Analysis of Service-oriented Modeling Approaches for Viewpoint-specific Model-driven Development of Microservice Architecture

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Abstract—Microservice Architecture (MSA) is a novel service-based architectural style for distributed software systems. Compared to Service-oriented Architecture (SOA), MSA puts a stronger focus on self-containment of services. Each microservice is responsible for realizing exactly one business or technological capability that is distinct from other services’ capabilities. Additionally, on the implementation and operation level, microservices are self-contained in that they are developed, tested, deployed and operated independently from each other.

Next to these characteristics that distinguish MSA from SOA, both architectural styles rely on services as building blocks of distributed software architecture and hence face similar challenges regarding, e.g., service identification, composition and provisioning. However, in contrast to MSA, SOA may rely on an extensive body of knowledge to tackle these challenges. Thus, due to both architectural styles being service-based, the question arises to what degree MSA might draw on existing findings of SOA research and practice.

In this paper we address this question in the field of Model-driven Development (MDD) for design and operation of service-based architectures. Therefore, we present an analysis of existing MDD approaches to SOA, which comprises the identification and semantic clustering of modeling concepts for SOA design and operation. For each concept cluster, the analysis assesses its applicability to MDD of MSA (MSA-MDD) and assigns it to a specific modeling viewpoint. The goal of the presented analysis is to provide a conceptual foundation for an MSA-MDD metamodel.

Index Terms—Services Architectures, Services Engineering, Modeling of computer architecture

I. INTRODUCTION

Microservice Architecture (MSA) [1] is an architectural style for service-based software systems. It emphasizes high cohesion, loose coupling and self-containment of services. A microservice denotes a component with well-defined interfaces that (i) provides a distinct, cohesive business or technological functionality to consumers; (ii) is autonomously developed and operated by one responsible team; (iii) comprises all technical artifacts for execution and deployment [2], [3]. Expected benefits of MSA adoption comprise (i) better flexibility of software system adaptation, as services are independently deployable and replacement is simplified; (ii) increased service quality and safety, because of isolated testability, higher resilience and runtime scalability; (iii) increased development team productivity as the architecture’s structure can be aligned to the team structure and each service being maintained by exactly one team [1], [2].

Compared to Service-oriented Architecture (SOA) [4], which is applied and studied for more than a decade, MSA is relatively young. It started to gain broad attention from practitioners and academia in 2014 and 2015, respectively [5]. However, with both architectural styles relying on services as building blocks for distributed software systems, they face similar challenges, e.g., in identifying, tailoring, composing and providing services [6]. Thus, it seems sensible to investigate findings from SOA research and practice with regard to their applicability to MSA. In this paper we focus on assessing the applicability of existing Model-driven Development (MDD) [7] approaches to SOA (SOA-MDD) in the context of MSA (MSA-MDD). MDD is a research area whose adoption to SOA has been object to extensive research [8].

Specifically, the paper aims at providing the conceptual foundation of a metamodel to subsequently implement an MSA-MDD modeling language. Such a language could facilitate design and operation of MSA-based software systems, e.g., by code generation [9]. It therefore presents an analysis of existing approaches to SOA modeling that yields a threefold contribution. First, our analysis surveys existing approaches to SOA modeling to identify and characterize modeling concepts related to service design and operation. Second, the analysis clusters semantically equivalent concepts of different modeling approaches and identifies clusters applicable to MSA-MDD. Third, it assigns applicable clusters to three modeling viewpoints [10] for MSA-MDD, i.e., Data, Service and Operation.

The paper is organized as follows. Section II presents differences between SOA and MSA relevant to service-based MDD. Section III elucidates the analysis. Subsection III-A first introduces the considered SOA modeling approaches. Next, Subsections III-B, III-C and III-D present the analysis method and results, including SOA modeling concepts applicable to MSA-MDD. Section IV discusses these results. Section V presents related work and Section VI concludes the paper.
II. Distinguishing Characteristics of Service-oriented and Microservice Architecture Relevant to Model-driven Development

MDD is a software engineering approach that considers models as means for abstracting the software to be built [11], as well as first-class citizens in the engineering process [7]. In particular, the development of complex software systems benefits from employing MDD [12], [13]. This is due to MDD providing modeling concepts on the problem-level that abstract from implementation details. Sets of coherent concepts define metamodels, i.e., abstract syntaxes for modeling languages, which enable the expression of all models conforming to the underlying metamodel [7]. Another cornerstone of MDD is model transformation [14], e.g., the automatic generation of implementation artifacts from models.

The application of MDD to SOA engineering is perceived to exhibit significant potential, because of the naturally high implementation complexity of distributed, service-based software systems [8], [12]. Hence, lots of effort has been spent on SOA-MDD research [8] and practice-oriented standardization [15]. SOA modeling puts a strong focus on generating code from models in the Development activity of software engineering [8], which is commonly expected to increase developer productivity [16]. SOA-MDD metamodels and languages comprise modeling concepts for services, interfaces, messages and ports, and are rather created from scratch than reused across the proposed MDD approaches [8].

While means for MSA-MDD might draw on the outlined knowledge about SOA-MDD, differences between SOA and MSA limit the applicability of existing SOA-MDD approaches to MSA [9]. Thus, to substantiate the analysis of such approaches with the aim to identify SOA modeling concepts applicable to MDD of MSA design and operation (cf. Section III), Table I lists relevant distinguishing characteristics (DCs) of SOA and MSA investigated in a previous work [9].

III. Analysis of Service-oriented Modeling Approaches

This section presents the protocol and results of our analysis of existing service-oriented modeling approaches. Therefore, Subsection III-A introduces the modeling approaches that were subject to our analysis. Following, Subsection III-B presents the protocol we applied to perform our analysis, as well as general results of initial protocol steps. Subsection III-C presents the modeling concepts identified as being applicable to MSA-MDD and their semantic clustering. Subsection III-D assigns applicable concepts to modeling viewpoints relevant to MSA-MDD, i.e., Data, Service and Operation.

A. Analyzed Service-oriented Modeling Approaches

We considered ten existing SOA modeling approaches for our analysis. As our primary goal was to establish a conceptual foundation for subsequent deduction of an MSA-MDD metamodel that (i) targets two phases of MSA engineering, i.e., design and operation, and (ii) is preferably comprehensive, we selected modeling approaches that (i) aim at enabling holistic SOA modeling, i.e, define modeling concepts for multiple SOA engineering phases, and (ii) exhibit different degrees of abstraction and formality, i.e., comprise conceptual as well as practical elements. Specifically, our analysis comprises modeling approaches of the following types.

Reference Models: A reference model is a conceptual framework that identifies relevant concepts of a given problem domain [15]. It further specifies relationships between concepts and is technology-independent.

Reference Architectures: Reference architectures describe concepts of a problem domain with a focus on software architecture implementation [22] and thus, compared to reference models, exhibit a lower degree of abstraction [15].

Modeling Languages and Profiles: Modeling languages are based on metamodels that formally describe the structures of valid models expressed with the language (cf. Section II). A metamodel may integrate a mechanism for tailoring or extending deduced modeling languages in modeling profiles [10]. Because modeling languages and profiles rely on a metamodel, they exhibit a high degree of formality, i.e., modeling concepts have well-defined structures and relationships, which enable applications to automatically process models [11].

Architecture Description Languages: An architecture description language (ADL) is a supportive modeling means for architecture-based software development [23]. In contrast to modeling languages and profiles, ADLs must comprise concepts for expressing architectural components, connectors and their configurations. ADL-based configuration modeling also covers component composition [23], which is a crucial characteristic of service-based architectures [6].

Table II lists the service-oriented modeling approaches, which we considered in our analysis. It also states, per approach, publication year, type with respect to abstraction and formality, foundational approaches if any and description.

B. Analysis Protocol and General Results

In the following, we outline the protocol for our analysis of the approaches in Table II to identify service-oriented modeling concepts applicable to MSA-MDD and assign them to related modeling viewpoints. Furthermore, we present general results yielded by initial protocol steps.

The analysis protocol comprised the following steps:

S.1 Identification and extraction of modeling concepts and concept-specific information from approach publications (cf. Table II).

S.2 Further characterization of modeling concepts per approach by surveying extracted concept-specific information. This step comprised three sub-steps:

S.2.1 Identification of relationships to other modeling concepts of the respective approach.

S.2.2 Identification of structures, i.e., concepts’ properties not represented as relationships.

S.2.3 Identification of formal constraints that exceed multiplicity specifications for relationships and structures.
Distinguishing Inter-service Application 24

MSA: Promotes to apply at most two different communication protocols, one for one-to-one and one for one-to-many service interactions. SOA: ESBs may implement protocol transformations, enabling hypothetic support for an arbitrary amount of protocols.

C3 Protocols

MAA: Microservices and consumers typically have to use the same message formats/structures. SOA: Interaction of services with consumers using different message formats/structures is enabled by transformation capabilities of an Enterprise Service Bus (ESB).

C4 Inter-service Interaction

MAA: For architecture-internal service interaction MAA prefers choreography over orchestration. SOA: SOA may equally apply both interaction patterns.

C5 Extra-service Interaction

MAA: For architecture-external interactions API gateways, i.e., rather simple façades for abstracting services’ endpoints and granularity, are employed. In particular, they do not implement sophisticated message or protocol transformation means like ESBs.

C6 Application Scope

MAA: Mostly applied to (i) realize workflow-based applications with clear process flows; (ii) decompose monoliths with decreased scalability; (iii) realize web applications without generic message formats/structures or protocols. SOA: Typically applied in enterprise-wide or cross-enterprise systems with heterogeneous message formats/structures, protocols or middleware technologies.

C7 Practice Orientation

MAA: Higher perceived orientation towards practitioners due to (i) a reduced service taxonomy; (ii) less complex implementation technologies, e.g., API gateways instead of ESBs; (iii) interoperable frameworks for implementation and provisioning of business-related and various infrastructural MAA components; (iv) focus on communication means perceived as being “lightweight”, e.g., REST instead of SOAP; (v) teams’ freedom of choice regarding service technologies, i.e., technology heterogeneity.

C8 Processes

MAA: Alignment of teams to features facilitates the application of container-based DevOps within development processes.

S.2.4 Survey of textual concept descriptions that, next to formally expressed relationships, structures or constraints, express further semantics or characteristics of concepts.

S.3 Removal of concepts from the extracted set to which at least one of the following exclusion criteria applies:

- Concept is used in an SOA engineering phase other than design or operation.
- Concept enables advanced modeling of (i) architecture structure above service level; (ii) applicable concepts with lower abstraction level; (iii) governance; (iv) policies; (v) QoS; (vi) service-internal behavior.
- Concept lacks relationships, structure, constraints and its textual description is too generic or imprecise.

S.4 Identification and bundling of semantically equivalent remained concepts in concept clusters across approaches.

S.5 Assessment of concept clusters’ applicability to MAA-MDD on the basis of SOA and MAA DCs (cf. Table I).

S.6 Identification of modeling viewpoints for MAA-MDD and assignment of applicable concept clusters to them.

The following paragraphs describe the executions of the initial steps S.1 to S.3 and their general results. The executions and results of the main protocol steps S.4 to S.6 are covered in more detail in Subsections III-C and III-D.

In step S.1 we performed a full reading of the approach publications listed in Table II whereby we identified and extracted 434 modeling concepts. Next, step S.2 yielded that of these concepts (i) 268 have relationships to others; (ii) 93 exhibit formal structure specifications; (iii) 15 comprise formal constraints not expressed in relationship or structure specifications. Table III breaks down these numbers per approach.

For reasons of space we do not present the raw results of steps S.1 to S.3, but provide them as supplemental material.\(^1\)

\(^1\)Link to raw results of protocol steps S.1 and S.2: https://fh.do/seaa2018-sm

| # | Distinguishing Characteristic | Peculiarity |
|---|---|---|
| C1 | Service Granularity | MSA: Alignment of service functionality to a distinct business or technological capability. For business-related services, bounded contexts [17] for clustering and isolation of related domain concepts may be applied. SOA: No explicit guidance. |
| C2 | Interface Abstraction | MSA: Microservices and consumers typically have to use the same message formats/structures. SOA: Interaction of services with consumers using different message formats/structures is enabled by transformation capabilities of an Enterprise Service Bus (ESB). |
| C3 | Protocols | MAA: Microservices and consumers typically have to use the same message formats/structures. SOA: Interaction of services with consumers using different message formats/structures is enabled by transformation capabilities of an Enterprise Service Bus (ESB). |
| C4 | Inter-service Interaction | MAA: For architecture-internal service interaction MAA prefers choreography over orchestration. SOA: SOA may equally apply both interaction patterns. |
| C5 | Extra-service Interaction | MAA: For architecture-external interactions API gateways, i.e., rather simple façades for abstracting services’ endpoints and granularity, are employed. In particular, they do not implement sophisticated message or protocol transformation means like ESBs. |
| C6 | Application Scope | MAA: Mostly applied to (i) realize workflow-based applications with clear process flows; (ii) decompose monoliths with decreased scalability; (iii) realize web applications without generic message formats/structures or protocols. SOA: Typically applied in enterprise-wide or cross-enterprise systems with heterogeneous message formats/structures, protocols or middleware technologies. |
| C7 | Practice Orientation | MAA: Higher perceived orientation towards practitioners due to (i) a reduced service taxonomy; (ii) less complex implementation technologies, e.g., API gateways instead of ESBs; (iii) interoperable frameworks for implementation and provisioning of business-related and various infrastructural MAA components; (iv) focus on communication means perceived as being “lightweight”, e.g., REST instead of SOAP; (v) teams’ freedom of choice regarding service technologies, i.e., technology heterogeneity. |
| C8 | Processes | MAA: Alignment of teams to features facilitates the application of container-based DevOps within development processes. |

| | Concept Count | ... with Relationships | ... with Structures | ... with Constraints |
|---|---|---|---|---|
| A1 | 10 | 7 | 2 | 0 |
| A2 | 15 | 10 | 3 | 0 |
| A3 | 25 | 21 | 2 | 0 |
| A4 | 35 | 35 | 4 | 0 |
| A5 | 24 | 0 | 11 | 0 |
| A6 | 45 | 0 | 0 | 0 |
| A7 | 12 | 10 | 0 | 0 |
| A8 | 157 | 92 | 4 | 0 |
| A9 | 34 | 27 | 18 | 15 |
| A10 | 77 | 48 | 49 | 0 |
| Σ | 434 | 250 | 93 | 15 |

In step S.3 we applied the mentioned exclusion criteria to each of the extracted and characterized modeling concepts. Hence, we filtered out concepts that do not support design and operation, but other phases of the SOA engineering process. For example, these phases comprised requirements’ elicitation with concepts like Non-Function Requirement of approach A7 (cf. Table II) and business modeling with concepts like Business-Goal Use Case from approach A1 or MotivationElement from approach A9.

We further removed concepts from the extracted set for modeling of (i) architecture structure above service level, e.g., SubArchitecture from approach A5 or InterCloud from approach A6; (ii) concepts at a lower abstraction level without being directly employable for SOA design or operation themselves, e.g., RelationshipType from approach A10; (iii) governance, e.g., SOA Governance from approach A8;
TABLE II
SERVICE-ORIENTED MODELING APPROACHES SELECTED FOR ANALYSIS AND IDENTIFICATION OF MODELING CONCEPTS APPLICABLE TO MSA-MDD.

| #  | Modeling Approach                                                                 | Year | Type          | Foundational Approach | Description                                                                                       |
|----|-----------------------------------------------------------------------------------|------|---------------|------------------------|---------------------------------------------------------------------------------------------------|
| A1 | Modeling and Design of Service-Oriented Architecture [24]                         | 2004 | Modeling      | UML                    | The approach employs service components as SOA building blocks. Interface-based design and UML are used to express capabilities as Business Service Components (BSCs). BSCs are composed from other BSCs and Application Service Components (ASCs) that implement fine-grained operations. Component interaction is contract-based. |
| A2 | A Modeling Framework for Service-Oriented Architecture [25]                       | 2006 | Modeling      | 3C-modeling [26]       | Proposition of a metamodel with service components as first-class citizens of SOA modeling. The metamodel also comprises modeling concepts for expressing: (i) required and provided ports to specify service interfaces; (ii) contracts; (iii) service choreographies. |
| A3 | Reference Model for Service-Oriented Architecture [27]                            | 2006 | Reference Model| n/a                   | The reference model identifies essential SOA concepts and their relationships. Next to concepts for service, contract and interaction modeling, it considers execution contexts and visibility of services. |
| A4 | A platform independent model for service oriented architectures [28]              | 2007 | Modeling      | MDA [10]               | The paper introduces the PIM4SOA approach. The underlying metamodel is structured on the basis of the four aspects: (i) Information, i.e., modeling of information elements the other aspects rely on; (ii) Service, i.e., technology-independent description of business capabilities; (iii) Processes for modeling message-based service interactions; (iv) Quality of Service (QoS) addressing non-functional aspects. |
| A5 | A New Architecture Description Language for Service-Oriented Architecture [29]    | 2007 | ADL           | XML                    | The presented SOADL language comprises concepts for modeling service interfaces, behavior, semantics and QoS-related aspects. Service composition is addressed by "port bindings". |
| A6 | Service-oriented Modeling Framework (SOMF) [30]                                   | 2011 | Modeling      | n/a                    | SOMF comprises a graphical modeling language for SOA-MDD. In addition to modeling concepts for services, interactions and compositions, it also considers modeling of cloud-based deployments as well as service, organizational and deployment boundaries. |
| A7 | SOA Reference Architecture [31]                                                   | 2011 | Reference Architecture | [32], approach A3 | The approach clusters SOA modeling concepts in Architectural Building Blocks (ABBs). ABBs are assigned to five functional and four non-functional, cross-cutting layers. Relationships between ABBs and hence modeling concepts are expressed as layered "interactions". |
| A8 | Reference Architecture Foundation for Service Oriented Architecture [22]          | 2012 | Reference Architecture | approach A3 | Ascertainment of the reference model in approach A3 with concept structures and additional concepts. The approach clusters concepts in Service Ecosystem, Realizing SOAs and Owning SOAs viewpoints. |
| A9 | Service oriented architecture Modeling Language (SoaML) Specification [33]        | 2012 | Modeling Profile | UML, approach A3     | The SoaML profile extends UML with concepts for SOA-MDD. It specifically provides means for sophisticated modeling of interfaces and interactions in the context of service-based software systems. |
| A10| Topology and Orchestration Specification for Cloud Applications (TOSCA) [34]     | 2013 | Modeling      | XML                    | TOSCA specifies a metamodel for expressing service deployment and operation. Despite not exclusively targeting SOA, we analyzed TOSCA to strengthen the consideration of operation-related modeling concepts. |

(iv) policies, e.g., Service Policy from approach A3 or Policy from approach A10; (v) QoS, e.g., QoSCharacteristic form approach A4; (vi) internal service behavior, e.g., Behavior from approach A5.

The extracted concept set was additionally reduced by removing modeling concepts that did not exhibit relationships to other concepts of their defining approach, structures or constraints in combination with a too generic or imprecise textual description. The approaches A3 and A8 comprise the majority of such concepts, e.g., Real World Effect and Risk. However, even publications of modeling languages, whose formality is expected to be high (cf. Subsection III-A), partially contain concept descriptions, which were insufficient for our analysis, e.g., Context from approach A2.

After finishing the execution of concept reduction step S.3, 100 concepts remained as inputs for protocol steps S.4 and S.5. Figure 1 relates the count of those concepts to the overall concept count per approach. The first percentage under each approach is the share of remained in the overall concept count.

C. Semantic Clustering of Concepts and Assessment of Clusters’ Applicability to Modeling for Microservice Architecture

The execution of protocol step S.4 (cf. Subsection III-B) included the encapsulation of modeling concepts, which remained after finishing protocol step S.3, in concept clusters.
across approaches. The clustering was based on the semantics of these modeling concepts, as defined by their characteristics identified in step S.2. Next, each concept’s applicability to MSA-MDD was assessed in step S.5.

The results of steps S.4 and S.5 are shown in Tables IV and V. Table IV lists concept clusters in which all concepts were assessed as being fully applicable to MSA-MDD. On the other hand, Table V includes all clusters that, next to fully applicable concepts, comprise at least one concept assessed as being partially applicable to MSA-MDD. Both tables exhibit an “Approaches” column, in which they state the modeling approaches whose concepts are part of the respective cluster. The column further states concepts’ names that differ in their defining approaches from the respective cluster’s name. Additionally, Table V differentiates partially (+) from fully (++) applicable modeling concepts, if both peculiarities of applicability occur within a concept cluster. Otherwise all concepts of a cluster in Table V were assessed as being partially applicable to MSA-MDD. For each concept assessed as being partially applicable, the “Comments” column of Table V contains a justification of the assessment that, if necessary, is based on the DCs of SOA and MSA (cf. Table I).

In total, we assessed 80 SOA modeling concepts as fully or partially applicable to MSA-MDD with 54 modeling concepts being assessed fully applicable (68%). Figure 1 also depicts the counts of applicable concepts per approach, as well as their shares in the overall concept count of the respective approach (second percentage under each approach).

D. Identification of Viewpoints for Microservice Architecture Modeling and Assignment of Applicable Concept Clusters

The last protocol step S.6 of the analysis of the service-oriented modeling approaches comprised the identification of modeling viewpoints for MDD of MSA design and operation. A modeling viewpoint provides a certain type of stakeholder with appropriate criteria to construct, select or present information about a system [10]. It hence reduces the complexity practitioners of MDD have to deal with. As microservice teams usually apply DevOps [21], typical MSA stakeholder types are service developer and operator. Hence, we defined a viewpoint for each of these types. The Service viewpoint for service developers comprises concept clusters from Tables IV and V, which focus modeling of microservices. The Operation viewpoint encapsulates clusters for specifying aspects of service deployment and operation. It thus addresses service operators.

Next to these viewpoints for typical MSA stakeholder types, we also included a Data viewpoint. Its addition was perceived to be sensible while executing protocol step S.3, because the analyzed approaches partially comprise explicit concepts for modeling information used by services. For example, Structure from approach A3 (cluster 31 in Table IV) enables expression of structural data types. While the number of concepts in the Data viewpoint is comparatively small, their semantics are extensive, e.g., as for Information Model from approaches A3, A7 and A8 (cluster 36 in Table V).

Based on the described semantics and scopes of the viewpoints, we assigned the concept clusters from Tables IV and V to them as shown in Table VI.

| Viewpoint | Concept Clusters | Approaches |
|-----------|-----------------|-------------|
| Data      | 31, 36          | A3, A7, A8  |
| Service   | 1, 2, 4, 7–9, 12, 14, 16–19, 21, 23, 27, 29, 33, 34, 37, 40–45 | A1–A6, A8, A9 |
| Operation | 3, 5, 6, 10, 11, 13, 15, 20, 22, 24–26, 28, 30, 32, 35, 38, 39, 46–48 | A1, A3, A4, A7–A10 |

Figure 2 shows for each viewpoint the count and share of assigned concept clusters.

The Data viewpoint comprises concept clusters for modeling data structures (cluster 31) and their integration in services’ information models (36).

The Service viewpoint’s concept clusters enable modeling of (i) services and basic service roles (1, 2, 4, 7–9, 23, 27, 29, 40, 41); (ii) message types and structures (12, 14, 16–19, 21, 37, 42); (iii) interfaces and contracts (43–45); (iv) collaborations and compositions (33, 34).

The Operation viewpoint encapsulates concept clusters for modeling (i) service artifacts (3, 22); (ii) technical infrastructure (5, 11, 13, 15, 20, 28, 35, 38, 39, 46–48); (iii) service provisioning (6, 10, 24–26, 30, 32).

IV. DISCUSSION

Subsections IV-A and IV-B discuss the impacts of the presented analysis results on subsequent metamodel deduction and elaborate on threats to the analysis’s validity.

A. Deduction of a Viewpoint-specific Metamodel for Microservice Architecture Modeling

The results of our analysis provide the basis for deducing a viewpoint-specific metamodel for MSA-MDD with a focus on microservice design and operation. The concept clusters shown in Tables IV and V may become initial concepts of the metamodel. Furthermore, it would be necessary to identify those characteristics of the applicable concepts (cf. Subsection III-B) that may be adopted to the metamodel.

Another aspect of the metamodel’s deduction is the linkage of the identified viewpoints. For example, it is conceivable that the Service viewpoint needs to refer to the Data viewpoint...
so that message models may use data structures as types, or that Service and Operation viewpoint have to be associated to enable modeling of microservice deployment. Viewpoint linkage may be achieved by defining relationships between metamodel concepts of different viewpoints, either based on adopted concept characteristics or the introduction of intermediate concepts.

Additionally, we expect the occurrence of contradictory overlaps in concept semantics when deducing the metamodel. In this case it has to be decided for each concept identified as being applicable to MSA-MDD in our analysis (cf. Section III) how such inconsistencies may be dissolved on the metamodel level. It is further likely that the deduction process will reveal clusters that can be merged with others to comprehensively cover an aspect relevant to MSA design or operation in the metamodel. For example, the clusters InMessage and OutMessage (cf. Table IV) may be represented by a property direction of a superior Message metamodel concept.

To cope with the mentioned challenges, we plan to deduce the metamodel in an iterative process, which continuously yields a more consistent version of the metamodel.

### B. Threats to Validity

Our analysis is affected by the following threats to validity.

**T1 Incomplete Selection of Modeling Approaches:** The analysis focused on surveying modeling approaches that take a holistic view on SOA-MDD (cf. Subsection III-A). However, it may be possible that we accidentally did not consider additional approaches with possible relevance to MSA design and operation. From our perspective, the impact of this threat is mitigated by the fact that Tables IV and V comprise clusters that directly correspond to the most recurrent metamodel concepts for modeling SOA design, i.e., Service, Operation, Message and Port [8]. In addition, all of these concepts occur in more than one analyzed approach, which makes us confident that they are central to service-oriented modeling in general. Considering the modeling of MSA operation, the threat’s impact is likely to be lowered by the fact that the cluster count of the Operation viewpoint exhibits a scale similar to that of the Service viewpoint (cf. Figure 2).

**T2 Missing Applicable Concepts:** Despite the fact that we are confident to have captured essential modeling concepts applicable to MSA design and operation, we may have missed other relevant concepts of the analyzed approaches. As we executed reduction step S.3 of our protocol (cf. Subsection III-B) manually, it is possible that we accidentally filtered out modeling concepts with potential applicability to MSA-MDD. We tried to mitigate this threat’s impact by double checking the results of the reduction step, as well as discussing and jointly deciding on edge cases. Furthermore, when deducing the metamodel, we plan to review further approaches, which specifically focus on a certain aspect of service-oriented modeling, to detail concept characteristics or identify additional concepts. This will apparently become necessary for the Data viewpoint, as it comprises comparatively few concept clusters (cf. Figure 2).
TABLE V
CONCEPT CLUSTERS COMPRISING AT LEAST ONE MODELING CONCEPT ASSESSED AS BEING PARTIALLY APPLICABLE TO MSA-MDD.

| # | Cluster          | Approaches (cf. Table II) | Comments on partial Applicability |
|---|------------------|---------------------------|----------------------------------|
| 33 | Collaboration    | A4, A9: Collaboration     | Modeling of complex service collaborations with roles. MSA has a simpler view on service interaction (cf. DCs C4 and C5 in Table I). |
| 34 | Composite Service| A5: Composite Service     | Sophisticated means for composing sets of fine-grained services with heterogeneous granularities to coarse-grained services. MSA facilitates composition as it proposes to align services to a self-contained, distinct functionality (cf. DC C1). |
| 35 | Enabling Technology | A7                       | MSA relates technologies to services rather than architectural layers (cf. DC C7). |
| 36 | Information Model | A3 (++), A7 (+), A8 (+)   | A8: In MSA-MDD, service models may not need to comprise abstracted message semantics for transforming exchange formats or structures (cf. DC C2). |
| 37 | Message          | A4 (+), A5 (+), A8 (++)+  | A4: MSA exhibits a reduced application scope and service taxonomy not requiring role-based interaction modeling (cf. DCs C6, C7). A5: Microservices and consumers typically agree on the employed message formats/structures (cf. DCs C2). Modeling of semantics may hence not be necessary. |
| 38 | NodeTemplate     | A10                       | The minInstances and maxInstances properties denote concept parts applicable to modeling of container-based microservice deployments (cf. DC C8). |
| 39 | NodeTypeImplemen-| A10                       | When associated with the concept, the semantics of the DeploymentArtifact and ImplementationArtifact concepts are applicable to modeling of container-based microservice deployments (cf. DC C8). |
| 40 | Participant      | A9                        | Exhibits a high generality. Concept parts related to services are predominantly applicable to designing, e.g., microservice interfaces and contracts. |
| 41 | ProvidePort      | A2: ProvidePort (+)+      | A9: Abstract, technology-independent semantics and constraint models of service provisioning are not mandatory for MSA design and operation (cf. DCs C2, C3). |
| 42 | Service Component| A1: Service Component     | Both concepts provide, among others, means for sophisticated modeling of role-based service interaction, typically not applied by MSA (cf. DCs C4, C5). |
| 43 | ServiceContract  | A1: Contract              | Concepts comprise conceptual or concrete parts for modeling complex service collaborations with respect to roles. MSA usually does not realize such complex collaborations (cf. DCs C4, C5). |
| 44 | Service Interface| A2: InterfaceDeclaration (+) | A2: Service interfaces may not need abstract property or constraint descriptions for transforming message formats/structures or protocols (cf. DCs C2, C3, C6). |
| 45 | Service Operation| A1 (+), A3: Service (+)   | A1: Relationship to Business-Goal Use Case concept is not a mandatory prerequisite for MSA design and operation. |
| 46 | Solution Building Block | A7                     | Typically, MSA relates technology to services, not architectural layers (cf. DC C7). |
| 47 | Technical Assump-| A8                        | MSA-MDD may not need to consider modeling of physical limitations, e.g., flow speeds or disk access speeds (cf. DCs C6, C7). |
| 48 | Usage Management | A8                        | Financial resource modeling on the service level may not be needed for MSA-MDD. |

**T3 Lack of Practical Applicability:** MSA exhibits a high practice orientation (cf. DC C7 in Table I). However our analysis also considered modeling approaches with a rather theoretical focus, i.e., A3, A7 and A8. Hence, concept clusters may comprise elements with a comparatively low or even non-existent practical relevance. For now, we accept that this threat’s impact may result in superfluous metamodel concepts. However, we plan to identify and remove such concepts irrelevant to practical MSA design and operation from the metamodel by surveying (i) related experience reports; (ii) related solution proposals; (iii) MSA developers and operators.

### V. RELATED WORK

In the following, we present work related to analyzing SOA modeling approaches and metamodeling for MSA-MDD.

In 2013, Mohammadi et al. published a review of SOA modeling approaches for Enterprise Information Systems [35]. The review comprised seven modeling approaches and included the approaches A3, A4, A6, A8 and A9 of our analysis (cf. Table II). The two remaining approaches are the SOA ontology [32], on which approach A7 is based, and SOMA [36], which leverages SoaML [33] for service modeling, i.e., approach A9 of our analysis. Furthermore, the review is mainly focused on identifying and summarizing the major features of the considered modeling approaches. It does not analyze specific modeling concepts. Additionally, MSA in general and aspects of modeling SOA operation are not explicitly covered.

Ameller et al. published results of a comprehensive mapping study on SOA-MDD based on 129 papers in 2015 [8]. Among others, one of their research goals was to investigate characteristics of SOA-MDD approaches (cf. Subsection III-B) and the study reported on the seven most recurrent metamodel concepts in SOA-MDD. While considering a wide range of scientific publications for this purpose, the study did not involve an assessment of the concepts’ applicability based on their semantics. Furthermore, MSA and modeling of SOA operation were out of the study’s scope. However, papers from the study addressing modeling of SOA design may be surveyed for populating an initial MSA-MDD metamodel with further concepts or refining existing concepts. This would mitigate the
impact of threat T2 (cf. Subsection IV-B).

AjIL [37] is a graphical language for MSA-MDD. It comprises basic concepts for modeling (i) data structures; (ii) microservices and their interfaces; (iii) technical infrastructure. However, the metamodel lacks several essential concepts of SOA modeling [8] shown in Tables IV and V. For example, it does not comprise concepts for specifying (i) service contracts and messages; (ii) protocols and endpoints; (iii) artifact and security technologies. Furthermore, AjIL does not define modeling viewpoints. Despite these shortcomings, AjIL exhibits a high practice orientation, as it is based on publicly available MSA implementations. Hence, we will review AjIL when deducing a metamodel on the basis of our analysis to raise its practical applicability and mitigate the impact of threat T3.

VI. CONCLUSION AND FUTURE WORK

This paper presented an analysis of existing SOA modeling approaches with the aim to identify modeling concepts applicable to viewpoint-specific MDD of MSA design and operation. Therefore, we first elucidated differences between SOA and MSA relevant to MDD (cf. Section II). Next, we introduced the ten SOA modeling approaches (cf. Subsection III-A), which were analyzed following a rigorous protocol (cf. Subsection III-B). Its first three steps yielded 100 modeling concepts possibly applicable to MDD of MSA design and operation. The applicability was then assessed considering SOA and MSA differences (cf. Subsection III-C). This resulted in 48 applicable concept clusters, being assigned to three MSA-MDD viewpoints (cf. Subsection III-D). The analysis’s discussion covered, among others, challenges of deducing a metamodel from the results (cf. Section IV).

In future works we plan to define a metamodel on the basis of the presented results. Our goal is to implement a modeling language for the metamodel to provide practitioners with generative means for microservice design and operation.

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