incompatibilities
☐ Migrate Data
☐ Refactor Codes
☐ Develop Integrator
☐ Encrypt/Decrypt Entities
☐ Encrypt Database
☐ Obfuscate Codes
☐ Encrypt/Decrypt Messages
☐ Isolate Tenants
☐ Enable Application Customisation
☐ Isolate Tenant Availability
☐ Isolate Tenant Performance

Figure 4.c Specifying sequences among task method fragments



Metamodel
Method_fragment_Id
Method_fragment_name
Method_fragment_type
Method_fragment_definition
Method_fragment_relation
Method_fragment_ migration_type

Metamodel schema

Metamodel data

Method_fragment_Id	Method_fragment_name	Method_fragment_type	Method_fragment_definition	Method_fragment_relation	Method_fragment_ migration_type
MF1	Enable phase	Phase	The plan phase, is to understand the organisational context and legacy applications	Pre:Plan;Nxt: Maintain	Mandatory (I, II, III, IV, V)
MF21	Develop Integrator	Task	Develop a mediator component that resolves mismatches between legacy and cloud services that are plugged to the legacy. This component wraps/transforms incompatibility (e.g. message format, interaction protocols) between the legacy and cloud services.	Resolve Incompatibilities	Situational (I, II, III, IV, V)
...	...	...	...	...	...

EclipseSCADA Method (Metamodel instance)

Method_ fragment _Id	Method_fragment_name	Method_fragment_type	Method_fragment_definition	Method_fragment_relation	Method_fragment_ migration_type
MF1	EclipseSCADA_ Enable phase	Phase	The plan phase is defined as agreed.	Pre:Plan;Nxt: Maintain	Mandatory
MF21	EclipseSCADA_ Develop Integrator	Task	Use or implement wrappers to resolve incompatibilities occurring between EclipseSCADA and IaaS cloud NeCTAR that are to be plugged to these applications	Resolve Incompatibilities	Mandatory
...	...	...	...	...	...

Techniques to operationalize method fragment task

Task_Technique_ Id	Task_Technique_Name	Task_Technique_ Definition
MF24	Docker container	A form of virtualization technology, can be used to realize this method fragment
...	...	...

Method_fragment_Id	Task_Technique_Id
MF21	TT12
. . .	. . . .

Figure 5. Example of tables storing the metamodel and its EclipseSCADA instantiation

reengineering method, e.g. name and migration. The bottom-left section shows the method fragments reused from MLSAC metamodel. The bottom-right section (Figure 4) gives the information about a selected method fragment once the method engineer clicks it in the tree view.

Step iii. The method engineer can perform different optional sub-steps to tailor the base reengineering model instance to meet scenario requirements (Figures 4.b and 4.c). These include (a) adding new method fragments to the method if the pre-existing method fragments in MLSAC repository are insufficient to support requirements of the reengineering scenario, (b) extending the existing method fragments of MLSAC with new ones through the inheritance mechanism, (c) specifying alternative techniques to operationalise the method fragments (Figure 4.b) , and (d) defining arbitrary sequence among the method fragments (Figure 4.c). For example, the method engineer defines three custom sub-classes of *Define plan* task method fragments namely *Determine application disposition*, *Plan migration*, and *Define migration road map*. According to OMG modeling framework (Figure 1) [28], the abovementioned sub-steps are horizontal transformations at the same level of abstraction where the method instance at M1-level, as the source model, is evolved to its next operational target model to include/exclude method fragments as required in the migration scenario.

Step iv. Once tailored, the method model can be either stored in MLSAC database or exported as an XML document to be later shared with developers for the enactment. Figure 5 shows an instance of the relationships between MLSAC metamodel, *EclipseSCADA_Method*, and *TaskTechniques.*

5.2 Deriving new reengineering processes from MLSAC

We examined the tailorability of MLSAC in Hackystat project [41]. This illustrated how an existing reengineering method for an open-source legacy application in Hackystat project, called Hackystat SensorBase service, positioned at M1-level, can be stored and reused via MLSAC

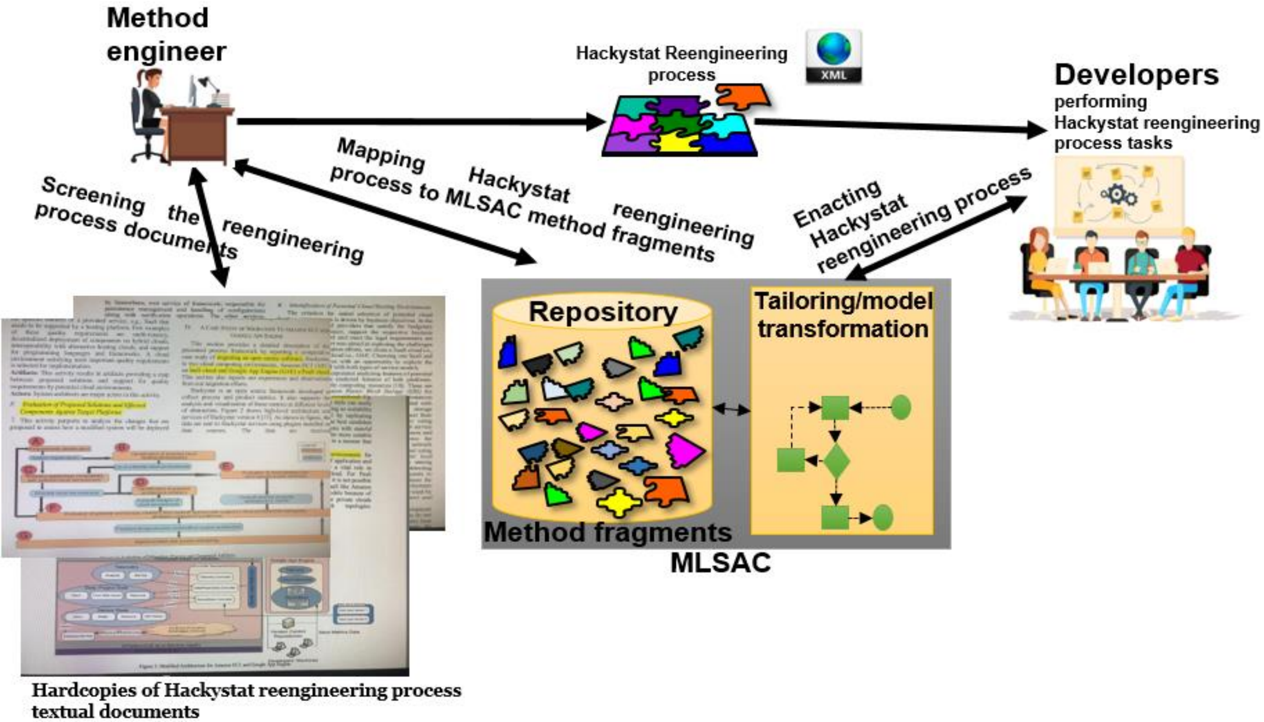
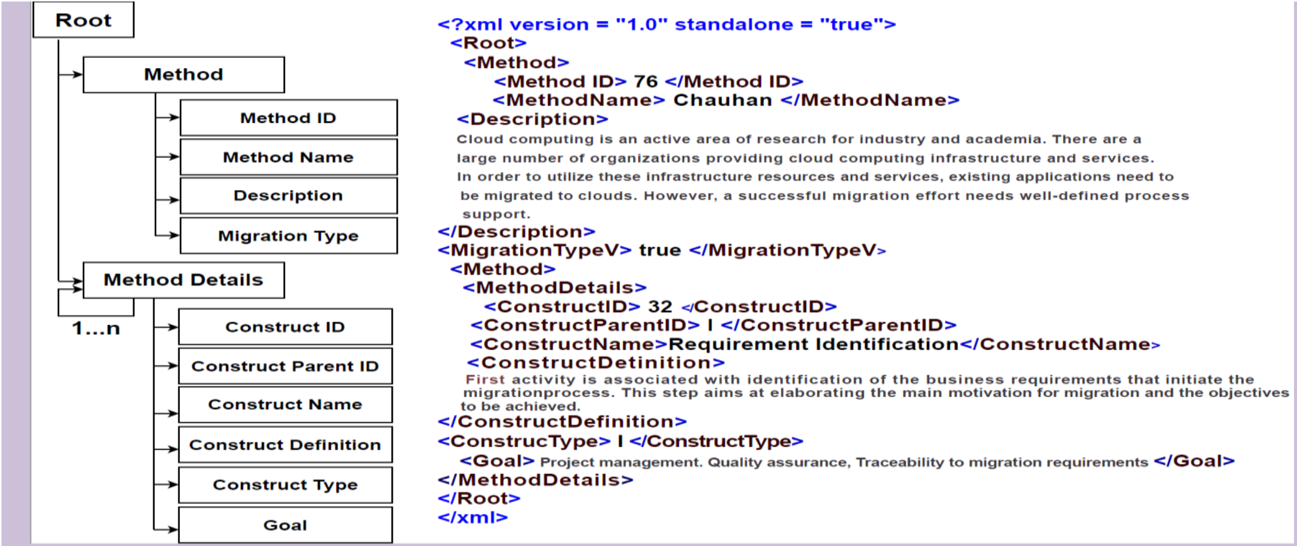


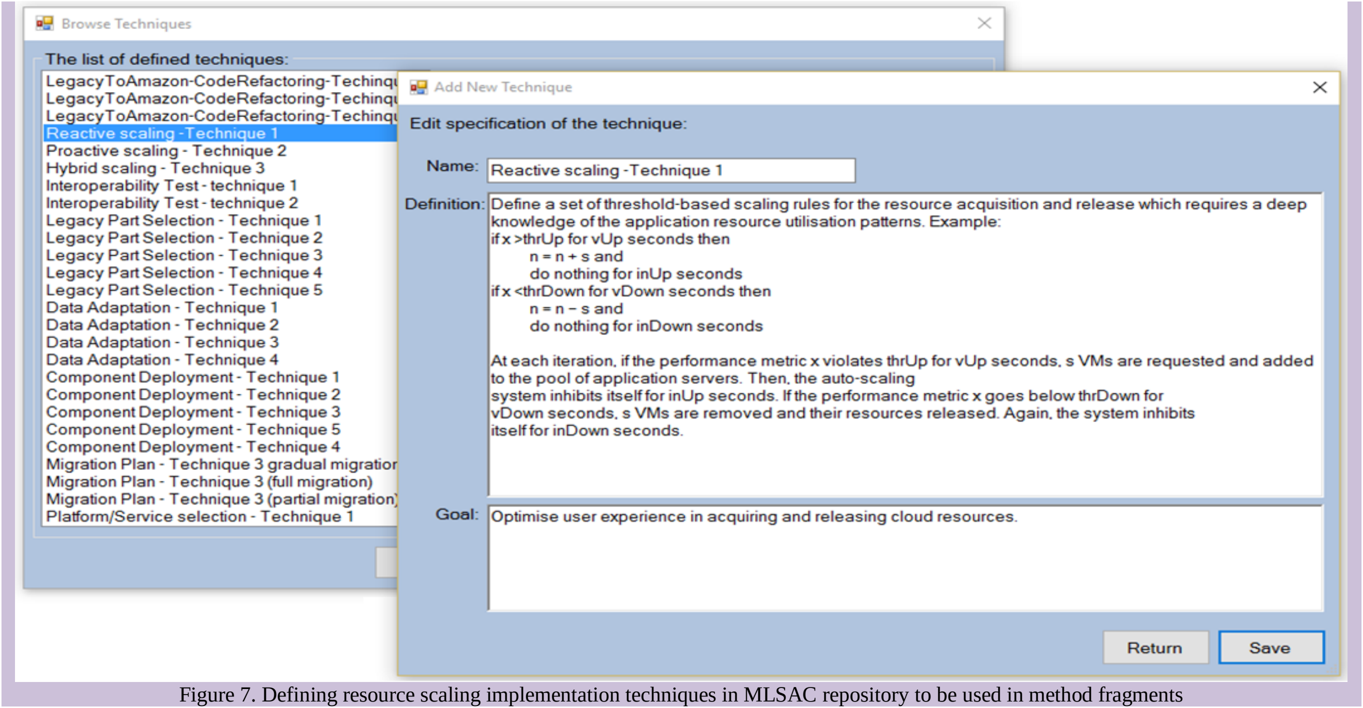
Figure 6.a Hackystat reengineering process method fragments, the entry for MLSAC method fragments



```
<?xml version = "1.0" standalone = "true">
 <Root>
  <Method>
     <Method ID> 76 </Method ID>
     <MethodName> Chauhan </MethodName>
 <Description>
 Cloud computing is an active area of research for industry and academia. There are a
 large number of organizations providing cloud computing infrastructure and services.
 In order to utilize these infrastructure resources and services, existing applications need to
  be migrated to clouds. However, a successful migration effort needs well-defined process
  support.
</Description>
<MigrationTypeV> true </MigrationTypeV>
 <Method>
  <MethodDetails>
    <ConstructID> 32 </ConstructID>
   <ConstructParentID> I </ConstructParentID>
   <ConstructName>Requirement Identification</ConstructName>
  <ConstructDetinition>
  First activity is associated with identification of the business requirements that initiate the
  migrationprocess. This step aims at elaborating the main motivation for migration and the objectives
  to be achieved.
</ConstructDefinition>
<ConstrucType> I </ConstructType>
  <Goal> Project management. Quality assurance, Traceability to migration requirements </Goal>
</MethodDetails>
</Root>
</xml>
```

Figure 6.b an excerpt of Hackystat reengineering process stored in MLSAC repository and exported in XML format

. The method for Hackystat project was sourced from a report describing the real experiences of cloud migration conducted by a software team. The method was described in natural language (Figure 6.a). This way of representation was inherently ambiguous, incomplete, and non-modular which could cause difficulties in the method maintenance. If a method fragment would be changed, the method engineer had to manually update and check the entire method document to assure the consistency of method content. This could be a very time-consuming and error-prone task. Using the provided method fragments that are organized in MLSAC's metamodel, the method engineer instead could define a core reengineering method including necessary tasks to move Hackystat application to the cloud. The



The list of defined techniques:

- LegacyToAmazon-CodeRefactoring-Techinqu
- LegacyToAmazon-CodeRefactoring-Techinqu
- LegacyToAmazon-CodeRefactoring-Techinqu
- Reactive scaling -Technique 1
- Proactive scaling - Technique 2
- Hybrid scaling - Technique 3
- Interoperability Test - technique 1
- Interoperability Test - technique 2
- Legacy Part Selection - Technique 1
- Legacy Part Selection - Technique 2
- Legacy Part Selection - Technique 3
- Legacy Part Selection - Technique 4
- Legacy Part Selection - Technique 5
- Data Adaptation - Technique 1
- Data Adaptation - Technique 2
- Data Adaptation - Technique 3
- Data Adaptation - Technique 4
- Component Deployment - Technique 1
- Component Deployment - Technique 2
- Component Deployment - Technique 3
- Component Deployment - Technique 5
- Component Deployment - Technique 4
- Migration Plan - Technique 3 gradual migratior
- Migration Plan - Technique 3 (full migration)
- Migration Plan - Technique 3 (partial migration)
- Platform/Service selection - Technique 1

Edit specification of the technique:

Name: Reactive scaling -Technique 1

Definition:

```
Define a set of threshold-based scaling rules for the resource acquisition and release which requires a deep
knowledge of the application resource utilisation patterns. Example:
if x >thrUp for vUp seconds then
        n = n + s and
        do nothing for inUp seconds
if x <thrDown for vDown seconds then
        n = n − s and
        do nothing for inDown seconds

At each iteration, if the performance metric x violates thrUp for vUp seconds, s VMs are requested and added
to the pool of application servers. Then, the auto-scaling
system inhibits itself for inUp seconds. If the performance metric x goes below thrDown for
vDown seconds, s VMs are removed and their resources released. Again, the system inhibits
itself for inDown seconds.
```

Goal: Optimise user experience in acquiring and releasing cloud resources.

Figure 7. Defining resource scaling implementation techniques in MLSAC repository to be used in method fragments

method could then be stored in MLSAC repository. As such, developers would be able to retrieve/import and enact this M1-level method for a given scenario at M0-level (Figure 6.a,b). Hackystat scenario was:

> *Hackystat is an open-source application developed to collect process and product metrics founded university of Hawaii in the US. It also supports the analysis and visualization of these metrics at different levels of abstraction. In this application, the data are sent to Hackystat services using plugins installed on data sources. The data is received by Sensor base, the root service of the application, which is responsible for persistence management and handling of configurations along with notification operations. The other services, DailyProjectData and Telemetry work via interaction with Sensorbase. These are used to compute daily, weekly, monthly and yearly abstractions of data. ProjectBrowser and TickerTape are client components used to present metrics through graphical user interfaces and post information on external applications like Nabaztag Rabbit and Twitter. The developers aim to reengineer Hackystat to serve as SaaS. It is expected to have the capability to scale for the required computing and storage resources. In this scenario, Hackystat's services are aimed to move to Amazon EC2 elastic computing and Google app engine".* [41], page.82

Evaluation procedure. MLSAC retrieves the base reengineering method model listing mandatory SaaS-specific method fragments (migration type II [3]) from the repository. These include method fragments such as *Isolate tenant availability*, *Isolate tenant customizability*, *Isolate tenant data*, *Isolate tenant performance*, *Handle transient faults*, *Identify incompatibilities*, *Analyze business requirements*, *Analyze migration cost*, and *Analyze migration feasibility*. The method engineer can tailor this base method regarding the scenario's characteristics. In Hackystat scenario, task *Requirement identification* is to find high-level requirements initiating the migrating Hackystat to the cloud. This knowledge is stored in the method fragment *Analyze migration requirements* in MLSAC. Hackystat report describes M1 level task *Identification of potential cloud hosting*, which is to list candidate cloud platforms that may address confidentiality and sensitivity requirements. Subsequently, potential incompatibilities between the legacy application and candidate cloud platforms are analyzed in a task named *Analysing applications' compatibility*. The method engineer structures and stores this fragment in MLSAC repository as the M2-level method fragment *Identify incompatibilities* in *Design* phase. The details of this task are stored in the method fragment's definition part. Furthermore, the method engineer can add new method fragments to the method as upcoming requirements arise during the project. For example, she defines an operationalization technique for the method fragment *Enable elasticity* in *Enable* phase. In this scenario, she uses three existing resource provision techniques based on the existing literature [42-44] (Figure 7): (i) *Reactive scaling* where developers define a set of threshold-based scaling rules for resource acquisition and release which requires a deep knowledge of the application resource utilisation patterns, (ii) *Proactive scaling* where developers use observation and prediction techniques to anticipate workload, and (iii) *Hybrid scaling* where a combination of reactive and proactive techniques are used to determine when to get a resource during a period of application execution. These techniques are then assigned to *enable elasticity*. Developers enact this base method for a scenario of migrating open-source software, named Hackystat, to two cloud platforms Amazon EC2 and Google App Engine.

As the result of the evaluation, the refinement was made to *Choose cloud service platform* defined in the *Design* phase to include high-level criteria for the cloud platform selection. According to Hackystat, the criteria were added to the definition of the task: budgetary constraints of a project, support of business domain of the project, and legal requirements.

5.3 User evaluation

We sought the opinions of two industry partners about MLSAC adherence to all the quality factors. We recruited a purposive sample [45] of interviewees to examine if MLSAC satisfies the quality factors. Two independent experts, called E1 and E2, from two different companies were selected based on the criteria (i) having real-world experience in cloud migration and (ii) speaking English fluently. The profile of users was as follows:

- E1 was a senior .Net developer and technical lead at Delotte Digital in Sydney, Australia, with expertise in developing SaaS applications. He had been involved as a technical lead in reengineering legacy customer relationship management (CRM) applications to serve as SaaS.
- E2 was a full stack iOS engineer at Nudge group in Sydney, Australia, with expertise in services for cloud-based application development, in particular, NoSQL and Amazon Web Service (AWS). He had played the role of the technical lead in implementing a real-time and location-based social network mobile application in the online dating domain.

We organized face-to-face individual meetings each took about 180 minutes including follow-up discussions. The research objectives, description of quality factors, and example screenshots of MLSAC were presented to them. Each expert user was asked to model the in-house reengineering method for a scenario that she/he wanted to provide for the software team to enact. The following criteria were set to select a scenario for the purpose of MLSAC evaluation: (i) having clear goals of reengineering such as the improving scalability, or performance of legacy applications, and (ii) involving with cloud-specific concerns during reengineering such as interoperability, platform selection, and server latency [3],[46]. Scenarios 1 and 2, classifying under the migration types IV/V and IV respectively, were as follows:

Case study 1: *reengineering a legacy CRM application to SaaS.* The CRM application was unable to support new business requirements such as scalability for the growing number of application users. SaaS version of the CRM, available in the marketplace, could be a viable solution to address this requirement. A generic method could provide an overall road map for making CRM application SaaS-enabled.

Case study 2: *migrating a real-time geosocial networking application to the cloud*. The application was recognizing the geographical zone of a registered person in the application and suggests upcoming events in that zone. The application data layer was using a relational database hosted on local servers. Over time, the relational data was found lacking in scalability since the database size was growing and search queries were becoming complicated. The application also lacked a real-time response to features such as instantaneous upload/download operations for resources used frequently. Migrating the database components to No-SQL and running the business logic components in Amazon could servers could improve the situation.

Table 5. Summary of domain expert evaluation results

Factors	Assessment question	Evaluation results
Semantic	Does MLSAC repository provides necessary and relevant method fragments for representing reengineering processes to cloud?	Yes, The repository provide major generic tasks and it is fully customizable so it can be extended easily based on project needs (E1).
		Yes, An advantage of the prototype is its extensibility and customizability for different needs (E2).
	Have names/definitions been used in the forms been clear and helpful?	Yes. Name and definitions are generic and easy to follow. The current version is understandable enough for a technical lead to finish the process. However, the user interface/user experience can be enhanced (E1). Yes (E2)
	Are visualizations e.g. tree-view structure is understandable and helpful for organizing processes?	Yes, tree-view is easy to understand and helps to come up with an organized structure of the plan but the order and relation of tasks are not very intuitive. It would be nice if I could change the order of tasks easier (e.g. drag and drop). I also noticed that the newly defined task or subtasks are always appended to the end of the corresponding branch and it is not currently possible to change the order (E1).
		Yes, but It would be good if the visualization was able to show iterative development. This notion could be realized by showing a simple icon in the tasks (E2).
	Is the classification of method fragments based on the migration types is correct?	Yes (E1)
		Yes, the flexibility of the framework allows modifying the classification of the method fragments (E2).
Tailorability	Does MLSAC provide sufficient support of necessary parameters for process tailoring?	Yes, because the prototype provides customization support if required. But, it would be nice if the user could have access to a list of suggestive tasks classified under different domains like Mobile cloud etc. (E1).
		No, a hybrid process is hard to support by the current prototype (for example both type I and type V) and cannot be easily defined by the current version. As such, user needs to choose a migration type that is conceptually similar to the migration type (E2).
	Are the defined steps in MLSAC are easy to perform for process creation/configuration/maintenance/sharing?	Yes, but I would also like to have a “share with email option” instead of exporting and attaching an XML file separately. Also, it would be very nice if I could configure to share the database of MLSAC and export data in cloud spaces used by everyone who needs to be exposed to the generated data (E1).
		Yes, but a Web-based version of the prototype could be more efficacious (E2).
	Does MLSAC reduce efforts for process tailoring?	Yes, but there is a lack of support for reusable templates to be used as a starting point based on different architecture design styles which can lead to better efficiency by saving time and increasing user satisfaction (E1).
		Yes, but it would be great if the prototype could support pre-defined templates for different legacy system types such as finance, insurance, and e-commerce (E2).
	Does MLSAC provide a suitable environment for process tailoring in a given migration scenario to the cloud?	Certainly, there is room for improvement but the main features are there (E1).
		Yes, in comparison with other existing tools like Microsoft Project, MLSAC provides a pre-built rich repository of important items required for creating migration strategies. This feature protects users from missing some important considerations for cloud migration (E2).
	Does MLSAC facilitates reuse in designing bespoke reengineering processes?	Yes (E1).
		Yes. The pre-built-in repository is helpful (E2).
	Is MLSAC useful for sharing reengineering processes among development teams?	Yes (E1).
		As a suggestion, it would be good if the prototype could be Web-based with support for multiple user support. Users could simultaneously work on the method and share it. With the current version of the prototype, there is a need to multiple saves and restores the XML file of a method which may cause inconsistency of the method content. Furthermore, it would be good if MLSAC would be able to keep track of method changes such as adding, removing, modifying tasks during the method lifetime (E2).
Pragmatic	Do you believe MLSAC is a practical tool for its audiences. In what ways do you think MLSAC would create value to the audience? Please explain why.	The method fragments are complete. Due to the fact that the repository is fully customizable, I believe it does provide all necessary components and I can’t think about a major improvement (E1).
		The prototype is simple and easy to use to the point of meeting major objectives of a method customization process, but it could be further enhanced to include a more features and a more professional look and feel. The prototype system saves time for creating migration strategies by proving a pre-built-in repository. Visualization instead of documentation helps to a better understanding of the process. XML output can be integrated with other tracking and visualization systems (E2).

Evaluation procedure. The E1 and E2 individually used MLSAC to derive their in-house methods via reusing MLSAC metamodel method fragments. In each scenario, the users could configure the method including phases, tasks, operationalization techniques, and sequences to meet the scenario requirements. For example, Figure 8 shows the corresponding conceptual representation of the method for Delotte Digital via MLSAC method fragments. During the interviews, we used a questionnaire form (Appendix B) to capture the users' feedback in line with the quality factors. The feedback of users is presented in Table 5.

Results. The overall feedback from the users was positive along with suggestions for the improvements of the metamodel. Both E1 and E2 mentioned that providing such a rich repository of the method fragments with the possibility for an extension with new method fragments are excellent features of MLSAC. They believed that MLSAC positively contributes to the quality of the reengineering process as its comprehensiveness feature helps method engineers avoid missing any important method fragments for inclusion into a reengineering project. E1 highlighted that MLSAC is helpful for practitioners who may not be familiar with the cloud migration concepts. E2 noted that MLSAC is a move from a text-based presentation to a well-structured one that potentially facilitates method integration with other process modeling tools. Regarding the adherence to the semantic quality factor, both experts agreed that MLSAC covers major method fragments that are incorporated into a typical reengineering scenario. They also acknowledged the clarity of names, definitions, and classifications used in MLSAC.

The users raised some issues in relation to the pragmatic quality factor, specifically to user interface design. That is, E1 suggested adding a drag and drop feature for moving method fragments among phases to give better flexibility in working with the tool. Both E1 and E2, jointly, requested adding pre-built reusable templates relevant to specific domains such as mobile cloud computing, finance, or insurance as it seems MLSAC to be generic. Such templates would facilitate method creation, increase reusability, and reduce the tailoring effort for a given domain. They also suggested adding versioning control allowing multiple users to concurrently work on the same method in a way that if a user changes the method content, then MLSAC can automatically integrate this change into new a version of the method instance. Such concurrent access to a method is not supported by MLSAC at the current stage of this research. Furthermore, E2 suggested adding warning messages when users define an illogical sequence among method fragments that is against common reengineering scenarios, i.e. knowledge source. The above suggestions, yet applicable, but are outside of the main objectives of the current research and are noted as possibilities for future works.

5.4 Findings

MLSAC's metamodel captures a collection of typical and reusable method fragments for incorporation into typical cloud-specific reengineering processes. The method fragments have been carefully identified from the cloud computing literature and iteratively evaluated and revised towards its purported quality factors

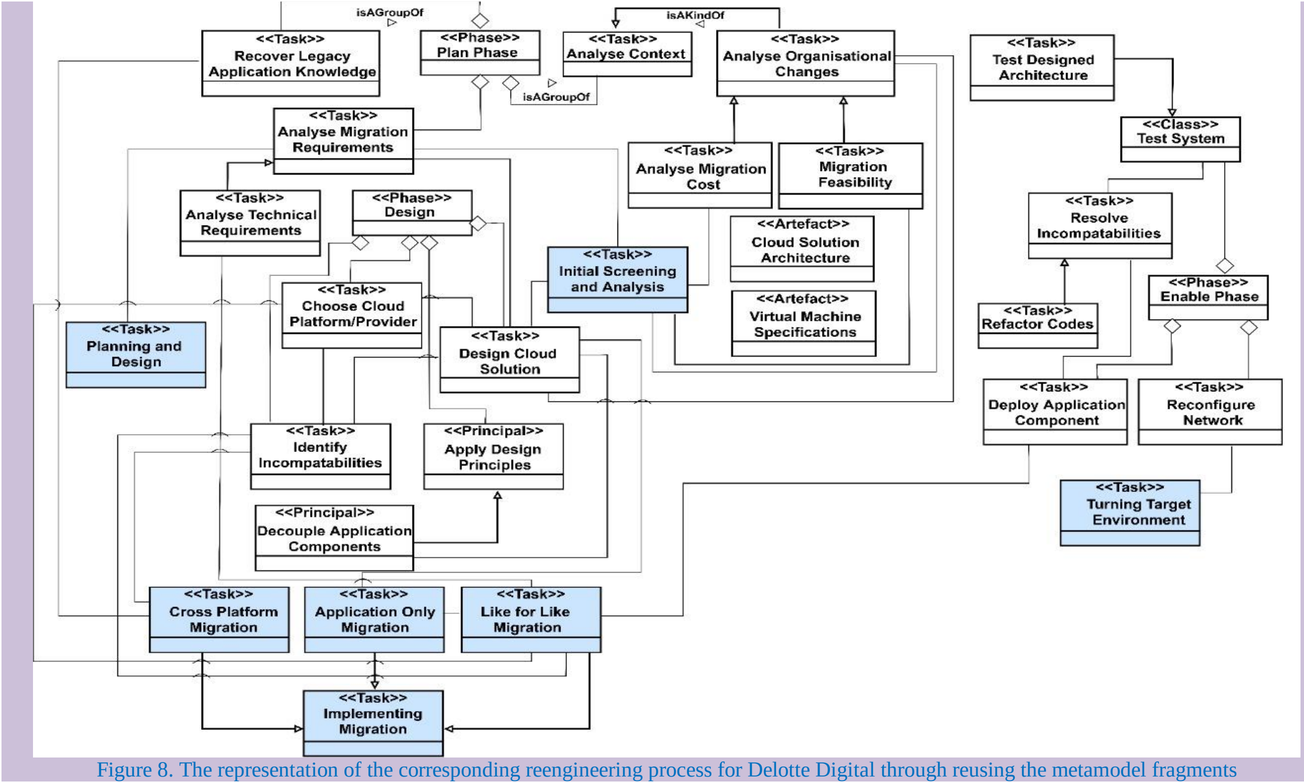


Figure 8. The representation of the corresponding reengineering process for Delotte Digital through reusing the metamodel fragments

. We report on these quality factors as a set of observations. Firstly, an observation regarding the semantic quality factor is that we cannot expect to achieve complete coverage of method fragments since every reengineering process may have its own detailed technical method fragments. However, the semi-formalism and modularity of the metamodel allow refining it to new method fragments whenever new requirements arise. Apart from that, during the third evaluation (Section 5.3), we found that development teams may have their in-house methods for the cloud migration projects. Our industry partners commonly agreed that MLSAC provides a good checklist and guidelines to assess the semantic quality of their in-house methods. Furthermore, an observation regarding the evaluation is that MLSAC has been more capable of representing commonalities and frequent concepts in reengineering processes rather than representing commonalities in the orders/sequences of method fragments. We believe that the definition of order for the method fragments is situation-specific, fluid, and attuned to the context of a project.

Secondly, an observation related to the tailorability quality factor is that achieving an appropriate level of abstraction for the development process description is a challenge. This is related to the granularity level chosen to represent a domain's concepts [47]. On the one hand, we had a tension to keep method fragments inclusive, generic, and applicable to represent different reengineering scenarios. On the other hand, the abstraction, inevitably, has caused the possibility of missing potential fine-granular and platform-specific method fragments in the repository. Re-structuring and storing an existing reengineering method, which is typically presented in a textual format, into MLSAC might be a cumbersome task initially as shown in Section 5.2. However, once the method is stored, its tailoring and maintenance will be more effective as MLSAC provides modularity and separation of concerns between method design and method operationalization.

6 Related Works

A wide range of modeling languages has been proposed in the cloud computing literature. While they overlap, they apply several diverse modeling viewpoints to cloud-based application development. We used the taxonomy proposed by Bergmayr et al. [48] to classify the areas of concerns and capabilities of the languages and to also compare our proposed framework with the existing works. The taxonomy defines aspects of *modeling design for cloud service deployment*, *elasticity*, *cloud services*, and *application architecture*. We discarded studies related to conventional legacy application reengineering as they fail to address technical and non-technical issues specific to reengineering for the cloud. For example, reengineering methods proposed by Sneed et al. [49], Bianchi et al. [50], Stroulia et al. [51], to name a few, are too general and do not provide method fragments ~~that are~~ pertinent to cloud migration, such as the heterogeneity of cloud services and legacy applications, multitenancy, dynamic scalability, and data security [3],[46].

Reengineering to cloud platforms shares similar characteristics and challenges with other themes of legacy software reengineering to Internet-based platforms. For example, in SOA hyped organizations, migration projects aim to enable new service chains to third parties. ~~, the i~~Integration and interoperability of multiple, redundant, and dispersed data with the service providers are all ~~certainly~~ also needed. The key contribution of the work by Razavian and Lago [52] is to design a conceptual model to classify ~~and classifications of~~ activities involved. These include~~ing~~ code analysis, architecture recovery, service design, and implementation with the aim ~~in order~~ to integrate ~~with and componentize~~ legacy applications to Web Services. An advantage of our framework over this and other ~~this work and other similar~~ SOA reengineering studies (~~,~~ e.g. [52],[53],[54],[55],[56]) ~~,~~ is that it caters for ~~to cover~~ cloud-specific reengineering challenges that have been less visible. These include ~~in SOA such as~~ multi-tenancy, scalability, statelessness, multiple cloud interoperability, application licensing, legal issues, and unpredictability of cloud services. Moreover, our MLSAC framework incorporates task method fragments *identify incompatibilities* in *design phase* (Figure 2.b) and *resolve incompatibilities*, which itself includes sub-tasks *adapt data*, *refactor code*, and *develop integrator* in *Enable phase* (Figure 2.c) into addressing integration and interoperability between on-premise software systems and cloud services. ~~We deem t~~The operationalization of these method fragments can certainly be augmented by the integration techniques presented in [52],[53],[54],[55],[56]. The following ~~subsections~~ further elaborates ~~discuss~~ how our MLSAC ~~framework is positioned in the literature and the way it~~ supersedes other notable related works.

6.1 Modeling related to cloud service deployment

Modeling enables developers to represent the target configuration and deployment of cloud applications that are a composition of cloud services. From this perspective, modeling languages are used to represent the location of services, availability zones, and storage services. Generated models are processed by tools to initiate service provisioning of computing and storage services based on deployment topology. Feature models and ontologies are a means to represent a deployment environment. For instance, computation and storage services can be captured as features of a cloud environment. MULTICLAPP [57] and the approach of Nhan et al. [58] adopt feature models to configure the target cloud environment by selecting the required cloud services. In contrast, MLSAC's objective is to provide a broad and general-purpose method model, including cloud service deployment-related method fragments, which is fundamentally at a higher level of abstraction compared to the above works. These works can be viewed as means to operationalize method fragment *Configure environment* in the *Maintain phase* of MLSAC's metamodel (Figure 2.d).

6.2 Modeling related to elasticity

Elasticity modeling provided by cloud platforms is used to define upper and lower bounds for service instances and elasticity rules based on which new resources are provisioned and released. CloudMIG [59] provides a modeling environment to describe elasticity rules for infrastructure level, e.g., CPU and storage. On the other hand, RESERVOIR-ML [60] and StratusML [61] offer a language for defining elasticity rules at a service level. Unlike CloudMIG [59], RESERVOIR-ML [60], and StratusML [61], we narrowed our view to the process lifecycle aspect. MLSAC itself defines *enable elasticity* method fragment in *Enable* phase (Figure 2.c). However, it does not provide an implementation technique for elasticity, whereas CloudMIG, RESERVOIR-ML, and StratusML define techniques to realize it. As stated earlier, the realization of method fragments goes beyond our metamodeling goal.

6.3 Modeling related to cloud services

In the cloud computing literature, modeling is used to represent QoS policies, constraints, and requirements such as scaling latency, 24/7 availability, and data security ~~to be satisfied by cloud services~~. For ~~instance~~example, models express terms such as *response time < 3 sec* or *Data storage is only within the Netherlands*. ~~The~~ Studies applying modeling a such ~~application modeling in this group of studies is~~ aim to ~~to~~ ensure ~~if~~ that service provisioning satisfies the service consumers~~'s~~ QoS. There are other studies that also ~~few examples in the literature~~ support~~ing~~ QoS modeling ~~concepts for capturing service levels~~ using either a structured language or natural language. GENTL [58] is capable of describing QoS constraints. Using predefined stereotypes and relational operators such as =,>, <*, and key-value pairs,* MULTICLAPP [57] allows capturing QoS constraints. TOSCA [61], on the other hand, enables developers to define policies for expressing QoS that a cloud service can declare to expose. These works largely omit the method modeling perspective, which is central to our research project.

6.4 Modeling related to application architecture

In [62],[63] metamodels have principally been employed to ease legacy application code refactoring to enable interactions with cloud services and to facilitate interoperability across multiple cloud platforms. This is based on feature-oriented techniques for managing requirements variability and transformation techniques to instantiate an application description into multiple cloud platforms. The MULTICLAPP [57] proposes a cloud-based application development in three phases. In the application modeling phase, UML is used to represent a cloud platform-independent model of the application. The model is transformed to class skeletons and subsequently to an XML-coded deployment plan containing target cloud-information. Metamodels have also been developed to address the issue of application interoperability over multiple cloud platforms. These include CloudML [64], C3 [65], WSDL metamodel [66], Cloud-Agnostic Middleware [67], OCCI metamodel [68] and many others. For instance, the CloudML [64] proposes an extension of SOAML (Service-oriented architecture Modeling Language) to model network resources required by applications from cloud services. The CloudML engine generates script models using the JClouds APIs where they define necessary adapters to allow the application deployable across multiple cloud platforms. In MODAClouds [63], three layers of application models are defined as follows: (i) computation independent models (CIM) to represent non-functional requirements, (ii) cloud provider independent models (CPI) to include generic cloud concepts, and (iii) cloud provider model (CPM) in which details of a chosen cloud platform are added to models. In contrast to the above works, our metamodel broadens its view throughout the reengineering process instead of code level, though one can utilize the above techniques during MLSAC instantiation to a specific reengineering method.

Frey et al. [69] propose using OMG's Knowledge Discovery Metamodel to extract a utilization model of legacy application architecture, including statistical properties such as service invocation rates over time and submitted datagram sizes per request. Such models are then automatically transformed to multiple cloud platforms. The work by Zhou et al. [70] is to identify application components that their deployment on cloud servers makes business value. Its five-step approach creates an ontology of the application architecture to decompose it into candidate services. These candidate services are the potential to move to the cloud. In another work by Hamdaqa et al., [71] a metamodel is suggested to represent main design principles, configuration rules, and semantic interpretation related to a cloud-based architecture. This facilitates a high-level architecture design of applications independent of cloud platforms. We believe these works could provide further supportive techniques for operationalization of MLSAC method fragment named *Design cloud solution* under *Design* phase (Figure 2.d).

7 Summary and Future Extensions

We presented MLSAC, a novel framework to create, maintain, share, and tailor method fits for migrating legacy applications to cloud platforms in actual practice. MLSAC provides an extensible set of method fragments, derived from the literature, in a fashion such that they complemented each other to address most aspects of cloud migration methods. The three-step evaluation of MLSAC shows its practical value. We do not anticipate major refinements to the methodological approach to design and evaluate MLSAC; however, we deem several future opportunities for augmenting MLSAC according to the quality factors.

Firstly, the tailorability of MLSAC can be improved by the ecosystem encompassing it. This includes a new set of guidelines to employ the metamodel. A further improvement is to define the development roles and responsibilities associated with the method fragments allowing method engineers to track the progress of the reengineering process.

Secondly, to increase the level of method reusability, we plan to enable method engineers to explore MLSAC repository to identify family-related method fragments through advanced visualization functions such as querying and filtering. Reusing a synergistic combination of individual methods or collection of method fragments can serve as a basis for creating new hybrid reengineering methods. For example, a reengineering method might be particularly designed to organize migrating legacy application database layers to Microsoft Azure SQL database. On the other hand, other methods might be suitable to be accommodated for deploying an application stack on AWS. Method fragments from both methods can be combined to create a new hybrid reengineering method to complement each other and address the overall reengineering process.

Fourthly, the evaluation of a newly created method is the last stage of a method tailoring effort [30]. This is not yet supported by our framework. It is a promising direction to provide techniques for semi-automated reasoning on a method validity. For example, this feature can uncover inconsistencies between selected and combined method fragments and identify missing important ones according to the requirements of a reengineering scenario. A higher level of automated validation can be achieved by providing consistent management rules and constraints in MLSAC.

Finally, in line with the pragmatic quality factor, MLSAC is currently limited to the tree view control, i.e., a common user interface control to visualize complex data structures, to represent the metamodel and method instances. It may raise difficulties in method design and visualization, particularly, for specifying the sequence among method elements (Figure 4.c). We plan to add new controls such as box, connector, and visual concrete syntax to enhance the usability of the framework.

ACKNOWLEDGMENTS

We would like to thank our industry partners who provided detailed and constructive feedback in different stages of this research. We would like to express our special thanks to anonymous reviewers whose comments improved this paper.

Appendix A

The list of selected core studies identified from literature review

ID	Authors and title	Abbreviation	Channel	Source	Year	Type*	Affiliation	Validation
[S1]	Krasteva, I., S. Stavru, et al., "*Agile Model-Driven Modernisation to the Service Cloud*"	ICIW	Conference	ThinkMind	2013	Methodology	Rila Solutions EAD, Bulgaria	Case study
[S2]	Beserra, P. V., A. Camara, et al, "*Cloudstep: A step-by-step decision process to support legacy application migration to the cloud*"	MESOCA	Workshop	IEEE	2012	Decision Making Framework	Brasil	Case study
[S3]	Mohagheghi, P., "*Software Engineering Challenges for Migration to the Service Cloud Paradigm: Ongoing Work in the REMICS Project*"	SERVICES	Conference	IEEE	2011	Method	SINTEF ICT, Norway	Case study
[S4]	Conway, G. and E. Curry, "*The IVI Cloud Computing Life Cycle*"	CCSS	Book Chapter	Springer	2013	Method	Innovation Value Institute, National University of Ireland	Example scenario
[S5]	Khajeh-Hosseini, A., D. Greenwood, et al, "*Cloud migration: A case study of migrating an enterprise it system to iaas*"	CLOUD	Conference	IEEE	2010	Experience	Cloud Computing Co-laboratory School of Computer Science University of St Andrews, UK	Case study
[S6]	Tran, V., J. Keung, et al, "*Application migration to cloud: a taxonomy of critical factors*"	SECLOUD	Workshop	ACM	2011	Experience	CSE, University of New South Wales, Australia	Experience report
[S7]	Khajeh-Hosseini, A., D. Greenwood, et al, "*The cloud adoption toolkit: supporting cloud adoption decisions in the enterprise*"	SPE	Journal	Wiley Online Library	2012	Approach	Cloud Computing Co-laboratory, School of Computer Science University of St Andrews, UK	Case study
[S8]	Kundra, V., "*Federal cloud computing strategy*"	Acmait	White Paper	Online	2011	Decision Making Framework	USA	Case study
[S9]	Chauhan, M. A. and M. A. Babar, "*Towards Process Support for Migrating Applications to Cloud Computing*"	CSC	Conference	IEEE	2012	Method	Software & Systems Group IT University of Copenhagen, Denmark	Case study
[S10]	Strauch, S., et al. "*Migrating eScience Applications to the Cloud: Methodology and Evaluation*"	-	Journal	CRC Press / Taylor & Francis	2014	Method	Institute of Architecture of Application Systems, University of Stuttgart, Germany	Case study
[S11]	S. Strauch, V. A., D. Karastoyanova, F. Leymann, "*Migrating Enterprise Applications to the Cloud: Methodology and Evaluation*"	JBDI	Journal	Perpetual Innovation Media	2014	Method	Institute of Architecture of Application Systems, University of Stuttgart, Germany	Case study
[S12]	Leymann, F., et al., "*Moving applications to the cloud: An approach based on application model enrichment*"	JCIS	Journal	World Scientific	2011	Approach	Institute of Architecture of Application Systems, University	Case study

							of Stuttgart, Germany	
[S13]	Zhang, W., et al., "*Migrating legacy applications to the service Cloud*"	OOPSLA	Conference	Unipub	2009	Method	SINTEF, Norway	Case study
[S14]	Frey, S., et al., "*Automatic conformance checking for migrating software systems to cloud infrastructures and platforms*"	JSEP	Journal	Wiley InterScience	2011	Approach	Software Engineering Group, University of Kiel, Germany	Simulation
[S15]	Miranda, J., et al., "*Assisting Cloud Service Migration Using Software Adaptation Techniques*"	Cloud Computing	Conference	IEEE	2013	Method	Dept. of Information Technology and Telematic Systems Engineering, University of Extremadura, C´aceres, Spain	Experience report
[S16]	Fehling, C., et al, "*Service Migration Patterns--Decision Support and Best Practices for the Migration of Existing Service-Based Applications to Cloud Environments*"	SOCA	Conference	IEEE	2013	Pattern and Method	Institute of Architecture of Application Systems, University of Stuttgart Stuttgart, Germany	Case study
[S17]	Tak, B. C., et al., "*To move or not to move: the economics of cloud computing*"	USENIX	Conference	USENIX Association	2011	Experience	The Pennsylvania State University, USA	Simulation
[S18]	Guillén, J., et al., "*A service-oriented framework for developing cross cloud migratable software*"	JSS	Journal	ScienceDirect	2013	Approach	GloIn, Calle Azorín 2, Cáceres, Spain	Case study
[S19]	Ardagna, D., et al., "*Modaclouds: A model-driven approach for the design and execution of applications on multiple clouds*"	ICSE	Workshop	MISE	2012	Approach	Politecnico di Milano, Italy	Simulation
[S20]	Hajjat, M., et al. "*Cloudward bound: planning for beneficial migration of enterprise applications to the cloud*"	SIGCOMM	Conference	ACM	2010	Approach	Purdue University, USA	Simulation
[S21]	Moens, H., et al., "*Design and evaluation of a hierarchical application placement algorithm in large scale clouds*"	IM	Conference	IEEE	2011	Approach	Ghent University - IBBT Department of Information Technology, Belgium	Simulation
[S22]	SUN, K., Li, Y., "*Effort Estimation in Cloud Migration Process*"	SOSE	Conference	IEEE	2012	Conceptual Model	IBM Research - China	Case Study
[S23]	Rabetski, P. and G. Schneider, "*Migration of an On-Premise Application to the Cloud: Experience Report*"	ESOCC	Conference	Springer	2013	Approach	Department of Computer Science and Engineering Chalmers University of Technology, and the University of Gothenburg Gothenburg, Sweden	Experience report
[S24]	C.,Pahl, H. Xiong, et al., "*A Comparison of On-Premise to Cloud Migration Approaches*"	SOCC	Conference	Springer	2013	Approach	IC4, Dublin City University, Dublin, Ireland	Experience report
[S25]	Laszewski, T. and P. Nauduri, "*Migrating to the Cloud: Oracle Client/Server Modernisation*"	Book	-	Elsevier	2012	Method	USA	Experience report

[S26]	Guo, X., "*Evaluation of a Methodology for Migration of the Database Layer to the Cloud based on an eScience Case Study*"	-	Thesis	-	2013	Method	Institute of Architecture of Application Systems University of Stuttgart, German	Two case studies
[S27]	Ahmad, Aakash, and Muhammad Ali Babar. "*A framework for architecture-driven migration of legacy systems to cloud-enabled software*"	WICSA	Conference	ACM	2014	Approach	IT University of Copenhagen, Denmark	Retrospective studies
[S28]	Ridha, Gadhgadhi, Khazri Saida, and Cheriet Mohamed. "*OPENICRA: Towards A Generic Model for Automatic Deployment of Applications in the Cloud Computing*"	IJ-CLOSER	Journal	Institute of Advanced Engineering and Science	2013	Approach	Multimedia Communication in Telepresence, Montréal (QC), Canada	Two case studies
[S29]	Council, C. S. C., "*Migration applications to public Cloud Services: roadmap for success*"	-	-	Cloud Standards Customer Council	2013	Method	Cloud Standards Customer Council	Experience report
[S30]	Menzel,M., "*(MC2) 2 : A Generic Decision-Making Framework and its Application to Cloud Computing*"	-	Journal	Wiley Online Library	2012	Decision Making Framework	Research Center for Information Technology Karlsruhe Institute of Technology, Karlsruhe, Germany	Simulation
[S31]	Quang Hieu, V. and R. Asal, "*Legacy Application Migration to the Cloud: Practicability and Methodology*"	SERVICES	World Congress	IEEE	2012	Pattern	ETISALAT BT Innovation Centre Khalifa University, UAE, United Arab Emirates	Experience report
[S32]	H.A.Huru, "*MILAS: Modernsing Legtacy Applications towards Service Oriented Architecture (SOA) and Software as a Service (SaaS)*"	-	Thesis	-	2009	Experience	University of Oslo	Two case studies
[S33]	Benguria, G., Elvesæter, B., Ilieva, S., "*REuse and Migration of legacy applications to Interoperable Cloud Services"*	-	Technical Report	Remics Consortium	2013	Method	Remics Consortium	Experience report
[S34]	Tang,K., Zhang J.M, Feng, C.H, "*Application Centric Lifecycle Framework in Cloud*"	E-Business Engineering	Conference	IEEE	2011	Method	IBM Research China	Example scenario
[S35]	Bezemer, C.-P., et al., "*Enabling multi-tenancy: An industrial experience report*"	ICSM	Conference	IEEE	2010	Pattern	Delft University of Technology, The Netherlands	Experience report
[S36]	Guo, C. J., et al., "*A framework for native multi-tenancy application development and management*"	CEC/EEE	Conference	IEEE	2007	Pattern	IBM China Research Laboratory, Beijing, China	Experience report
[S37]	Mietzner, R., et al., "*Cafe: A generic configurable customisable composite cloud application framework*"	-	Book Chapter	Springer	2009	Approach	Institute of Architecture of Application Systems University of Stuttgart, Germany	Example scenario
[S38]	Strauch, S., Andrikopoulos, V., Gómez Sáez, S., Leymann, F.	CLOSER	Conference	SciTePress	2014	Approach	Institute of Architecture of	Experiment

	"*Transparent Access to Relational Databases in the Cloud Using a Multi-Tenant ESB*"						Application Systems University of Stuttgart, Germany	
[S39]	Marimuthu C, K. Chandra Sekaran, "*Software Development for Cloud: An Experiential Study*"	CloudCom-Asia	Conference	IEEE	2013	Experience	National Institute of Technology Karnataka Mangalore, Karnataka, India	Experience report
[S40]	Anstett, T., et al., "*Towards BPEL in the Cloud: Exploiting Different Delivery Models for the Execution of Business Processes*"	Services-I	Conference	IEEE	2009	Pattern	Institute of Architecture of Application Systems, University of Stuttgart, Germany	Experience report
[S41]	Varia, J., "*Architecting for the cloud: Best practices*"	Technical Report	Book	Amazon	2010	Experience	USA	Experience report
[S42]	Bessani, A., et al., "*DepSky: dependable and secure storage in a cloud-of-clouds*"	TOS	Journal	ACM	2013	Approach	University of Lisbon, Faculty of Sciences, Portugal	Simulation
[S43]	Curino, C., et al., "*Relational cloud: A database-as-a-service for the cloud*"	-	Technical Report	MIT	2011	Experience	Massachusetts Institute of Technology. Computer Science and Artificial Intelligence Laboratory, USA	Simulation
[S44]	Binz, Leymann et al. , "*CMotion: A framework for migration of applications into and between clouds*"	SOCA	Conference	IEEE	2011	Method	Institute of Architecture of Application Systems University of Stuttgart, Germany	Example scenario
[S45]	Fehling, C., et al., "*Pattern-based development and management of cloud applications*"	-	Journal	Future Internet	2012	Pattern	Institute of Architecture of Application Systems, University of Stuttgart, Germany	Experience report
[S46]	Chauhan, M. A. and M. A. Babar, "*Migrating Service-Oriented System to Cloud Computing: An Experience Report*"	CLOUD	Conference	IEEE	2011	Experience	School of Innovation, Design, and Engineering Mälardalen University, Sweden	Experience report
[S47]	Zagarese, Q., et al., "*Enabling advanced loading strategies for data intensive web services*"	ICWS	Conference	IEEE	2012	Experience	Department of Engineering University of Sannio Benevento, Italy	Simulation
[S48]	Cisco Systems, *"Planning the Migration of Enterprise Applications to the Cloud"*	-	White Paper	Cisco Systems	2010	Experience	Cisco Systems	Experience report
[S49]	Duplyakin, D., et al., "*Rebalancing in a multi-cloud environment*"	-	Workshop	ACM	2013	Approach	University of Colorado, USA	Simulation
[S50]	Ali Babar, M., Chauhan, M.A., "*A Tale of Migration to Cloud Computing for Sharing Experiences and Observations*"	SECLOUD	Workshop	ACM	2011	Experience	IT University of Copenhagen, Copenhagen, Denmark	Experience report

[S51]	Pahl, C. and H. Xiong, "*Migration to PaaS clouds-Migration process and architectural concerns*"	MESOCA	Conference	IEEE	2013	Experience	the Irish Centre for Cloud Computing and Commerce, Ireland	Expert interviews and focus groups
[S52]	Saleh,E., Shaabani,N., Meinel, C., "*A Framework for Migrating Traditional Web Applications into Multi-Tenant SaaS*"	INFOCOMP	Conference	IARIA	2012	Approach	Hasso-Plattner-Institut University of Potsdam Potsdam, Germany	Case Study
[S53]	Karampaglis,Z., Mentis,A., Rafailidis,F., Tsolakidis, P., Ampatzoglou, A., "*Secure Migration of Legacy Applications to the Web*"	SEFM	Conference	Springer	2012	Approach	Department of Informatics, Aristotle University of Thessaloniki, Thessaloniki, Greece	Case Study
[S54]	Ilieva,S., Krasteva, I., Benguria, G., Elvesæter, B., "*Enhance your Model-driven Modernisation Process with Agile Practices*"	SEM	Workshop	SciTePress	2013	Method	IICT-BAS, Bulgaria	Case study
[S55]	Bahga, A., Madisetti, V.K., "*Rapid Prototyping of Multitier Cloud-Based Services and Systems*"	IEEE Computer	Journal	IEEE	2013	Method	Georgia Tech, USA	Simulation
[S56]	Logicalis, "*Logicalis, Migrating to the Cloud – A Logicalis How to Guide*"	-	White Paper	Logicalis	2013	Method	Logicalis	Experience report
[S57]	Lindner, M.A., McDonald, F., Conway, G., Curry E., "*Understanding Cloud Requirements - A Supply Chain Lifecycle Approach*"	-	Conference	XPS	2011	Method	SAP Research, Palo Alto, USA	Example scenario
[S58]	Zhu.Y., "*A Platform for Changing Legacy Application to Multi-tenant Model*"	IJMUE	Journal	SERSC	2014	Approach	School of Economic and Management, Shiyou University, China	Case study
[S59]	Zhou, H., Yang, H.,Hugill, A., "*An Ontology-Based Approach to Reengineering Enterprise Software for Cloud Computing*"	COMPSAC	Conference	IEEE	2010	Approach	Software Technology Research Laboratory De Montfort University Leicester, UK	Case study
[S60]	Frey.S., Hasselbring, W., "*An Extensible Architecture for Detecting Violations of a Cloud Environment's Constraints During Legacy Software System Migration*"	CSMR	Conference	IEEE	2011	Approach	Software Engineering Group University of Kiel, Germany	Case study
[S61]	Frey, S. and W. Hasselbring, "*The cloudmig approach: Model-based migration of software systems to cloud-optimised applications*"	-	Journal	GEOMAR	2011	Approach	Software Engineering Group University of Kiel, Germany	Simulation
[S62]	Banerjee, J., "*Moving to the cloud: Workload migration techniques and approaches*"	HiPC	Conference	IEEE	2012	Method	IBM Kolkata, India	Experience report
[S63]	Nussbaumer, N. and X. Liu, *"Cloud Migration for SMEs in a Service Oriented Approach*"	COMPSACW	Conference	IEEE	2013	Method	School of Computing Edinburgh Napier University	Case study

							Edinburgh, United Kingdom	
[S64]	Menychtas, A., Santzaridou,C., Kousiouris, G., Varvarigou, T., "*ARTIST Methodology and Framework: A novel approach for the migration of legacy software on the Cloud*"	SYNASC	Conference	IEEE	2013	Method	National Technical University of Athens Athens, Greece	Experience
[S65]	Andrikopoulos, V., Binz, T., Leymann, F., Strauch, S., "*How to Adapt Applications for the Cloud Environment*"	Computing	Journal	Springer	2013	Experience	Institute of Architecture of Application Systems, University of Stuttgart, Germany	Experience report
[S66]	S., Rajaraajeswari, R., Pethuru, "*Cloud Application Modernisation and Migration Methodology*"	-	Book Chapter	Springer	2013	Approach	Department of Master of Computer Applications, India	Example scenario
[S67]	Duarte and Silva 2013, "*Cloud Maturity Model*"	-	Thesis	-	2013	Method	Tecnico University, Lisbon	Case studies, interviews
[S68]	Kwok, T., "*A Software as a Service with Multi-tenancy Support for an Electronic Contract Management Application*"	SCC	Conference	IEEE	2008	Experience	IBM Research Division, Thomas J.Watson Research Center	Experience report
[S69]	La and Kim 2009, "*A systematic process for developing high quality saas cloud services. Cloud Computing*"	-	Book Chapter	Springer	2009	Method	Department of Computer Science Soongsil University, Korea	Feature evaluation
[S70]	Meiländer, Bucchiarone et al., "*Using a lifecycle model for developing and executing real-time online applications on clouds*"	ICSOC	Workshop	Springer	2012	Method	University of Muenster, Germany	Case study and experiment
[S71]	Varia, J., "*Migrating Your Existing Application to the AWS Cloud. A Phase-Driven Approach to Cloud Migration*"	-	White paper	Amazon	2010	Method	Amazon, USA	Experience report
[S72]	Wu, J., et al., "*Migrating a Digital Library to a Private Cloud*"	ICE	Conference	-	2014	Approach	Information Sciences and Technology Computer Science and Engineering Pennsylvania State University, USA	Simulation
[S73]	Betts,D., Homer, A., Jezierski, A., Narumoto, M., Zhang, H., "*Moving Applications to the Cloud on Microsoft Windows Azure*"	-	Book	Microsoft	2012	Approach	Microsoft, USA	Experience report
[S74]	Maenhaut, p., Moens, H., Ongenae, V., Turck, F "*Migrating legacy software to the cloud: approach and verification by means of two medical software use cases*"	SPE	Journal	Wiley Online Library	2015	Method	Ghent University, Belgium	2 case studies

Appendix B

The list of questions that domain experts were asked about MLSAC during the evaluation. This was organized into six steps:

Step i. Evaluate the quality of MLSAC repository containing relevant domain elements for representing the current in-house models.

Step ii. Evaluate the definitions and clarity of the method fragments.

Step iii. Click the Create New Method and follow the wizard steps to create the in-house method.

Step iv. Once the base method is created by MLSAC, browse and analyze to check if it covers relevant fragments that would be needed for the incorporation into the defined scenario.

Step v. Check if the definition of method fragments, representation, and symbols are understandable.

Step vi. Evaluate the simplicity of MLSAC to tailor the created models. Try to modify the method by:

Step vii.i. Adding new method fragments (e.g. phase, task, and work-product).

Step vi.ii. Modifying the existing definitions of method fragments.

Step vi.iii. Defining realization mechanisms/techniques and assigning them to method fragments.

Step vi.iv. Removing method fragments that are not necessary for inclusion in the method if needed.

Step vi.v. Defining relationships among method fragments as required.

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