

A Commitment-based Reference Ontology for Services

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Abstract

The concept of “service” has been characterized in different disciplines and by different authors from various points of view. This variety of characterizations has emerged because although this notion seems intuitive, it is far from trivial, with many interrelated perspectives. Given their importance in enterprise computing and Service Science in general, we believe that a clear account of services and service-related concepts is necessary and would serve as a basis for communication, consensus and alignment among approaches and perspectives. In this paper we propose a commitment-based account of the notion of service captured in a core reference ontology called UFO-S. We address the commitments established between service providers and customers, and show how such commitments affect the service lifecycle. Moreover, we show that the commitment-based account can serve to harmonize different notions of service in the literature.

Keywords

Service science; service computing; service ontology; service commitments; service perspectives.

1. Introduction

The notion of “service” has had a major impact on Marketing, Business and Computer Science over the last decades, leading to cross-discipline efforts under the banners of “Service Science” and “Service Computing”. Several authors from different disciplines have referred to this notion under various perspectives, leading to a variety of characterizations for “service”, each emphasizing different aspects. For example, the *service as behavior* perspective focuses on the interactions among service participants to achieve results or generate effects [1][2][3][4]; *service as value co-creation* focuses on services as the basis of economic exchange [5][6][7]; *service as capability* focuses on the capability of a provider to produce benefits to customers [8][9]; *service as application of competences* focuses on the manifestation of one party’s capability to act in benefit of another party [5]; finally, *service as software* focuses on pieces of software that can be accessed through well-defined interfaces [10][11].

We believe these characterizations are influenced by many aspects, such as the research community to which their authors belong (e.g., Service Science or Service Computing), the targeted application area (e.g., Data Communication or Distributed Computing [12]), or the layer in an Enterprise Architecture (Business, Application, or Technology [2]). We claim that this variety of characterizations has emerged because although this notion seems intuitive, it is far from trivial. Under close inspection, we have observed that the term “service” often denotes different (possibly related) underlying concepts. A possible problem from this is that

“even if different communities of practice can live with their own somewhat inconsistent views of service, conflicting views of service surely cannot facilitate effective communication between business and IT practitioners and between business and computer science researchers” [13].

Given the importance of services in Service Computing and Service Science in general, we believe that a clear account of the underlying concepts is necessary and would serve as a basis for communication, consensus and alignment of the various approaches and perspectives. Thus, we propose in this paper a *core reference ontology for services*, called UFO-S, that intends to address the notion of service broadly in such a way as to harmonize different service perspectives, and has application to both Service Science and Service Computing. Several conceptual models and ontologies of service have been proposed, including: OWL-S [14], WSMO [15], The Open Group’s Service Ontology [16], the Reference Ontology for Semantic SOA [17], the HL7 SOA Healthcare Ontology [18], The Service Ontology [19], the Goal-Based Service Ontology (GSO) [20], The Onto-ServSys [21], and the model of services of Bergholtz et al. [22]. The focus of each of these models is on particular applications and/or perspectives, none of them serving as a reference ontology capable of harmonizing the various service perspectives.

A core reference ontology provides a semantic characterization of the core terms used in a specific field that spans different application domains, with the purpose of minimizing ambiguities and misunderstandings [23][24]. The ontology we present here, named UFO-S, is indeed designed to account for a conceptualization of services that is independent of a particular application domain, and is designed to be applied in an off-line manner to assist humans in tasks such as meaning

negotiation and consensus establishment. To this end, we ground our axioms and definitions in a *foundational ontology*, namely the Unified Foundational Ontology (UFO) [25][26], which provides us with basic concepts for objects and events, their types, relations and properties, as well as intentional and social elements to account for agents, the social relations they establish, the actions they undertake, etc. By grounding UFO-S in a foundational ontology, we are able to reveal important conceptual distinctions that would otherwise be ignored in informal characterizations of services.

Our account builds upon earlier works that treat services under the perspective of the *commitments* involved in service relations [27][28][29][30]. This perspective emphasizes that, throughout the service life-cycle, commitments of several natures are established between service providers and service customers. We address three main aspects: (i) the characterization of commitments (and corresponding claims) in service relationships; (ii) the roles played by agents in service relationships, as a consequence of the established commitments; and (iii) the dynamics of the relationships between the agents along the service life-cycle, in which commitments are established and fulfilled. As we shall see, it is exactly the capability of describing such dynamics (by means of the “relator” notion) that mainly motivates our choice of UFO with respect to other foundational ontologies (like, for instance, DOLCE, adopted in previous approaches [27][28]). This paper extends our previous work on UFO-S [31] by: (i) defining an axiomatization to increase the ontology’s precision; (ii) showing how UFO-S explains and clarifies the relations between the various service perspectives, providing at the same time core notions which can account for the various perspectives; and, (iii) discussing a number of additional related service ontologies and conceptual models. The axiomatization presented here is the result of a formalization process employing a model simulation approach using the Alloy Analyzer [32]. Consistence of the axiomatization and diagrams is guaranteed by checking the satisfiability of the corresponding Alloy specification. Other quality aspects (such as completeness) are assessed by visual simulation following the approach discussed in [32]. Details of this formalization process are presented in an accompanying technical report [33].

This paper is further structured as follows: Section 2 motivates the commitment-based characterization of services; Section 3 presents the foundational ontology we adopt as a basis for UFO-S and justifies this choice; Section 4 presents UFO-S by means of well-founded models and correspondent axiomatization; Section 5 presents a complete running example of UFO-S in the car rental application domain; Section 6 describes how UFO-S (based on the perspective of “service as commitment”) can harmonize various service perspectives; Section 7 discusses related work; Section 8 presents a discussion about the polysemy of the term “service” and suggests a *core meaning* for the “service” concept; and, Section 9 presents the final considerations.

2. Service and Commitments

A number of works in Service Science [13][28][30] and Service Computing [20][34][35] explicitly mention commitments/promises/obligations established between service participants in the service life-cycle. For Dumas et al. [35], a service instance is essentially a promise by one party (the *provider*), to perform a function on behalf of another party (the *consumer*). Ferrario and Guarino [28] associate the concept of service to an explicit commitment between provider and customer, and also to the corresponding service process. Santos et al. [20] define a service as a temporal entity related to the provider’s commitment, on behalf of a client, to perform an action of a certain type whose outcome satisfies a client’s goal. Sullivan [34] defines the notion of “obligation” for capturing the responsibilities of both the service provider and the service requester.

The benefits of a characterization based on commitments have been discussed from the perspective of business [30] as well as IT [29]. For example, Alter [13] points out the mutual responsibilities associated to service commitments are important aspects for characterizing service dynamics. Mingming and Yubei [30] highlight that service commitments are useful to deal with service intangibility, by offering means to convert intangible service aspects into more “concrete service standards”. Singh and colleagues [29] remark that commitments can be used for raising the low-level of abstraction of existing service-oriented architectures, allowing to reduce the gap between the business and the IT perspectives. In their view, commitments capture business meaning, which is not directly represented in process-oriented approaches such as BPMN [29].

Further, some kinds of service business models cannot be suitably explained without the notion of commitments. To show this, Ferrario and Guarino [28] bring the example of an insurance

service, where the customer pays for having someone (an insurer) who is *committed* to intervene in case of an accident. Arguably, both the customer and the insurer hope that such intervention will never occur. In this case, the service is provided by the mere existence of a commitment even if no actions are executed.

Commitments affect the overall service life-cycle, which we can broadly split in three main phases: (i) service offer, (ii) service negotiation, and (iii) service delivery. *Service offer* is the initial phase in which services are presented to target customers, and important aspects such as provider's availability, pricing, payment, security, quality of service, and reputation [35] are described and published. *Service negotiation* is characterized by the interaction between customer and provider in order to establish an agreement about their responsibilities [28]. If service negotiation is successfully achieved, a service agreement is established, determining what has been settled between service participants for service delivery. Finally, *service delivery* concerns the execution of actions needed to fulfill the established commitments [35]. The broad impact of commitments in the service life-cycle, as well as the benefits of such a view, motivated us to consider a commitment-based account as a focal point for our reference service ontology.

3. The Unified Foundational Ontology

The service ontology we present in this paper, called UFO-S, is a specialization of a more general ontology, the UFO (Unified Foundational Ontology) [25][26][36][37]. UFO is a *foundational ontology*, in the sense that it aims at providing a system of basic categories and relations whose intended meaning is grounded in very general principles inspired by Formal Ontology, Philosophical Logic, Linguistics, and Cognitive Psychology, and formally characterized by means of logical axioms. UFO-S, which is based on UFO, belongs to the class of so-called *core ontologies*, situated in a region between foundational and domain-specific ontologies. A core ontology provides a refinement to a foundational ontology in a specific field, while remaining at the same time general enough in order to be used for multiple application domains. So, foundational ontologies serve as basis for core ontologies, as core ontologies do for domain ontologies [23].

UFO consists of three main modules: UFO-A, an ontology of endurants (objects) [25], UFO-B, an ontology of events (perdurants) [26][36], and UFO-C [26][37], an ontology of social entities built up on UFO-A and UFO-B. All these modules are used for offering the ontological foundation of UFO-S.

Similarly to other foundational ontologies, such as DOLCE [38] or GOL/GFO (General Formalized Ontology) [39], UFO is inspired in the so-called "Aristotelian Square", which allows for the construction of an ontology that is able to account both for natural science as well as linguistic and cognitive phenomena [25]. However, differently from these other two foundational ontologies, which have been developed with different primary foci, UFO was constructed with the primary goal of developing foundations for conceptual modeling. As a consequence, there are many aspects that are essential for conceptual modeling, but which have not received a sufficiently detailed attention in DOLCE and GOL/GFO. A major difference with respect to DOLCE and GOL/GFO is a detailed account of so-called *universals* (such as unary or binary relations), which refines and extends the OntoClean distinctions [40]. In particular, concerning binary relations, an important distinction is made between formal and material relationships, since in order for the latter to hold the existence of a specific truth-making individual (the so-called "relator") is required. As we shall see, the explicit modeling of relators will turn out to be crucial for characterizing the notion of service commitment, and in general the various relations between service participants (service providers and service customers). Finally, the support offered by UFO (more specifically, by UFO-C) for addressing social aspects (e.g., social commitments/claims, delegation, dependence, and agents) is essential for characterizing the dynamic of service relations, which are inherently a social phenomenon. Besides of the aforementioned characteristics of UFO, our choice of using UFO also relies on that fact that this foundational ontology has been successfully applied in previous works to evaluate, redesign, and ground ontologies, models, and frameworks of several research areas, such as Software Engineering, Conceptual Modeling, and Enterprise Modeling [26][41][42][43][44][45]. The UFO fragments that are relevant to this work are discussed in the sequel.

3.1. UFO-A and UFO-B

UFO makes a fundamental distinction between individuals and universals [25]. *Individuals* are entities that exist in reality and possess a unique identity, while *universals* are abstract patterns of features that can be realized in a number of different individuals. UFO-A focuses on *endurants* whose patterns of features are called *endurant universals* [25]. UFO-B, in turn, focuses on events (a.k.a. *perdurants*) whose patterns of features are *event universals* [26].

Fig. 1 presents a fragment of UFO (A and B) that focuses on categories of individuals.

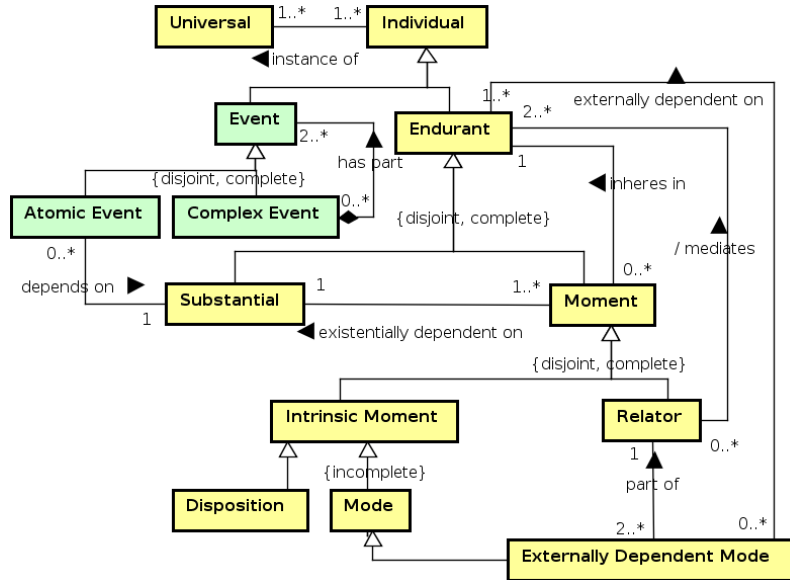


Fig. 1. A fragment of UFO-A and UFO-B (Individuals).

Endurants are individuals that are wholly present whenever they are present. The category of endurants can be further specialized into substantials and moments. *Substantials* are existentially-independent endurants (e.g., a person, a car). *Moments* are individuals that can only inhere in other individuals, and, thus, they are existentially-dependent on their bearers (e.g., a person's headache, a covalent bond between atoms) [25].

Intrinsic moments are moments that inhere in one single individual (e.g., an apple's color). *Modes* are intrinsic moments that are not directly measurable (e.g., John's desires, intentions, perceptions, symptoms, skills) [25]. Following [46][47], *dispositions* in UFO are intrinsic moments (e.g., the fragility of a glass) that may be manifested in particular situations through the occurrence of certain events, and that can also fail to be manifested. Take for example the disposition of a magnet to attract metallic material. The magnet has this disposition even if it is never manifested, e.g., because the magnet was never close to any magnetic material. Nonetheless, it can certainly be said to possess that intrinsic property [36].

Relators, introduced in [25], are moments that existentially depend on two or more endurants. They come into existence when a *material* relationship between such endurants is established. For example, assume that John and Mary get married. In this case, several externally-dependent (i.e., relational) modes come into existence, such as all emotions, commitments and claims towards each other, originated by the same foundational event (in this case the wedding event). The relator is an endurant that, at each time the marriage relationship holds, aggregates all the externally-dependent modes that the two persons acquire in virtue of participating in this relation. In the UFO literature, relator names are commonly nominalizations of the verb that expresses the underlying relation (e.g., married-to/marriage). It is important however to stress that, despite such nominalizations are often understood as referring to perdurants (e.g., 'marriage' denotes the life of the couple after the wedding), a relator is not a perdurant. Rather, it can be seen as the constitutive subject of the relationship's life, whose changes in time account for the *way* the relationship evolves².

² This short introduction to relators marks a difference with respect to the original notion discussed in [25], which reflects our most recent understanding of this important construct. A detailed discussion of such difference is however not relevant to the goals of this paper.

Fig. 2 presents a fragment of UFO (A and B) that focuses on the categories of universals.

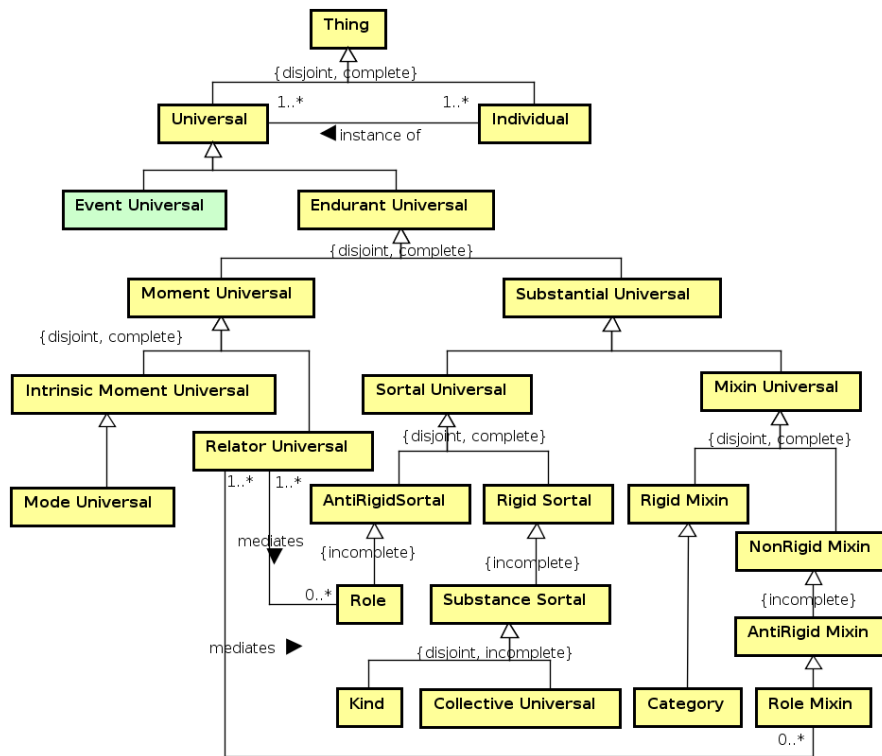


Fig. 2. A fragment of UFO-A and UFO-B (Universals).

In UFO-A, *substantial universal* and *moment universal* are kinds of universals whose individuals are substantial individuals and moments [25], respectively. Concerning the *Substantial Universal* hierarchy, *Sortal universals* are substantial universals that carry a principle of identity for their individuals (e.g., Apple, Person, Student). The particular salient specialization of *Sortal Universal* is based on a meta-property called rigidity. A universal is *rigid* if it necessarily applies to its instances, i.e., if it classifies its instances in every possible world (e.g., Apple, Person). *Kinds* are rigid sortal universals that provide a uniform principle of identity for substantial individuals that instantiate them (e.g., Person). *Collective Universals* are rigid universals that represent collections of individuals with uniform structure (e.g., deck of cards, a forest, a group of people, a pile of bricks). Such universals provide a principle of identity for the instances of a collection (but not for every individual in the collection), which can be either intensional or extensional [25]. In contrast to rigid universals, a universal is *anti-rigid* if none of its instances is necessarily an instance of such universal. For example, an individual x , which is an instance of the universal Student in a world w_1 can cease to instantiate this universal in another world w_2 without ceasing to exist as the same individual (i.e., as the same Person). *Roles* are anti-rigid and relationally dependent sortal universals (e.g., Student) [25]. This means that roles are played by an object in a relational context represented by a relator connecting the role players to other entities in that context (e.g., in order for someone to be a Student, she must be connected via an enrollment relator to an Educational Institution).

Mixin Universals are substantial universals that represent an abstraction of properties common to instances of multiple kinds and, therefore, do not carry a unique principle of identity for these instances (e.g., Physical Object, Living Entity). *Categories* represent rigid and relationally independent mixin universals that aggregate essential properties common to different kinds (e.g., Intelligent Agent). *Role Mixins*, in turn, represent anti-rigid and relationally dependent non-sortal universals that aggregate properties common to different roles.

Finally, as opposed to endurants, *events* are individuals that may have temporal parts. They happen in time in the sense that they extend in time and accumulate temporal parts (e.g., a conversation, a business process). Whenever an event is present, it is not the case that all its temporal parts are present. *Event universals* are patterns of features that can be realized in a number of different events [26][36]. Events can be complex or atomic. *Atomic events* have no proper parts

and are dependent on a substantial. *Complex events* are aggregations of at least two disjoint events [26][36]. The notion of *foundation* as a type of *historical dependence* [48][49] offers an important grounding for associating events to relators, since relators are founded by events (e.g., the *marriage* relator is founded on a particular *wedding* event) [48]. In this work, this notion is important because it offers means to explain the association between events in a service life-cycle, and the relators created among service participants, as discussed in Section 4.

3.2.UFO-C

UFO-C is an ontology of social entities that specializes UFO-A and UFO-B [26][37]. A basic distinction in UFO-C is related to agents and (non-agentive) objects. *Agents* (described in Fig. 3 in more detail) are agentive substantial individuals that are classified as *physical agents* (e.g., a person) or *social agents* (e.g., an organization, a society). *Objects* are non-agentive substantial individuals that are classified in *physical objects* (e.g., a book, a table) and *social objects* (e.g., money, language). A *normative description* is a type of social object that defines one or more rules/norms recognized by at least one social agent, and that can define nominal universals, such as social moment universals (e.g., social commitment types), social objects (e.g., the crown of the King of Spain) and *social roles* (e.g., president, pedestrian). Examples of normative descriptions include contracts in general, but also sets of directives on how to perform actions within an organization. A plan description is a special type of normative description that describes complex action universals (complex plans) [41] (i.e., complex plans, such as processes or guidelines). Fig. 3 presents a fragment of UFO-C that focuses on the distinction between agents and objects, and on the definition of normative description.

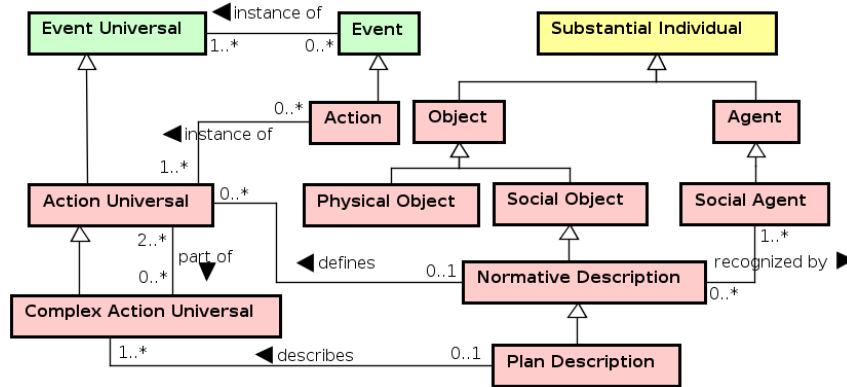


Fig. 3. Agents, objects, and normative descriptions.

Fig. 4 presents a fragment of UFO-C that focuses on types of intentional moments. *Agents* are substantials that can bear special types of modes named *intentional moments*. In this case, intentionality refers to the capacity of certain individuals to refer to possible situations in reality. Thus, intentional moments (also called in the literature *propositional attitudes*) have a propositional content (*proposition*), which is an abstract representation of a class of situations referred to by that intentional moment.

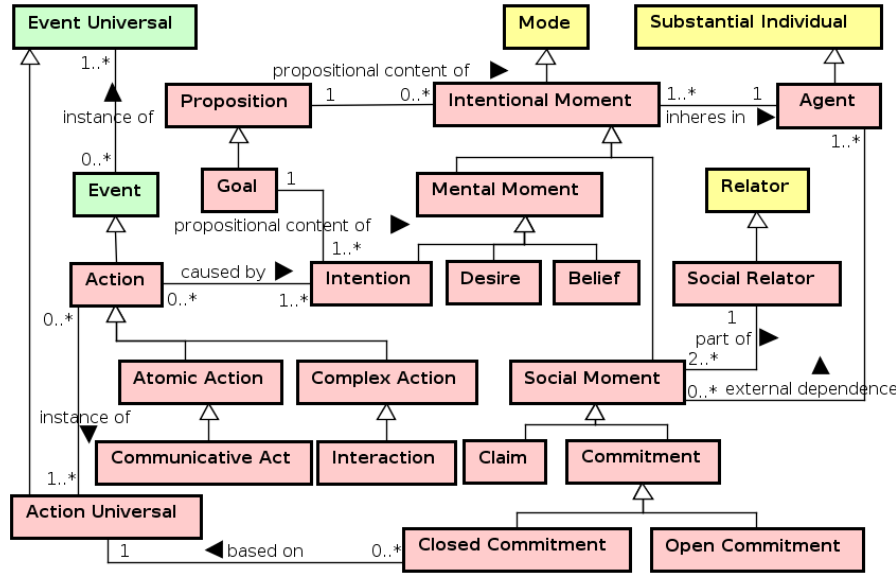


Fig. 4. Actions, mental moments, and social moments.

Intentional moments inhere in agents and can be mental or social. *Mental moments* are specialized in intentions (internal commitments), beliefs, and desires. *Beliefs* can be justified by situations in reality (e.g., the belief that the Moon orbits the Earth). *Desires* and *intentions* can be fulfilled or frustrated. Whilst *desires* just expresses an agent's positive attitude towards a state of affairs in reality, intentions are desired states of affairs which the agent commits to pursue [50][51]. Intentions cause the agent to perform actions. *Actions* are types of events that can be complex or atomic. *Communicative acts* (speech acts such as inform, ask or promise in the sense of [50]) are types of atomic actions [26]. *Interactions* are types of complex actions composed of action contributions from different agents.

Social moments are types of intentional moments that are created by social actions (e.g., an interaction composed of the exchange of communicative acts). *Social commitments* and *social claims* are types of social moments. *Social relators* are relators composed of one or more pairs of social commitments and social claims [41]. As with all relators, social relators are founded in particular events. What "counts as" the founding event of a social relator, as well as the social responsibilities and claims entailed by that social relator, depends on a social context, typically in a manner described by a normative description which is valid in that context. For example, a particular family law can define the responsibilities and claims entailed by the marriage relator type, and a particular speech act (e.g., "I hereby declare you husband and wife") uttered by a Judge in a specific context (e.g., in the presence of witnesses) is sufficient for the creation of a relator of that type.

As an additional example, suppose that John rents a car at a car rental office. When signing a business contract, John performs a communicative act (a promise). This act creates a commitment (a social commitment towards that organization) to return the car in a certain state. It also creates a social claim of the rental car office towards John with respect to that particular propositional content. Commitments and claims always form a pair that refers to a unique propositional content. Commitments are classified as open and closed. In an *open commitment*, the agents responsible for fulfilling the commitment are free to define how they will honor the commitment. In a *closed commitment*, the agent must fulfill the commitment by performing an action that is an instance of a particular action universal [37].

4. A Commitment-Based Service Ontology

UFO-S is a commitment-based service ontology whose conceptualization, in agreement with [28], is based on the establishment and fulfillment of commitments and claims between *service participants* (used to refer to both service providers and service customers) along the service life-cycle. In this paper, we focus on the three main phases of the service life-cycle, namely: *service offer*, *service negotiation*, and *service delivery*. Despite their relevance to certain areas of

investigation (such as service marketing), we consider all service-related actions that occur before service offer and after service delivery as outside the scope of this paper.

UFO-S is represented in OntoUML [25], which is a UML profile that incorporates the foundational distinctions in UFO-A and UFO-B. Besides the benefits that come from the explicit adoption of a foundational ontology, the choice of OntoUML was further motivated by the availability of a well-maintained tool with a substantial ontology engineering support. This includes model verification [52] and model validation via visual simulation [32], as well as model transformation to languages such as OWL (Web Ontology Language) for supporting computationally efficient automated reasoning [53]. Table 1 presents the OntoUML stereotypes used in this paper. In addition to the ontological concepts corresponding to such stereotypes, we further ground UFO-S with respect to the social and intentional concepts of UFO-C, which support our discussion in terms of social aspects inherent in service relations.

Table 1. A Subset of OntoUML Stereotypes

Stereotype	Corresponding Concept in UFO
<<category>>	Category
<<kind>>	Kind
<<collective>>	Collective Universal
<<rolemixin>>	Role Mixin
<<role>>	Role
<<mode>>	Mode Universal
<<relator>>	Relator Universal
<<event>>	Event Universal

Furthermore, we added axioms in first-order logic to reflect the relevant constraints that are not directly implied by the models. Such axiomatization was a result of a “build-and-assess” iterative model simulation approach [32], which consisted, basically, in transforming OntoUML models (and OCL constraints) into Alloy³ specifications, and generating conforming instantiations of the model automatically⁴. Such automatically generated model instantiations were then examined manually, to decide whether they were in conformance with our conceptualization. If not, either the OntoUML model or the OCL constraints were changed, as illustrated by Fig. 5. Consistence of the axiomatization and OntoUML models is guaranteed by checking the satisfiability of the corresponding Alloy specification. Further details about the process of formalization of the UFO-S models can be found in [33].

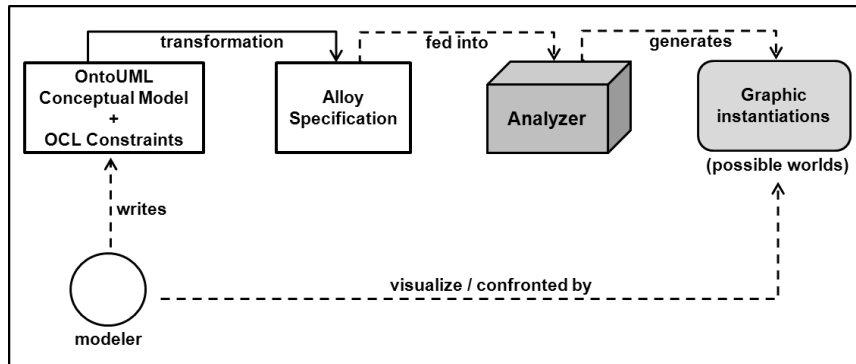


Fig. 5. Model simulation approach.

³ Alloy specifications are used as input to Alloy Analyzer 4.2 tool, which generates instances of the model and represents these instances in a graphical representation.

⁴ Such model instantiations are sometimes called ‘models’ themselves, indeed they are *logical (Tarskian) models*. Unfortunately there is a terminological clash here. We shall use the term ‘model’ for UML specifications; allowed instantiation of such specifications correspond to logical models.

According to our commitment-based approach, at the beginning of a service relation there is a promise, a speech act that establishes a pattern of commitments and corresponding claims. We call such speech act *service offer*, and the resulting pattern of commitments and claims *service offering* relationship. Fig. 6 shows an OntoUML class diagram with the main concepts and relations involved in a service offering, according to UFO-S. A *service offer* event results in the establishment of a *service offering* between a *service provider* and a *target customer community*. A service offering relationship is composed of *service offering commitments* from the *service provider* towards the *target customer community* and the corresponding *service offering claims* from the target community towards the service provider.

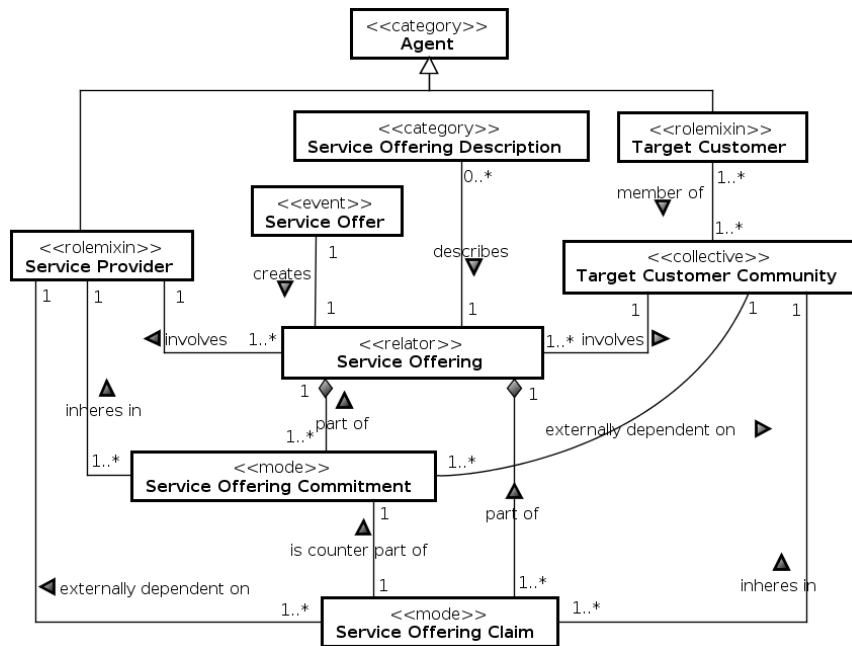


Fig. 6. Service Offer Model.

According to UFO-C, a service offer is a communicative act, and what “counts as” a service offer (i.e., which actions are service offers) depends ultimately on the (social) context in which services are offered. A service offer could thus be the registration of a service provider organization in a chamber of commerce, service advertisements, face-to-face communication, etc. The context will also determine the kinds of commitments that are established and the consequences that arise from a failure to fulfill such commitments. For example, in some legal systems, it is unlawful for an organization that has offered a service to refuse arbitrarily to deliver it to a particular customer unless legitimate business reasons are provided (in order to rule out arbitrary discrimination).

The actual content of service offering commitments (and corresponding claims) depends on the particular service business model, and, therefore, can refer to several different elements, such as conditions and requirements for providing the service, types of actions to be performed in the scope of service delivery, constraints, required customer's commitments (such as payment), etc. These elements may be described in *service offering descriptions* (such as folders, registration documents in a chamber of commerce, artifacts in a service registry, etc.).

Take as example the case of a car rental service. When the service is offered by a particular car rental company (e.g., through advertisements), the car rental company plays the role of service provider. It commits, under certain conditions, to grant temporary use of a vehicle to a customer. Examples of such conditions include minimum period of rental, car availability, qualifications and properties of the renter (e.g., being a registered driver older than 21), expected payment guarantees, minimal rental period, etc. The members of the target community are entitled to rent a car if all conditions are fulfilled.

What is established in the service offering commitments also determines the level of flexibility for a subsequent service negotiation phase, in which a particular service customer and a service provider establish a particular service agreement. Because of that, *offering commitments* are in fact

meta-commitments [51] (i.e., they are commitments to accept commitments), because they refer to commitments that can be established later during the negotiation phase and that do not yet exist as a result of a service offer alone.

In UFO-S, *agent* is a category that represents the essential properties of any type of agentive substantial, such as person, organization, or software agent, which may have distinct principles of identity. *Service provider* is the role played by agents when these agents commit themselves to a target customer community by a service offer event. In terms of UFO, service provider is a role mixin, since it can be instantiated by agents of different kinds, e.g., persons and organizations. *Target customer community* is a collective that refers to the group of agents that constitute the community to which the service is being offered. The community has a non-extensional principle of identity, in the sense that agents can enter or leave the community without altering the community's identity. The criteria for defining the target customer community membership are included in the content of the service offering. This may range from offerings with no restrictions to strictly targeted service offerings.

The *target customer* is the role played by agents when, as a consequence of a service offer, they become members of a target customer community and, therefore, have claims for the fulfillment of the service provider's commitments. A *service offering* is the social relator that arises from the *service offer* event, and that can be described by *service offering descriptions*, i.e., normative descriptions in UFO-C. A service offering is the aggregate of offering commitments and the corresponding claims. *Service offering commitments* and *claims* are social moments (in the sense of UFO-C), i.e., offering commitments are intrinsic moments, which inhere in the meta-committed agent (acting as service provider) and are externally-dependent on the target customer community. Offering claims, in turn, are intrinsic moments that inhere in the target customer community and are externally-dependent on the meta-committed agent (acting as service provider).

Table 2 presents the axioms that accompany the UFO-S Service Offer model. These axioms ensure that the decomposition of a service offering relator into service offering commitments and claims is valid.

Table 2. UFO-S Service Offer model axioms.

ID	Description
SO01	Service offering commitments and claims, which are counterparts, are part of the same service offering.
	$\forall co, cl ((ServiceOfferingCommitment(co) \wedge ServiceOfferingClaim(cl) \wedge isCounterPartOf(cl, co)) \rightarrow (\exists so (ServiceOffering(so) \wedge partOf(cl, so) \wedge partOf(co, so))))$
SO02	Each service offering commitment that is part of a service offering, which involves an agent called service provider and a target customer community, inheres in such agent and is externally-dependent on this target customer community.
	$\forall co, so, sp, tcc ((ServiceOfferingCommitment(co) \wedge ServiceOffering(so) \wedge ServiceProvider(sp) \wedge TargetCustomerCommunity(tcc) \wedge partOf(co, so) \wedge involves(so, sp) \wedge involves(so, tcc)) \rightarrow (inheresIn(co, sp) \wedge externallyDependentOn(co, tcc)))$
SO03	Each service offering claim that is part of a service offering, which involves an agent called service provider and a target customer community, inheres in this target customer community and is externally-dependent on such agent.
	$\forall cl, so, sp, tcc ((ServiceOfferingClaim(cl) \wedge ServiceOffering(so) \wedge ServiceProvider(sp) \wedge TargetCustomerCommunity(tcc) \wedge partOf(cl, so) \wedge involves(so, sp) \wedge involves(so, tcc)) \rightarrow (inheresIn(cl, tcc) \wedge externallyDependentOn(cl, sp)))$

4.2. Service Negotiation

Fig. 7 shows an OntoUML class diagram with the main concepts and relations involved in service negotiation, according to UFO-S. Once a service is offered, service negotiation may occur. In general, service negotiation is motivated by the interest of a target customer in the service offering, considering its contents (including the conditions to be satisfied by the service customer in case it hires the service). During service negotiation, service provider and target customer interact in order to establish an agreement regarding their commitments and claims with respect to an eventual service delivery.

If service negotiation succeeds, a *service agreement* is established, and the *service provider* starts to play the role of *hired service provider*, while the *target customer* starts to play the role of *service customer*. Like a service offering, a service agreement is composed of commitments and claims. However, in contrast to the service offering, in a service agreement, service customers may also establish commitments to service providers (e.g., the commitment to pay for the service). Service agreement involves not only commitments from the hired service provider towards the service customer, but may also involve commitments from the service customer towards the hired service provider. Thus, these two participants become co-responsible for the service delivery. In the case of the car rental service, when John, a particular target customer, goes to the Highway car rental office, and rents a car, he becomes a service customer, whereas Highway acts as a hired service provider. John and Highway commit themselves to perform some actions and to respect certain conditions. Examples of these conditions include amount to be paid per day, period of rental, conditions of the vehicle, and so on.

A service agreement should conform to what was previously established in the corresponding service offering. A service offering is a bundle of pairs of meta-commitment/meta-claim such that each of these pairs has a propositional content of establishing (in case of agreement) pairs of commitment/claim of a given type. A conformant service agreement is a bundle of pairs of commitments/claims that instantiate types that exists in the service offering. For example, consider that a restaurant establishes the meta-commitment of accepting the commitment of serving Caesar Salad in less than 10 minutes after order. When a customer sits down, checks the menu and orders a Caesar Salad via the waiter (an event which can be understood as a simplistic service negotiation leading to a service agreement), the restaurant becomes committed towards that customer to serve a Caesar Salad in less than 10 minutes. In that moment, we can say that the meta-commitment was fulfilled. Thus, an agreement *X* conforms to an offering *Y* if every pair of commitment/claim in *X* is of a type *T* that is referred to by a pair of meta-commitment/meta-claim in *Y*.

As in the case of a service offer, what is agreed between the parties (commitments and claims) of both hired provider and service customer) depends on the context of the service agreement, as well as on the particular service business model, and, therefore, can refer to several different elements. These elements may be described in *service agreement descriptions* (such as a service contract).

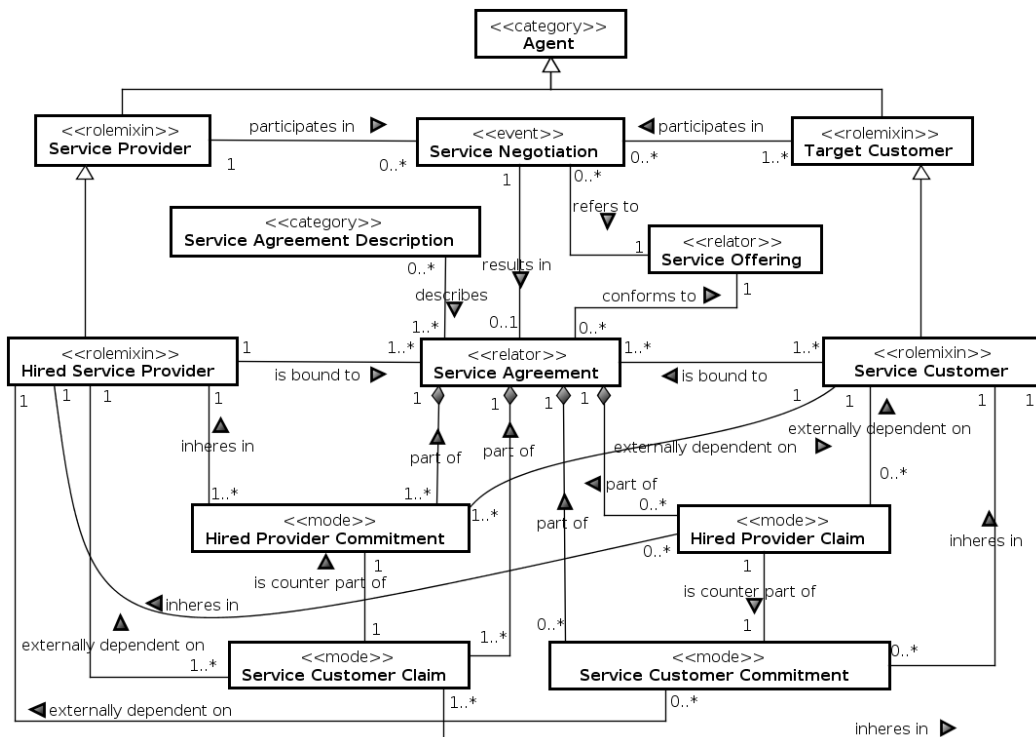


Fig. 7. Service Negotiation model.

In terms of UFO-C, a service negotiation is an *interaction* involving the participations of the service provider and the target customers. When a service negotiation (an *event*) succeeds, this

event is the foundation for a service agreement (a *relator*). Hired provider and service customer commitments and claims are *social moments*. Hired provider commitments and claims are intrinsic moments that inhere in a hired service provider and are externally-dependent on a service customer. Service customer commitments and claims are intrinsic moments that inhere in a service customer and are externally-dependent on a hired service provider.

In a manner analogous to how a service offering (as a social relator) mediates the relation between service provider and target service customers by aggregating offering commitments and claims, a *service agreement* mediates the relation between hired service provider and service customers by being a social relator composed by the *hired provider commitments and claims* and the *service customer commitments and claims*.

The role of *hired service provider* is played by an agent *A*, when this agent commits itself to an agent *B* (playing the role of service customer) to perform actions or to achieve the results determined in the service agreement. This means that a service agreement includes a delegation relation [37]: when establishing a service agreement, agent *B*, who plays the role of service customer, delegates a goal/plan to the agent *A*, who plays the role of hired service provider. Thus, claims of *B* towards *A*, and commitments of *A* towards *B* are created, since *A* has committed to pursue the delegated goal or to execute the delegated plan. Depending on the business service model, this delegation may be open or closed [37]. In *open delegation*, the hired service provider is free to determine how a commitment is to be fulfilled, which may include further delegation (common in service systems and economic networks). On the other hand, in *closed delegation*, the hired service provider commits to the execution of a pre-defined plan (i.e., instantiating an agreed action universal).

When agent *B* delegates a goal/plan to agent *A*, *B* becomes (at some level) dependent on *A*. Thus, before hiring a service (and, therefore, establishing a delegation), the customer typically makes an analysis of feasibility, not only associated to monetary aspects, but also to aspects such as dependency, rights and commitments to be established. Considering the notion of co-responsibility arisen by the mutual commitments, the hired service provider also depends on the service customers for the fulfillment of their own commitments (e.g., a consultancy firm needs access to information from customers in order to provide its services). Thus, in the context of a service agreement, the agent who plays the role of hired service provider (*A*) is also dependent on the agent who plays the role of service customer (*B*).

Table 3 presents the axioms that accompany the UFO-S Service Negotiation model. For the sake of brevity, we omit here the axioms that constrain the decompositions of agreements. These axioms are similar to those that were introduced to constrain the decomposition of offerings (SO01-SO03 in Table 2), and in fact apply to any decomposition of social relators into pairs of commitments and claims.

Table 3. UFO-S Service Negotiation model axioms.

ID	Description
SN01	When a service negotiation results in a service agreement, that agreement must conform to the offering to which the negotiation refers. $\forall sn, sa \ ((\text{ServiceNegotiation}(sn) \wedge \text{ServiceAgreement}(sa) \wedge \text{resultsIn}(sn, sa)) \rightarrow (\exists so \ (\text{ServiceOffering}(so) \wedge \text{conformsTo}(sa, so) \wedge \text{refersTo}(sn, so))))$
SN02	An agent cannot simultaneously play the roles of service provider and target customer in the same service negotiation. $\forall sp, tc, sn \ ((\text{Agent}(sp) \wedge \text{Agent}(tc) \wedge \text{ServiceNegotiation}(sn) \wedge \text{participatesIn}(sp, sn) \wedge \text{participatesIn}(tc, sn)) \rightarrow (sp \neq tc))$
SN03	The service provider that participates in a service negotiation is involved in the service offering to which the negotiation refers. $\forall sp, sn \ ((\text{ServiceProvider}(sp) \wedge \text{ServiceNegotiation}(sn) \wedge \text{participatesIn}(sp, sn)) \rightarrow (\exists so \ (\text{ServiceOffering}(so) \wedge \text{involves}(so, sp) \wedge \text{refersTo}(sn, so))))$
SN04	Every target customer that participates in a service negotiation is a member of the target customer community involved in the service offering to which the service negotiation refers.

	$\forall tc, sn ((\text{TargetCustomer}(tc) \wedge \text{ServiceNegotiation}(sn) \wedge \text{participantesIn}(tc, sn)) \rightarrow (\exists tcc, so (\text{TargetCustomerCommunity}(tcc) \wedge \text{ServiceOffering}(so) \wedge \text{memberOf}(tc, tcc) \wedge \text{involves}(so, tcc) \wedge \text{refersTo}(sn, so))))$
SN05	<p>The agents that are bound to a service agreement as hired service provider and service customer, have acted, respectively, as service provider and target customer in the service negotiation that resulted in this agreement.</p> $\forall sc, hsp, sa ((\text{ServiceCustomer}(sc) \wedge \text{HiredServiceProvider}(hsp) \wedge \text{ServiceAgreement}(sa) \wedge \text{isBoundTo}(sc, sa) \wedge \text{isBoundTo}(hsp, sa)) \rightarrow (\exists sn (\text{ServiceNegotiation}(sn) \wedge \text{resultsIn}(sn, sa) \wedge \text{participatesIn}(sc, sn) \wedge \text{participatesIn}(hsp, sn))))$

4.3. Service Delivery

Service delivery concerns the execution of actions aimed at fulfilling the commitments established in the service agreement. A service is successfully delivered if the actions are performed in such a way that their results (and also the way they are performed) fulfill the service agreement.

Fig. 8 shows an OntoUML class diagram presenting the main concepts and relations involved in service delivery according to UFO-S. *Service delivery* is a complex action, which is composed by several actions, including actions performed only by the hired service provider (*hired provider actions*), actions performed only by the service customer (*customer actions*), and actions performed by both in an interaction (*hired provider-customer interaction*). All of these actions are motivated by the commitments established in the service agreement, between the hired provider and the service customer. Depending on the business service model, other agents can also perform actions. For instance, the service provider can delegate some actions to a third-party. These actions are also part of the service delivery process, although they are not explicitly represented in Fig. 8.

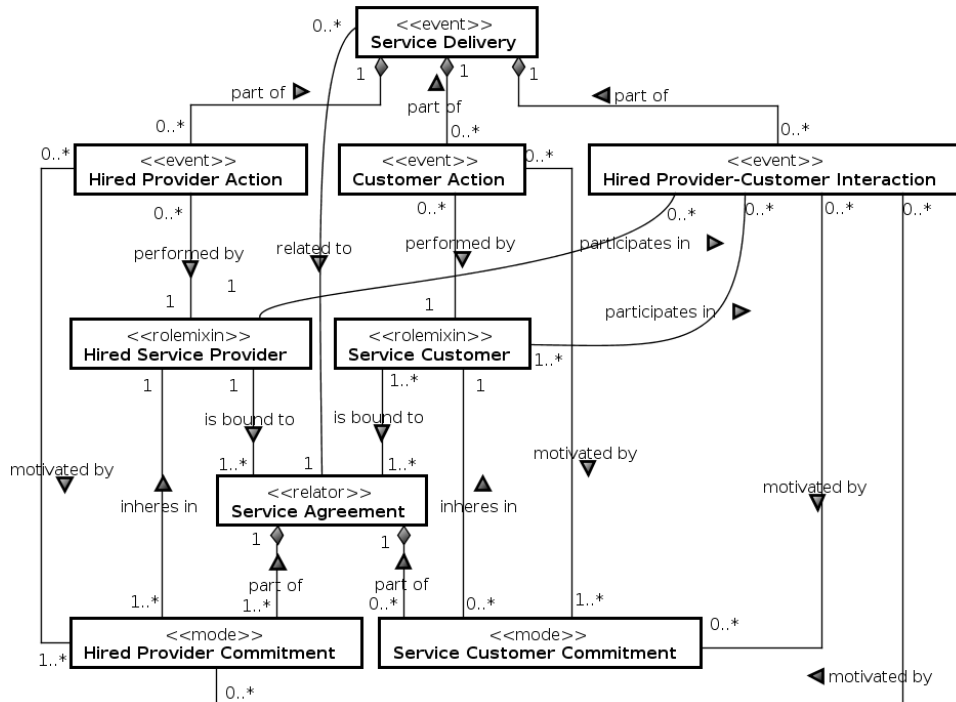


Fig. 8. Service Delivery model.

Table 4 presents the axioms that further describe the UFO-S Service Delivery model.

Table 4. UFO-S Service Delivery model axioms.

ID	Description
SD01	Every service delivery has at least one part that is a hired provider action, a customer action, or a hired provider customer interaction.

	$\forall e \text{ (ServiceDelivery}(e) \rightarrow (\exists e' \text{ (partOf}(e, e') \wedge (\text{HiredProviderAction}(e') \vee \text{CustomerAction}(e') \vee \text{HiredProviderCustomerInteraction}(e')))))$
SD02	<p>The commitments that motivate a hired provider action inhere in the hired service provider that performs the action.</p> $\forall ac, co \text{ (((HiredProviderAction}(ac) \wedge \text{HiredProviderCommitment}(co) \wedge \text{motivatedBy}(ac, co)) \rightarrow (\exists hsp \text{ (HiredServiceProvider}(hsp) \wedge \text{inheritsIn}(co, hsp) \wedge \text{performedBy}(ac, hsp))))$
SD03	<p>The commitments that motivate customer action inhere in the service customer that performs the action.</p> $\forall ac, co \text{ ((CustomerAction}(ac) \wedge \text{ServiceCustomerCommitment}(co) \wedge \text{motivatedBy}(ac, co)) \rightarrow (\exists sc \text{ (ServiceCustomer}(sc) \wedge \text{inheritsIn}(co, sc) \wedge \text{performedBy}(ac, sc))))$
SD04	<p>Each hired provider-customer interaction is motivated by at least one commitment (a hired provider commitment or a service customer commitment).</p> $\forall i \text{ (HiredProviderCustomerInteraction}(i) \rightarrow (\exists co \text{ ((HiredProviderCommitment}(co) \vee \text{ServiceCustomerCommitment}(co)) \wedge \text{motivatedBy}(i, co))))$
SD05	<p>The hired provider commitments that motivate a hired provider-customer interaction inhere in the hired service provider that participates in the interaction.</p> $\forall i, co \text{ ((HiredProviderCustomerInteraction}(i) \wedge \text{HiredProviderCommitment}(co) \wedge \text{motivatedBy}(i, co)) \rightarrow (\exists hsp \text{ (HiredServiceProvider}(hsp) \wedge \text{inheritsIn}(co, hsp) \wedge \text{participatesIn}(hsp, i))))$
SD06	<p>The service customer commitments that motivate a hired provider-customer interaction inhere in a service customer that participates in the interaction.</p> $\forall i, co \text{ ((HiredProviderCustomerInteraction}(i) \wedge \text{ServiceCustomerCommitment}(co) \wedge \text{motivatedBy}(i, co)) \rightarrow (\exists sc \text{ (ServiceCustomer}(sc) \wedge \text{inheritsIn}(co, sc) \wedge \text{participatesIn}(sc, i))))$
SD07	<p>Each hired provider action that is part of a service delivery related to a service agreement is performed by the hired service provider bound to that agreement.</p> $\forall ac, sa, sd \text{ ((ServiceDelivery}(sd) \wedge \text{HiredProviderAction}(ac) \wedge \text{ServiceAgreement}(sa) \wedge \text{partOf}(ac, sd) \wedge \text{relatedTo}(sd, sa)) \rightarrow (\exists hsp \text{ (HiredServiceProvider}(hsp) \wedge \text{performedBy}(ac, hsp) \wedge \text{isBoundTo}(hsp, sa))))$
SD08	<p>Each customer action that is part of a service delivery related to a service agreement is performed by the service customer bound to that agreement.</p> $\forall ac, sa, sd \text{ ((ServiceDelivery}(sd) \wedge \text{CustomerAction}(ca) \wedge \text{ServiceAgreement}(sa) \wedge \text{partOf}(ac, sd) \wedge \text{relatedTo}(sd, sa)) \rightarrow (\exists sc \text{ (ServiceCustomer}(sc) \wedge \text{performedBy}(ac, sc) \wedge \text{isBoundTo}(sc, sa))))$
SD09	<p>Each hired provider-customer interaction that is part of the service delivery related to a service agreement, has the participation of the hired service provider and some service customers bound to that agreement.</p> $\forall i, sd, sa \text{ ((HiredProviderCustomerInteraction}(i) \wedge \text{ServiceDelivery}(sd) \wedge \text{ServiceAgreement}(sa) \wedge \text{partOf}(i, sd) \wedge \text{relatedTo}(sd, sa)) \rightarrow (\forall ag \text{ (participatesIn}(ag, i) \rightarrow ((\text{HiredServiceProvider}(ag) \vee \text{ServiceCustomer}(ag)) \wedge \text{isBoundTo}(ag, sa))))$

5. A Complete Example: Car Rental Service

In this section we present an example in the car rental service application domain. This example encompasses all the service lifecycle phases (service offer, service negotiation/agreement, and service delivery) addressed by UFO-S. We use a tabular approach that describes the instantiation of UFO-S concepts, inspired by Alter's "service responsibility tables" [13], and Ferrario and Guarino's adaptation of that idea [27]. The example reflects terms and conditions of car rental services found in contracts and specialized websites available on the Internet. The example is organized in three tables each of which concerns the different service lifecycle phases: service offer (Table 5), service negotiation (Table 6) and service delivery (Table 7).

Table 5 concerns the service offer phase in which "Find a Car Inc." offers a car rental service towards its target community. In this example, the event of registration of the car rental service in a chamber of commerce is considered to create a service offering from "Find a Car Inc.". The content of this service offering is described in registration documents in the chamber of commerce

(and may also be referred to in marketing folders and other kinds of publicity). Besides the description of the target community's profile (the criteria for being a member of the community), the content of the service offering also includes the service offering commitments that "Find a Car Inc." (as a service provider) establishes towards the target community. Thus, "Find a Car Inc." is then committed to provide this service for all members of the community. "Jack", "John", "Mary", and "XYZ Bookstore Inc." are examples of members of this community (target service customer) by fitting the defined target community's profile.

In terms of UFO-S, in the service offer phase, only the service provider is committed to the target community (by means of service offering commitments). The target community has no commitments towards the provider. Despite that, when making an offering, the service provider usually makes reference to conditions that he/she expects to be fulfilled in the case of a future service agreement. These conditions will become commitments from service customer towards hired service provider in the case of a successful service negotiation.

Here it is important to remark that, since service claims are just counter parts of the service commitments, for sake of simplicity they were not represented on the tables.

Table 5 – Service offer phase: "Find a Car Inc. offers a car rental service".

Concepts	Instantiation(s) in the Example	Relationship(s)
Service Offer	Registration of the car rental service by "Find a Car Inc." in the chamber of commerce.	creates the car rental service offering
Service Provider	"Find a Car Inc." (an Agent that plays the role of Service Provider)	
Target Customer Community	The community of people or enterprises that are able to rent a car from "Find a Car Inc.", including "Jack", "John", "Mary", "XYZ Bookstore Inc." etc.	
Target Customer	"Jack", "John", "Mary", "XYZ Bookstore Inc." etc.	is member of the car rental service target customer community
Service Offering	The car rental service offering involves the "Find a Car Inc." and the target customer community	involves the car rental service target customer community involves the "Find a Car Inc." (as service provider)
Service Offering Description	Registration documents in the chamber of commerce (but also marketing folders, and/or publicity material).	describes the car rental service offering
Service Offering Commitment	<p>In a particular service agreement, "Find a Car Inc.", will:</p> <ul style="list-style-type: none"> - provide a clean and ready-to-use car to its service customers (from the to be agreed category and in the to be agreed date). - replace the rented car in case of failure <p>As long as service customer commits to:</p> <ul style="list-style-type: none"> - pay the rental fee according to the table of "vehicle categories and prices" - pay fines due to delays according to the table of "vehicle categories and prices" - pay for damages in the car which to not result from normal use 	<p>is part of the car rental service offering</p> <p>inherits in "Find a Car Inc."</p> <p>is externally dependent on the car rental service target customer community</p>

Table 6 presents a service negotiation between "Find a Car Inc." (as a service provider) and "Jack" (as a target customer) that resulted in a service agreement between them. This specific service negotiation results in a service agreement, which conforms to the service offering by "Find a Car Inc.". From now on, "Jack" and "Find a Car Inc." play, respectively, the service customer

and the hired service provider roles. As such they are bound to the car rental service agreement. The content of this agreement is described in a car rental service contract (service agreement description). Thus, the contract includes the “Find a Car Inc.” commitments (hired service commitments) and Jack’s commitments (service provider commitment), since both parties are mutually committed in this agreement.

The commitments in a service agreement usually refer to the specific terms and conditions discussed in the negotiation. For example, whereas the service offering commitment does not refer to a specific value to be paid, the service customer commitment defines a specific value (“\$ 1000,00”) for the car rental (regular) period. Also, we can notice that some service customer commitments are directly derived from conditions/expected situations indicated in the service offering commitments. For example, the service customer commitment refers to “*Pay US\$ 100,00 per day of delay*”. This is related to what is referred to by the service offering commitment as “*As long as service customer commits to:[...] pay fines due to delays according to the table of ‘vehicle categories and prices’*”. Thus, besides returning the rented car, the service customer is also committed to pay fines for any delay. In fact, there is an interesting relation between service offerings and service agreements. The former presents a kind of general schema that can accommodate a number of variations in a certain space of negotiation. In the latter, therefore, this schema can be defined by means of values and conditions within a (allowed) space of negotiation.

Table 6 - Service negotiation phase: “Find a Car Inc.” and “Jack” enter into a service agreement.

Concepts	Instantiation(s) in the Example	Relationship(s)
Service Negotiation	A negotiation event (interaction) between “Find a Car Inc.” (as a service provider) and “Jack” (as a target customer).	results in the car rental service agreement between “Find a Car Inc.” and “Jack”. refers to the car rental service offering by “Find a Car Inc.”
Service Provider	“Find a Car Inc.” (an Agent playing the role of Service Provider)	participates in the car rental service negotiation with “Jack”.
Target Customer	“Jack” (an Agent playing the role of Target Customer)	participates in the car rental service negotiation with “Find a Car Inc.”
Hired Service Provider	“Find a Car Inc.” (an Agent and Service Provider now playing the role of Hired Service Provider)	is bound to the car rental service agreement with “Jack”
Service Customer	“Jack” (an Agent and Target Customer now playing the role of Service Customer)	is bound to the car rental service agreement with “Find a Car Inc.”
Service Agreement	A service agreement between “Find a Car Inc.” (as hired service provider) and “Jack” (as service customer).	conforms to the car rental service offering by “Find a Car Inc.”
Service Agreement Description	The car rental service contract between “Jack” and “Find Car Inc.”.	describes the car rental service agreement between “Jack” and “Find Car Inc.”.
Hired Provider Commitment	In the agreement established between "Jack" and "Find a Car Inc." in the date of 21/10/2014, “Find a Car Inc.” is committed to: - provide a clean and ready-to-use <<economy car>> from 21/10/2014 to “Jack” - replace the rented car in case of failure	is part of the car rental service agreement between “Find a Car Inc.” and “Jack” inherits in “Find a Car Inc.” is externally dependent on “Jack”
Service Customer Commitment	In the agreement established between "Jack" and "Find a Car Inc." in the date of 21/10/2014, “Jack” is committed to:	is part of the car rental service agreement between “Find a Car Inc.” and “Jack”

	<ul style="list-style-type: none"> - pay \$ 1000,00 - pay US\$ 100,00 per day of delay - pay for damages in the car which to not result from normal use 	inherits in “Jack” is externally dependent on “Find a Car Inc.”
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Table 7 presents the actions performed by “Find a Car Inc.” and by “Jack” during service delivery. In this example, service delivery is a complex event ranging from the provision of a car of the specified model (BMW 320) by “Find a Car Inc.” to the return of this car by “Jack”. This event is composed of actions performed by “Find a Car Inc.” (e.g., “*Clean car*”), actions performed by “Jack” (e.g., “*Pay \$1000*”), and interactions performed by both (e.g., “*Deliver the car*”, and “*Return the car*”). These (inter)actions are motivated by the service customer commitments and hired provider commitments established in the service agreement. Thus, in terms of UFO-S, the service delivery event is related to the service agreement whose commitments motivate (inter)actions that compose this event.

Table 7 - Service delivery phase: “Find a Car Inc.” and “Jack” act in the service delivery.

Concepts	Instantiation(s) in the Example	Relationship(s)
Service Delivery	The (complex) event regarding the delivery of what was agreed between “Find a Car Inc.” (as a hired service provider) and “Jack” (as service a customer).	related to the car rental service agreement between “Find a Car Inc.” and “Jack”.
Hired Provider Action(s)	- Clean and prepare the car.	part of the car rental service delivery agreed between “Find a Car Inc.” and “Jack”. performed by “Find a Car Inc.” motivated by the hired provider commitment of “Find Car Inc.”
Customer Action(s)	- Pay \$1000. (no fine or damages to be payed)	part of the car rental service delivery agreed between “Find a Car Inc.” and “Jack”. performed by “Jack”. motivated by the Jack’s service customer commitment
Hired Provider-Customer Interaction(s)	<ul style="list-style-type: none"> - Deliver the car. - Return the car. 	part of the car rental service delivery agreed between “Find a Car Inc.” and “Jack”. “Find a Car Inc.” and “Jack” participates in the “deliver the car” and “return the car” interactions. motivated by the hired provider commitment of “Find Car Inc.”, and by the Jack’s service customer commitment

6. Applying UFO-S to Various Perspectives on Service

UFO-S is assessed in this section by showing how it explicates and harmonizes various service perspectives. We cluster these perspectives according to their main characteristics. In the terminology for design science research proposed by Hevner et al. [54][55], this amounts to a descriptive evaluation of UFO-S as a design artifact.

6.1.1. Service as Co-Creation of Value

The literature on services often identifies the creation of value as the “raison d’être” for services, i.e., services exist for service participants to benefit or to extract value from their participation. Maglio and Spohrer [7], for example, have characterized service systems as “dynamic configurations of resources capable of providing benefit to other service systems”, forming dynamic network structures “(1) capable of improving the state of another system through sharing or applying its resources [...] and (2) capable of improving its own state by acquiring external resources” [6]. Vargo and Lusch have pushed this notion to the extreme, characterizing services as the fundamental basis of value creation through exchange (“all economies are service economies”) [5]. Spohrer et al. [6] have explained that “service systems engage in three main activities in order to co-create value: (1) proposing value, (2) accepting a proposal, and (3) realizing the proposal”.

In UFO-S, agents become service providers and service customers by participating in intentional actions (service offer and service negotiation). According to UFO-C, all actions are motivated by agents’ goals and beliefs, even if the result of the actions does not match these goals. Thus, entering into service commitments is motivated by the goals of service providers and service customers, and the beliefs they hold towards service commitments, e.g., that performing a service offer or establishing a service agreement will lead to benefits. However, entering into such commitments cannot be said to guarantee the accomplishment of the motivating goals, e.g., because agents may fail to fulfill their commitments. Even in case agents fulfill their commitments, they may not achieve the goals that led them to enter into these commitments yet, unless in the trivial case in which the satisfaction of the goals is entailed by the fulfillment of commitments.

Whether or not value is produced in the service life-cycle is, in fact, a subjective notion, which depends on how the service participants assess their participations, i.e., whether they ascribe to the experience in the service life cycle a positive assessment. Regarding this, we agree with Vargo and Lusch when they discuss that “value is always uniquely and phenomenologically determined by the beneficiary” and that “value is idiosyncratic, experiential, contextual, and meaning laden” [5]. As such, value cannot be (directly) transferred or exchanged. Thus, we refrain from using terminology that would suggest otherwise such as “transfers of value” and “service value exchange”. This terminology was used initially by Ferrario and Guarino in [27], but then abandoned it in [28], when they say that “it is service, not value that is exchanged, because value is subjective”. This is not to say that there are no objective outcomes or effects of the actions performed in order to fulfill service commitments. However, the value ascribed to these actions and the situations that are brought about by these actions are subjective.

6.1.2. Service as Capabilities and Application of Competences

Many authors have characterized services by focusing on the *capability* of providers to produce benefits to customers (e.g., [8][9]) or on the *application of such capabilities (competences)* of one party in benefit of another party [5].

This is accounted for in UFO-S by means of the notions of “dispositions” and their “manifestations” (through events) provided by UFO. These notions are offered by We regard a capability or competence as a disposition of an agent, be it human or organizational, which under certain conditions is manifested in actions, such as those in the service life-cycle. By combining this explanation with the notion of commitment, UFO-S reveals an important distinction, namely that between: (i) possessing a capability to perform certain actions or to produce certain outcome, i.e., bearing a certain disposition, and (ii) employing capabilities in order to fulfill social commitments, i.e., manifesting the disposition motivated by social commitments. The former is not sufficient for services, since the capability of an organization to wash cars (cf. (i)) does not automatically make it a car wash service provider. Even an organization that is not capable of washing cars may still offer a car wash service, delegating the actual car washing to a third party that is capable of doing it. Thus, the capability manifested by the provider is not that of car washing,

but that of delegating it to a capable party [56]. In any case, the picture is only complete by considering the commitments that influence the manifestation of dispositions (cf. (ii)).

Usually in service agreements not only providers but also customers commit themselves to manifesting capabilities under specific conditions. For example, while an online shop commits itself to manifest its capability of shipping goods, the customer commits itself to manifesting his capability of paying for the purchased goods, providing accurate information for delivery, ensuring that someone is present at the delivery address to receive the goods during delivery hours, and so on. This view emphasizes the aspect of co-production of services that was discussed in the original Service-Dominant logic article [5], and further shows that the asymmetry in the service provider/service customer relation cannot be explained solely by the application of competences of one party on the behalf of another, because the customer also employs its competences to the benefit of the provider. In order to account for the asymmetry, we need to consider the life-cycle of (meta-)commitments (service offering and service agreement) as discussed in Section 4.

Finally, the notion of capabilities/competences manifested in service relations is also related to the notion of resources applied in the service provision. A resource can be understood as a role an individual (agent or object) plays when employed in the scope of the efforts to achieve goals [57]. For example, the specific soap “X” used in a car washing company is a resource applied for cleaning cars. This soap has the capability (or disposition in terms of UFO) of removing smudges. “John”, in turn, is a human resource that acts cleaning cars in the same car washing company. “John” has the capability of cleaning cars. Thus, the car washing company, by counting on its resources, has the capabilities necessary for providing the service of cleaning cars, and then, can fulfill the established service commitments.

6.1.3. Service as Behavior

In service literature, the notion of service is also characterized by behavioral aspects that arise from the interaction between the service provider and the service customer. As such, the notion of service has been associated with concepts, such as, interaction, process, and functionality/function. The term “behavior” in this section encompasses these concepts.

In [1], Quartel et al. propose that, at a high-level of abstraction, a service can be considered as a single interaction between a “service user” and a “provider”. This interaction represents an (atomic) activity in which the involved participants produce some common result in cooperation. At this level of abstraction, the focus is on what is produced and not on how it is done. Further, at a lower level of abstraction, a service can be regarded “as multiple related interactions between a service user and provider”. Thus, a service as an interaction can be successively refined from the higher abstraction level (atomic activity) to the lower one (multiple related interactions).

In the context of the Unified Service Theory [3], Sampson defines the concept of service as a production process for which the customers provides significant inputs. In essence, service processes differ from other production processes, because the former obtains inputs from customers (e.g., information). Thus, service processes are distinguished from non-service process (manufacturing or extractive processes) only by the presence of customer inputs (and implications thereof). In non-service processes, the participation of customers is limited, e.g., to select and consume outputs, not contributing with inputs necessary for the production process [58]. According to Sampson, input refers specifically to components (resources) used in production, and not, e.g., payments after production or ideas about processes or outcomes (feedback). Sampson also admits co-production (kind of interaction), mainly in the case of what is called “customer-self inputs”, i.e., when the customer employs her labor in the service process.

ArchiMate is an enterprise architecture modeling framework currently maintained by The Open Group [2] in which the concept of service is based on the notion of “unit of functionality”, which is applied as a basic structuring element through the enterprise architecture layers (“Business”, “Application”, and “Infrastructure” layers). Thus, business services and computational (application and infrastructural) services are characterized as behavioral elements (a kind of “function”) that can be “used by” service customers. Besides being considered a behavioral element in ArchiMate, a service is “realized by” other behavioral elements such as processes, functions, and interactions, which reinforces the behavioral characterization of service in this framework.

In [4], Terlouw and Albani propose a definition for service that is based on the idea of transaction. However, in the case of service relations, the focus of the transaction is more on executor-side (service provider in terms of UFO-S) than on initiator-side (service customer in terms

of UFO-S). This notion is applied for specifying what is called “human services” (services implemented by human beings) and “IT services” (services implemented by IT systems). Terlouw and Albani highlight the importance of a comprehensive service specification approach, and focus on the analysis of “what” should be specified, instead of on “how”. Similarly to UFO-S, Terlouw and Albani use a theoretical basis (the ψ -Theory) for grounding the characterization of service. According to this theoretical basis, the notion of service is based on two types of acts that are performed by actors involved in transactions: coordination acts and production acts. By production acts, actors contribute to bring about the actual function of the organization, i.e., they deal with delivering material or immaterial goods. By coordination acts (request, quit, reject and accept), actors enter into and comply with commitments regarding production acts, i.e., they coordinate the execution of production acts. These acts are taken as part of a transaction, which encompasses three phases: order phase, execution phase, and result phase. The order phase is quite similar to service negotiation and agreement in terms of UFO-S, for example, when coordination acts are performed to establish commitments. The execution phase is related to the delivery phase in UFO-S, when actions are performed in order to fulfill commitments. In the result phase, coordination acts are also performed in order to evaluate and define if what was performed is in conformance to what was committed in the service negotiation.

The aforementioned works illustrate that “service as behavior” is an important perspective that has been applied for characterizing the notion of service. Nevertheless, as we have discussed in the example of the insurance service, it is possible that there is no action during service delivery and still the service is provided, due to the existence of the service agreement. Further, service delivery includes all actions caused by the intention to fulfill a service agreement, including those referred to in the content of the service agreement, in the case of closed delegation. In this case, the service agreement can refer to the planned actions (type of actions) that may be performed (instantiated) in case of a trigger event (e.g., an accident). In terms of UFO-S, depending on the particular business service model, service agreements may refer to types of customer-side actions, provider-side actions, interactions between provider and customer, or even third-party participations. For example, in the case of the car wash service, the service agreement may include that the car should be vacuum cleaned, specifying thus a type of action that the provider is responsible to perform during service delivery.

Finally, in the light of [59], we can say that, by considering social commitments, we bring the notion of service at a new level (so-called “mesoscopic”), in which the service relations are analyzed at a coarser-grained granularity, so that these relations are business activities that involve more than just service delivery actions/interactions. Thus, while the view defended in UFO-S encompasses that of “service as behavior”, we conclude that services should not be reduced only to interactions, and that a broad account must also include the notion of commitments. UFO-S also identifies that interactions occur in other phases of the service lifecycle, e.g., when a service agreement is negotiated.

6.1.4. Computational Services

In computer science, the notion of service has been used and defended as a software design paradigm for over three decades. From this perspective, services are, generally speaking, described/specified in terms of Inputs, Outputs, Pre-conditions, and Effects (hence the acronym IOPE) forming together a kind of “contract”. In fact, many of the current service-oriented software specification approaches are influenced by the “design by contract” paradigm [60], which was initially applied in object-oriented software engineering for building reliable (i.e., correct and robust) software components. As such, ‘clients’ and ‘suppliers’ have ‘obligations’ and ‘benefits’ (translated in terms of inputs, outputs, pre-conditions, and post-conditions) described by means of contracts (software specifications), which drive the tasks and interactions among software components.

In the context of data communication protocols, for example, service is characterized as “observable behavior” [61]. In that view, a service specification does not reveal the service provider’s internal structure, but it just defines the provider’s behavior as it can be observed from outside [1][61]. This notion of *observable behavior* can be accounted for in UFO-S, since it is possible to define a particular kind of service whose service agreement does not refer to how the commitments are fulfilled, by using open delegation. For example, the provider’s commitments towards the service customer can just refer to what is committed to be produced (in terms of outputs

and effects) when the expected inputs are received under the appropriate pre-conditions. In contrast, the customer may claim the fulfillment of these commitments when accessing the service as specified.

In a computational service-oriented architecture (such as that discussed in [10]), what counts as a service offer is typically the publication or registration of a service description, or the definition of a *contract* (in the sense of the “design by contract” approach [60]). In this case, the service offering description (in UFO-S) is often reduced to descriptions of operations (functions) that are typically characterized by a pair of “interaction types and their constraints” (possibly relating other operations). These service descriptions can be specified in many fashions, such as, by means of WSDL documents or API (Application Programming Interface) descriptions in natural language.

In UFO-S, such operations can be considered as units of service delivery. So, an operation invocation can count as an implicit and trivial service negotiation, which presupposes an agreement on a pre-defined kind of service offer. In any case, whether service negotiation is implicit, explicit, online or offline, the notion of commitment is instrumental in explaining both the semantics of service description publications and the establishment of service agreements.

Despite the particularities of computational services, we can say that the notion of service commitment establishes a link between the business and computational views. This is because commitments established between organizational and human agents affect those established at the computational level. By offering an interface through which certain capabilities are leveraged, an operation or a software application are driven by a set of aspects such as response time, semantics of data, and (possibly) the steps followed by the operation / application in order to produce the expected outcome. The agent that accesses the operation / application, in turn, has to respect all of these aspects (a set of constraints) in order to get the expected result. These aspects, therefore, can be described in terms of (mutual) commitments, and can be established at business level, constraining the implementations of services in operations or applications. Therefore, the notion of service commitments and claims offers an important mindset towards establishing a unified view on Business and Information Technology (IT), since it allows one to characterize business level services as well as computational level services by means of the same fundamental concepts.

6.1.5. UFO-S and Service Perspectives

Fig. 9 presents a schema that summarizes how UFO-S (by considering the service as commitment perspective) relates/harmonizes the other service perspectives. In summary, we advocate that the various service perspectives are related at some level, mainly through the notion of service commitments. For example, during the interactions between service provider and service customer in a service delivery (“service as behavior”), these agents can apply their capabilities/resources in benefit of each other (“co-creation of value”). However, in order to characterize these interactions and applications of capabilities/resources in the context of a service provision, we should take into account the mutual service commitments and claims established between these service participants. The service commitments and claims act as a “glue” in service relations, and characterize these kind of relations even if no action is performed or any capability is applied. Further, the notion of service commitment is related to the experience of value in service relations as agents enter into service commitments seeking to benefit from these commitments. The fulfillment of these commitments may “create value”. Finally, we have shown that computational services are also characterized by commitments and claims, even in the cases in which these commitments and claims are not explicitly represented in computational artifacts.

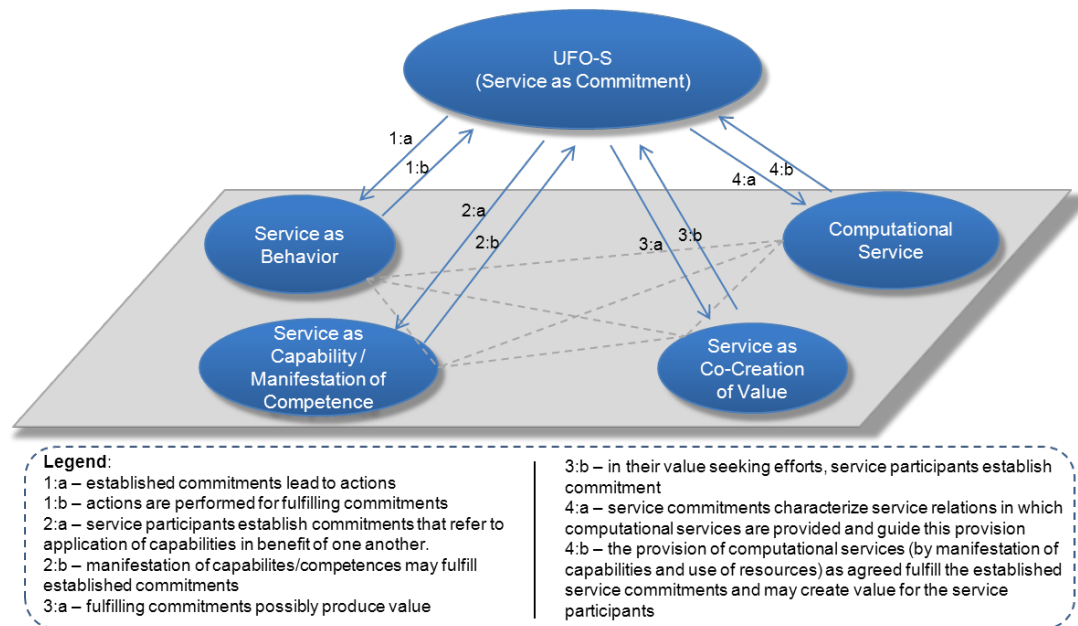


Fig. 9 - UFO-S (service as commitment) harmonizing service perspectives.

Table 8 presents correlations between UFO-S and the other service perspectives considering the most evident aspects between them. From these correlations, we can see how these aspects are mapped and addressed in UFO-S, which offers a panorama of the coverage of this service ontology.

Table 8 – Correlations between UFO-S and the other perspectives.

Service Perspectives	UFO-S (Service as Commitment)
Service as Capabilities and Application of Competences	
Capability/Competence	Disposition
Capability/Competence application	Manifestation of disposition
Focuses on provider-side capabilities /competences (customer as beneficiary)	Considers both provider-side and customer-side capabilities in service relations
Focuses on offering access to capabilities	Advocates that only by means of service commitments it is possible to guarantee systematic access to (or manifestation of) capabilities
Lacks a clear distinction between capability/competence and resources	Resources are substantial (that play a certain role in a given service delivery, e.g., “the soap used in a car clean service as a cleaning product”). Dispositions are intrinsic moments that inhere in substantial (e.g., “the disposition of removing dirt”).
Service as Behavior	
Behavioral aspects - Service process description	Action universals can be referred to in service offering and service agreement descriptions, describing how the service delivery will be executed.
Behavioral aspects - Service process execution	Service delivery is a (complex) event (which may be an instance of an action universal).
Service description is focused on process specification	Service (offering and agreement) description is taken from a broader notion, addressing not only

Does not account for commitments/motivation for behavior execution	“how to perform some behavior”, but, also the motivations (social commitments). Able to account for services which cannot be reduced to behavior (e.g., insurance services).
Service process is mainly characterized in terms of inputs, outputs, effects and pre-conditions	Accounts for the service commitments about the necessary input and pre-conditions, and the expected outputs and effects.
Service as Co-Creation of Value	
Co-creation of value	Intentional moments (intention/goal, desire, belief) offer the basis that accounts for: (i) what is expected in a service relation, and; (ii) what is experienced as value as a consequence of service relations (and possibly service delivery);
Does not make finer-grained distinctions concerning “co-creation of value”, “service commitments” and “service delivery”.	In their value-seeking behavior, service participants establish and fulfill service commitments. Distinguishes objective outcomes or effects of the actions performed in order to fulfill service commitments and the subjective value ascribed to these actions and the situations that are brought about by these actions.
Does not establish a clear distinction between provider and customer in terms of responsibilities (both are service relation’s parties that create value)	Establishes a clear distinction between customer and provider in terms of their commitments along the service life-cycle.
Computational Services	
Often collapses service negotiation and service agreement	Service negotiation and agreement are defined as two different well-defined ontological entities
Often reduces service description in terms of operation specifications	Service description is able to express not only technological aspects, but also social aspects between provider and customer
Often ignores intentional agents behind services, and focuses on technical resources (“server” and “client”)	Only intentional agents are service providers and customers. They apply resources/capabilities towards fulfilling established service commitments.
Often neglects the role of service commitments (as a social aspect) and focuses on constraints (as a technical aspect)	Constraints are analyzed in terms of the service commitments that have to be fulfilled for guaranteeing expected execution

7. Related Work

In this section, we present a number of ontologies and conceptual models of services found in the literature, and discuss how these works are related to UFO-S. These works range from ontologies for implementation purposes to ontologies that are applied as technical reference models.

OWL-S [14] and WSMO [15] are two Semantic Web service ontologies that focus mainly on technological aspects and are usually applied for automating tasks such as service discovery and composition [19]. These ontologies are not based on foundational ontologies and none of them addresses explicitly the notion of commitments. Further, both are focused on the *description* of computational services, while UFO-S aims instead at explicating service phenomena in order to support (offline) meaning negotiation. Finally, we should note that OWL-S and WSMO are built on Semantic Web languages that give precedence to computational tractability over expressiveness. As a consequence, these ontologies, as *operational ontologies* [62], are less suitable for meaning negotiation and consensus establishment between human beings, while UFO-S is a *reference ontology*.

The Open Group Service-Oriented Architecture Ontology aims to aid understanding in the domain of service-oriented architecture, and potentially be a basis for model-driven implementation [16]. In that ontology, the concept of “service” is defined as a logical representation of a repeatable activity that has a specified outcome. As we have discussed earlier, this view fails

to address the commitment aspects of services. Although the notion of service contract is addressed in this ontology, it is considered optional, and the content of contracts is not considered in enough detail. No distinction between service offer and service agreement is made. Finally, the Open Group Service-Oriented Architecture Ontology avoids defining concepts such as consumer and provider as core concepts [16], although it mentions that these concepts may be used in service contracts. This is a consequence of their view on services that cannot account for the asymmetry involved in service provider-customer relations (see Section 4.3).

The Reference Ontology for Semantic Service Oriented Architectures developed by OASIS [17] is an abstract framework for understanding concepts and relationships relevant for semantic service-oriented environments. Despite being useful for a number of service-based target application domains, this ontology focuses on software architectures. According to this ontology, a service is “a mechanism to enable access to one or more capabilities...”. The terms of this access are defined by a number of constraints and policies, which can be described in service descriptions. We believe that “a mechanism to enable access” is too narrow a notion for characterizing the concept of service, even in case of computational services. In UFO-S, in contrast, a service relation is characterized by the set of commitments and claims between a service provider and a service customer. This set of commitments and claims makes reference to the access/usage of capabilities of the service provider. In the case of computational services, as aforementioned, these set of commitments and claims could be understood as the constraints and policies that define the access to the functionality and that are usually described in service specifications, e.g., WSDL, and WADL. Regarding the rigor, this ontology does not explicitly use a well-defined theoretical foundation to ground its conceptualization. This limitation may lead to misunderstandings regarding the use of concepts and relationships. For example, in [17] the concept of capability is used in two ways: (i) as “some functionality”, and (ii) as something that “represents a functionality”.

The Healthcare SOA Ontology [18] is an ontology of service in the domain of eHealth services that follows the tenet of SOA-based approaches. This ontology is consistent with a number of reference models, such as, HL7 SAIF-CD [63], ISO RM-ODP [64], SoaML [65], and OASIS SOA Reference Architecture Framework [66]. The Healthcare SOA Ontology counts on a number of “core” concepts (e.g., service, service description, service user, service provider, contract, object) that are refined in the enterprise and computational viewpoints (e.g., in business service, computational service, business service description, and computational service description, among others). In this ontology, the concept of service is defined as a “behavior element” that can be specified, e.g., by means of business processes, in case of business services, or by RPC interactions in case of computational services. The ontology also proposes service agreements (possibly represented in a contract) as a key element for service phenomena. Differently from UFO-S, however, it does not distinguish explicitly service offerings and service agreements. The proposal is grounded on concepts for RM-ODP (such as that of community) which have been analyzed successfully with UFO in the past [44]. A similar effort for the Healthcare SOA Ontology is planned using UFO-S as a reference ontology, which should provide a sound foundation for this standard. We believe the commitment-based account is particularly useful in the Healthcare domain as commitments in providing services (e.g., “managing patient records”) have important consequences, and failing to fulfill them can bring grave consequences and serious sanctions.

The Service Ontology proposed by Oberle et al. [19] is structured so that the core modules span several application domains, such as healthcare, and automotive, and are also grounded by the upper level model, which consists of a foundational ontology (DOLCE [38]). Thus we consider it a core reference ontology. The Core Service Description module is one of the most important modules, since it represents general service aspects, such as service description, service provider and service consumer. This module presents two central notions: service and service description. These two central notions are based on the work of Ferrario and Guarino, especially [27]. Thus, Oberle et al, remark that this distinction is important, because in scenarios such as service marketplace, the service descriptions are managed instead of the service itself, since a service is defined as an event (in terms of DOLCE). The service descriptions would contain the terms regarding the service provision, such as, the commitments between providers and customer. Thus, the notion of commitment/claims as presented in UFO-S (as social relators that can be described in service descriptions, including service offering descriptions and service agreement descriptions) may be useful to refine the notion of service description in the Service Ontology.

The Goal-Based Service Ontology (GSO) [20] is a core reference ontology, also grounded in UFO. Thus, we can say that both GSO and UFO-S share the same grounding. However, GSO focuses on the concept of goal in order to define the notion of service. Thus, in GSO, the concept of service is characterized by the commitment of a service provider to perform a task on behalf of a service customer so that the outcome of this task satisfies a goal of that customer [20]. The notion of commitments addressed in GSO lacks a more detailed description. For example, GSO does not consider the kinds of commitments and how these kinds of commitments influence the definition of the agents' roles along the service life-cycle. As a consequence, in GSO, it is not possible to discuss the notion of target service customer, and hired service provider, for example. Further, in the service definition of GSO, only the provider is committed to achieving the goal. However, service relations are usually characterized by mutual commitments, since the service customer is also committed.

Onto-ServSys [21] is an ontology designed for the domain of service system and for other kinds of systems. In this ontology, the concept of service is characterized by three facets: (i) service interactions, (ii) service measures, and (iii) service outcomes. Service interaction regards an agreed and expected flow of interactions that involves people and other kinds of resources. Service measures concern objective metrics, being related to "efficiency" and "efficacy" issues. Service outcomes concern human-valued outcomes ("effectiveness", "ethical", or "aesthetical" issues), having some level of subjectivity. Onto-ServSys does not address explicitly the notion of service commitments and claims. Thus, the conceptualization of UFO-S can be useful for representing the service commitments and claims regarding the service interaction and the measures and outcomes to be produced from that. For example, the service interaction facet in Onto-ServSys can be analyzed, in terms of UFO-S, as being related to the service delivery (the execution). The service interaction as a plan (i.e., a planned sequence of actions to be performed by the provider and customers in tandem) can be analyzed as a set of service commitments established between provider and customers and that drive the service delivery. Therefore, a service interaction, as a flow of actions in execution, regards to the actions performed to fulfill the set of established commitments. Further, the understanding about service outcomes and service measures can benefit if analyzed in light of creation of value in the context of service relations. Thus, service measures and service outcomes concern to creation of value in so far the commitments established between providers and customers are fulfilled as expected. Finally, besides using a kind of ontological foundation based on a transcendental realistic ontology [67], the limited set of concepts incorporated to Onto-ServSys does not guarantee a well-defined ontological foundation.

In [22], Bergholtz et al. propose a model of services that is based on three perspectives: "service as means for co-creation of value", "service as means for abstraction", and "service as means for providing restricted access to resources". Similar to our work, the authors present a multi perspective approach for addressing the diversity of service views, instead of proposing a single service definition. In the "service as means for co-creation of value" perspective, a service is seen as a process in which providers and customers supply resources (inputs) and together co-create value. In the "service as means for abstraction" perspective, the service process is specified by means of the effects produced by the resources used in this process instead of the resource themselves. In the "service as means for providing restricted access to resources" perspective the notion of commitments and claims is discussed in the context of offerings and contracts, which make reference to how the resources can be used/accessed in benefit of the customers. Despite addressing the notion of commitments and claims in this latter perspective, unlike UFO-S, the notion is not used to unify the three perspectives. For example, what they call service process is not explicitly related to the commitments that motivate this process (and the events that are part of it). Further, the notion of resource is a central concept in the approach. The notion is rather abstract and subsumes entities of different ontological natures, including claims, goods, information and what they call "service resources". While this is interesting to show that these elements can be transacted between agents in events, this presents a challenge from the point of view of semantic clarity. Finally, the model of services proposed by Bergholtz and colleagues has its theoretical foundation in REA (Resource-Event-Agent) ontology [68] and Hohfeld's classification of rights [69]. Being based on REA, this model differs from UFO-S with respect to the ontological foundations employed. The relation between REA and UFO is discussed in [70].

Ferrario and Guarino [28][27] present an ontological model of service systems that is also based on the notion of commitments. The most salient differences between UFO-S and such previous works are: (i) the adoption of OntoUML, and (ii) the grounding in UFO (instead of DOLCE). With

respect to the former, OntoUML offers well-founded modeling capabilities that are associated with a number of tools (e.g., model verification and simulation [32] and generation of OWL implementations [53]), which were used in this work for guaranteeing a desirable degree of rigor in UFO-S. Regarding the latter, we highlight (among other features described in begging of Section 3): (i) the use of the social and intentional distinctions underlying UFO-C, (ii) the notion of “relator” as an important ontological entity useful for characterizing material relations between service participants (providers and customers) in service relations, and that, besides offering a hierarchy of individuals, UFO (in contrast to DOLCE) also offers a hierarchy of universals, which contributes, among other things, to the definition of types required in our account (e.g., role mixins, and relator universals). Finally, by understanding that the term “service” is laden with different meanings, we have refrained from settling on a specific definition for “service”, but we establish what we consider as the *core meaning* of “service” concept, inspired by *systematic polysemy* notions (see Section 8).

Finally, UFO-S was not designed to be an alternative service ontology that is based on a particular service perspective. As a core reference ontology, UFO-S establishes (besides, e.g., behavior, capabilities and resources, and co-creation of value aspects) the basis for the service phenomena along the service lifecycle considering the notion of service commitments as foundationally necessary. As a result, UFO-S aims to be useful for the existing service ontologies in so far it offers a detailing of service relations around service commitments, offering also a means through which different service ontologies can be aligned in a commitment-based reference point. As follows, we highlight the main contributions of UFO-S in contrast with related work on service ontologies:

- It makes a clear distinction between service offer, service offering, service negotiation and service agreement concepts, which are, as a whole, often neglected in current approaches.
- It reinforces the importance of what “contract” and “policy” elements represent in service relations, since these elements are used to communicate commitment-related aspects.
- It establishes the asymmetry between providers and customers regarding service commitments, and clearly defines the roles of target customer, service customer, service provider, and hired service provider, which are important for understanding the dynamics of service relations.
- It incorporates the notion of commitments into dynamics of behavior (relating it to actions and interactions) in service provisioning.
- It associates the notion of commitments to co-creation of value in order to support the characterization of value experience.
- It offers means to explicitly account for the notion of (provider and customer) goals in service relations. Especially by considering that commitments are “paired” with corresponding claims and established in a mutual relation, it offers supports to discuss, e.g., the fulfillment of customer commitments as a means for achieving provider’s goals.
- Taking UFO as a basis, UFO-S incorporates a clear distinction between capabilities (and called competences), application of capabilities, and resources. Such concepts are clarified, respectively, in terms of dispositions (as intrinsic moments), manifestation of dispositions, and individuals that bear such dispositions.
- It establishes that the application of capabilities is not, in isolation, enough for characterizing service provisioning. The establishment of service commitments is indeed a foundational notion that guarantees (in certain level) such systematic application in service relations.
- It offers means for characterizing service specifications (especially when referring to constraints) in terms of service commitments (as a social aspect), which is often neglected in computational approaches.

Table 9 summarizes four important design aspects of UFO-S and of the other service ontologies discussed in this section, such as: (i) the characterization of service advocated for each ontology, (ii) the primary purpose of application (general purpose, technical reference model, and implementation), (iii) the language used to represent the ontology, and (iv) the ontological foundations adopted.

Table 9. Summary of the four design aspects of UFO-S and related service ontologies

Ontology / Conceptual Model	Service Characterization	Application Purpose	Representation Language	Ontological Foundation
UFO-S	Based on the notion of “service relations” characterized by service commitments and claims	General	OntoUML + many-sorted logic	UFO [25][26]
OWL-S [14]	Based on the notion of dynamic web sites (performing of actions)	Implementation	Graphical notation and specification in OWL	---
WSMO [15]	“Web service” as computational entity “Service” is based on the notion of the value provided by the invocation of a “web service”	Implementation	UML and specification in Web Service Modeling Language (WSML)	---
The Open Group Service Ontology [16]	Based on the notion of repeatable activity	Technical Reference Model	UML and specification in OWL	---
The Reference Ontology for Semantic SOA [17]	Based on access to capabilities (as functionality)	Technical Reference Model	Concept Maps, UML, and specification in WSML	---
Healthcare SOA Ontology [18]	Based on the notion of behavior and contracts	Technical Reference Model with focus on eHealth	UML	---
The Service Ontology/ Core Service Description [19]	Based on the notion of temporal entity (event) and service commitments/claims	General	Graphical notation and specification in OWL-DL	DOLCE [38]
Goal-Based Service Ontology (GSO) [20]	Based on the notion of temporal entity and satisfaction of customer’s goal	General	UML	UFO [25][26]
The Onto-ServSys [21]	Based on three facets: (flow of) interaction, (objective) measures and (subjective) outcomes	General	A notation adapted from Common KADS Methodology	Transcendental realistic ontology [67]
Ferrario and Guarino’s service ontological foundation [28][27]	Based on the notion of temporal entity (event) and service commitments/claims	General	UML	DOLCE [38]

The model of services of Bergholtz and colleagues [22]	Multi perspectives of service: service as means for co-creation of value, service as means for abstraction, and service as means for providing restricted access to resources.	General	UML	REA ontology [68], and Hohfeld's classification of rights [69]
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8. What is a service after all?

We have shown that UFO-S is able to account for a number of perspectives on services, including those that emphasize (i) services as value co-creation, (ii) services as capabilities and application of competences, (iii) services as behaviors, and (iv) computational services. In order to relate the various perspectives, we have refrained so far from proposing a specific definition for the term “service”, understanding that the term is laden with different meanings. Indeed, in such cases of heavy semantic overloading, we strongly believe that, before attempting any terminological standardization, what is most important is to describe the different interconnected phenomena underlying services, providing a foundation that can be used to articulate the intended semantics of the related terms.

In fact, the term “service” is a case of *systematic polysemy*, in which the same nominal is used to denote different – *although related* – notions. This is a well-documented phenomenon in linguistics, which is explained with the semantic notion of “complex types” or “dot objects” (cf. Pustejovsky *apud* [71]). The idea is that the term assumes different senses depending on the context in which it is used, but all the senses are more or less implicitly present, so that in some cases a single occurrence of the word in a sentence carries more than one meaning (this is called *co-predication*). An instructive example of this phenomenon is the word ‘book’, which may refer to the physical object (a copy of the book) or to the abstract information object (the text or content) that is carried by the physical object. An example of co-predication is “The book weighs one kilogram but is easy to understand”. “Weighing one kilogram” is predicated of the physical copy and not of the text, while “easy to understand” predicates over the abstract information object and not over the physical copy. Thus, if one builds an ontology about books and demands a single ontological notion as the referent for the term “book”, one would be forced to choose one of the two meanings above. Of course, either option would be inadequate when both perspectives are relevant. An alternative is to replace the polysemous term with a set of unambiguous terms, each denoting a particular sense of the original term, while maintaining (and possibly explaining) the relation between them. Thus, an ontology about books would have two distinct, unambiguous terms to account for the two senses above (e.g., “physical copy” and “book text”), but would not settle on a single referent for the term “book”. Making use of a richer terminology would enable us to explain the relation between a “book text” and a number of “physical copies” (in the sense that the text is encoded in the physical copies).

The case of services is not much different from that of books. Both are examples of systematic polysemy. Consider the following case of co-predication involving the term service: “Dr. Smith’s dental service is expensive but unreliable”. “Expensive” is a property ascribed to Dr. Smith’s service offering, while “unreliable” is a property ascribed to the expected (or previously-experienced) service delivery. For the “service” term, one would have several alternatives, including service offering, service offering type, service agreement, service delivery, among others. The aforementioned sentence could be disambiguated by paraphrasing it as “Dr. Smith’s dental *service offering* is expensive but the *service delivery* is unreliable.” These are much less ambiguous terms, whose intended semantics has been carefully characterized in this paper. Not using these specific terms –relying instead on the generic term “service”– may result in serious problems: for instance, ontologies attempting at providing a notion of “service description” may end up confusing what is to be described (leaving too much room for interpretation), sometimes describing a service offering type (when no one is committed), sometimes describing a service offering (this problem in the context of the SOA Healthcare Ontology has been identified by analyzing it with

UFO-S [72]). Similar confusion in terminology arising from the polysemy of the term “service” also appears in technical glossaries⁵.

Considering that our intent is to establish a reference ontology for meaning negotiation, we have chosen to use a set of non-ambiguous concepts (e.g., service offering, service negotiation/agreement, and service delivery) all related to the generic notion of “service” (instead of proposing a regimented terminological definition, as attempted in some previous works [27][28]). Thus, when using the term “service”, it is important to determine pragmatically (i.e., based on the context) which of these concepts are being referred. We stress that various possible senses of the term “service” do not form a flat list: systematic polysemy means that there is an internal structure within a sense cluster, based on a relation of *ontological dependence* between the different senses. In our case, the concepts of service offering, service negotiation/agreement and service delivery such as they are organized in the service life-cycle model, fit in a (ontological) structure of senses around the term “service”. Thus, a service delivery depends on a service negotiation, which in turn depends on a service offering. This justifies our suggestion that, after all, the notion of service offering (which in turn builds on a pattern of commitments and claims) is the *core meaning* of the commonly used “service concept”. This means that when attempting to define what “service” means, some reference to this core must be taken in account.

9. Final Considerations

This work defined a foundation for Service Computing and Service Science with a core reference ontology for services called UFO-S. UFO-S is grounded in a foundational ontology (UFO) that includes social and intentional concepts that form the basis for our account of the social relations established throughout the service lifecycle. UFO-S accounts for the agent’s intentionality with respect to the actions they perform by entering into and aiming to fulfill their social commitments.

As a kind of “analysis theory” [73], UFO-S establishes the basic concepts and relationships around the notion of service with the purpose of being general enough to harmonize others perspectives of service. Thus, besides contributing to the body of knowledge around service, we have argued that the theoretical foundation of the service concept based on the notion of social commitments/claims provided by UFO-S can span the business and computational perspectives, with the potential of promoting a much-needed conceptual integration of Business and IT service aspects. We believe this observation can guide our future work on well-founded *modeling* of service-oriented enterprise architectures. For example, we intend to perform an ontological analysis of ArchiMate focusing on the service concept and how it is represented in this framework. This would contribute to the agenda we have been pursuing in the last decade towards well-founded enterprise modeling [42][43][44][45].

Rigor in the design ([54][55]) of UFO-S was achieved by: (i) grounding UFO-S in the Unified Foundational Ontology (UFO), and (ii) by defining an axiomatization for avoiding unintended model instantiations. With respect to (i), by refining concepts of UFO, UFO-S could count on a well-founded body of knowledge (already applied in a number of works, e.g., [41][42][44][45]) that offers important ontological distinctions, such as, endurants (objects) and moments (properties), perdurants (events), and social entities (e.g., agents, social commitment and claims, and social roles). With respect to (ii), the objective of the axiomatization was to ensure “precision” [74] in the specification of UFO-S. The axiomatization was a result of an iterative model simulation approach conducted over UFO-S models. The approach consists, basically, in transforming OntoUML models in Alloy specifications [32], and generating conforming instantiations of the models automatically. These instantiations were then analyzed in order to identify the lack of required constraints. The main constraints identified are reflected in the axioms presented in Section 4. Further details about the process of formalization of the UFO-S models can be found in a technical report [33]. The report shows the complete set of constraints expressed in OCL and the complete Alloy specification that was derived from the OntoUML model enriched with the constraints.

⁵ For an interesting example of the confusion between “service” and “service type” in the scope of a large service-based company, consider this definition, taken from the UPS glossary: “*Service: The UPS service type for a shipment. For more information on service types, refer to the UPS Rate and Service Guide.*” <http://www.ups.com/content/us/en/resources/ship/glossary/>

We have not yet addressed Quality of Service (QoS) aspects in service relations (e.g., reliability, responsiveness, assurance, empathy [75] or other “quality aspects” or “quality dimensions”). However, the current version of UFO-S and the adopted foundational ontology (UFO) create the basis for further discussion about QoS. Consider, for instance, the statement “the car will be cleaned within 1 hour”. Consider also that “within 1 hour” is a responsiveness quality aspect. In service offerings and service agreements, we can say that this aspect is part of the propositional content of a service commitment from the provider towards the customer. Such commitment, in turn, creates customer’s expectations about her car being cleaned within 1 hour. In the service delivery, actions are performed in order to fulfill this commitment. Thus, we say that this commitment is fulfilled if the whole cleaning process lasts at most 1 hour. “Lasting at most 1 hour” is now a measurable property (*quality* in terms of UFO) of the cleaning process (a *complex event* in UFO). By being amenable to measurement, we can analyze its value (a *quale* in UFO) and contrast it to the propositional content of the service commitment. While this is an informative example that illustrates how the notion of commitment may be related to QoS aspects, a more detailed account for QoS aspects requires careful consideration on its own, and would be a natural extension of our present work. A particular point of attention for further investigation is that quality statements may concern entities of multiple ontological categories (e.g., quality in service negotiation, quality in service delivery, quality in the description of service commitments, quality in the consumption of resources, qualities of dispositions of service participants). Ideally, an account for QoS should also address “vagueness” of quality statements and “subjectivity” in the assessments of qualities.

Finally, in this work we have focused on a core fragment of the service life cycle, leaving marketing-related phases (pre-service offer and post-service delivery) outside the scope of this paper. Also, future work could expand on that in order to provide a more detailed account for the origin of value propositions and to further explicate the subjective value experience aspects. Moreover, it is necessary to account for issues regarding resource allocation, usage and consumption in service delivery.

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