Understanding the Semantic Web through Descriptions and Situations

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Abstract. The Semantic Web is a powerful vision that is getting to grips with the challenge of providing more human-oriented web services. Hence, reasoning with and across distributed, partially implicit assumptions (contextual knowledge), is a milestone.
Ontologies are a primary means to deploy the Semantic Web vision, but few work has been done on them to manage the context-dependency of Web knowledge. In this paper we introduce an ontology for representing a variety of reified contexts and states of affairs, called D&S, currently implemented as a plug-in to the DOLCE foundational ontology, and its application to two cases: an ontology for communication situations and roles, and an ontology for peer-to-peer communication. The reified contexts represented in D&S have a rich structure, and are a middleware between full-fledged formal contexts and theories, and the often poor vocabularies implemented in Web ontologies...

1 Introduction

Ontologies, as discussed in Artificial Intelligence, are formal, partial specifications of an agreement over the description of a domain [1]. Ontology-based communication and the integration of passive knowledge sources, dynamic agents and services on a global scale is also known as the vision of the Semantic Web. However, the difficulty of reaching agreements in large and diverse communities and the decentralized, uncontrolled nature of the current web suggests that the Semantic Web will be likely to propose new challenges unknown to current centralized, single authority ontology applications.

Due to its decentralized nature, the Semantic Web will be dominated by multiple domain ontologies used in various systems by the different communities. Once the consensus surrounding the ontology of a domain breaks down, merely the constructs of the ontology language remain to aid interpretation. A solution could come from the adoption of a universal upper ontology; such attempts however seem to fail as upper ontologies are broken apart into hundreds of contexts or microtheories. A monolithic ontology that is adopted as a standard is not convincing either under many respects (see [2]).

Adds to the challenge that scalability requirements will push towards the use of automated methods to acquire, translate or merge ontologies. Such methods are known to degrade the level of formality of ontologies, resulting in the prevalence of lightweight ontologies [3]. We believe that such limitation is fundamental rather than technical; we refer the reader to the paper of Elst and Abecker for a detailed treatment of the contradiction of sharing scope, stability and formality of knowledge in information systems [4].

A possible direction might be adopting a complex workflow for ontology maintenance that allows a periodical maintenance of lightweight ontologies by means of well-crafted, expressive reference ontologies [2], and according to reconciliation, integration, and merging procedures [5]. But the massively distributed and unpredictable nature of Semantic Web ontologies does not easily yield to such a treatment for the level of detail required by the workflow.

The breakdown of consensus and the weakening of formality means a loss of both defining aspects of an ontology meant for communication. Ontologies transferred through the Semantic Web will be reduced to scanty structures, due to the lack of commitment and the low expressivity of the standard constructs that are used. We argue that such black-box ontologies will be a fact of life; which means we have to look elsewhere for meaning to be recreated.

We propose a mechanism to mime the human cognitive ability to contextualize our ontological commitments, even when we have scanty evidence of them. This ability originates from extensive reification, and from the representation of other cognitive processes described e.g. by Gestalt psychology [6], which allow us to refer synthetically to some commonly agreed context labels.

From the Semantic Web perspective, we propose that –when a complete theory is lacking– we may still recurse to contextual evidence to help interpretation. An ontological context can be preliminarily defined here as a first-order entity, usually quite complex, which is defined by certain typical elements that result from the reification of the elements of a theory.

In this paper we describe two advances along the road towards representing communication contexts for the Semantic Web. We have developed and are exploiting an ontology of contexts, called Descriptions and Situations (D&S), which provides a principled approach to context reification through a clear separation of states-of-affairs and their interpretation based on a non-physical context, called a description. The ontology of descriptions also offers a situtation-description template and reification rules for the principal categories of the DOLCE foundational ontology. Both DOLCE and the D&S extension to DOLCE are being developed in the EU WonderWeb project[3].

Our second contribution is a preliminary attempt to an ontology of communication. This ontology is modelled using D&S as this framework allows us to separate our theories of communication and interpretation (descriptions) from the level of a Semantic Web model (a setting where communication situations take place). Integrating theories of communication (linguistic theories) with theories of interpretation (computational semiotics), such an ontology is in fact an

[3] `http://wonderweb.semanticweb.org`

attempt to describe ontology-based communication on the Semantic Web. The inclusion of a theory of interpretation in this ontology is crucial in relating the contexts of ontology use to the communication system.

Although the Semantic Web is largely a vision, we demonstrate the validity of this ontology by extending it to model a peer-to-peer ontology-based knowledge sharing environment under development within the European SWAP (Semantic Web And Peer-to-Peer) project[4]. The SWAP system is a forerunner of Semantic Web technology and implements several important aspects of the vision, namely the use of ontologies for organizing domain knowledge and a distributed architecture without centralized control.

The remaining of the paper is organized as follows. In Sect. 2, we introduce the Descriptions and Situations framework and discuss its implementation in DOLCE. Next, in Sect. 3 we describe the development of the ontology of communication and show how it may applied and adapted for the SWAP system. Lastly, we conclude with a discussion of related and future work in Sect. 4.

2 Descriptions and Situations

This Section presents the motivation and development of our ontology of descriptions, called Descriptions and Situations (D&S). The D&S ontology is designed as a plug-in to the DOLCE foundational ontology [2], which is the first module of a future Foundational Ontology Library being developed within the European WonderWeb project. The WonderWeb architecture envisages a tight integration among web languages, ontology learning and manipulation tools, foundational ontologies and ontology building methodologies. With additional effort, however, the D&S ontology may be adapted to other foundational ontologies.

2.1 Motivation

Foundational ontologies in WonderWeb are ontologies that contain a specification of domain-independent concepts and relations based on formal principles derived from linguistics, philosophy, and mathematics. Formal principles are needed to allow an explicit comparison between alternative ontologies. Examples of formal principles are spatio-temporal localization, topological closure, heterogeneity of parts, dependency on the intention of agents, etc. We refer to [2] to a detailed explanation.

While formalizing the principles governing physical objects or events is (quite) straightforward, intuition comes to odds when an ontology needs to be extended with *non-physical objects*, such as social institutions, organizations, plans, regulations, narratives, mental contents, schedules, parameters, diagnoses, etc. In fact, important fields of investigation have negated an ontological primitiveness to non-physical objects [7], because they are taken to have meaning only in combination with some other entity, i.e. their intended meaning results from a

[4] `http://swap.semanticweb.org`

statement. For example, a norm, a plan, or a social role are to be represented as a (set of) statement(s), not as concepts. This position is documented by the almost exclusive attention dedicated by many important theoretical frameworks (BDI agent model, theory of trust, situation calculus, formal context analysis), to states of affairs, facts, beliefs, viewpoints, contexts, whose logical representation is set at the level of theories or models, not at the level of concepts or relations.

On the other hand, recent work (e.g. [7]) addresses non-physical objects as first-order entities that can change, or that can be manipulated similarly to physical entities. This means that many relations and axioms that are valid for physical entities can be used for non-physical ones as well.

Here we support the position by which non-physical entities can be represented both as theories/models and as concepts with explicit reification rules, and we share the following motivations:

- Technology and society are full of reifications, for example when we divide human experience into social, cultural, educational, political, religious, legal, economic, industrial, scientific or technological experiences
- In realistic domains, specially in socially-intensive applications (e.g. law, finance, business, politics), a significant amount of terms convey concepts related to non-physical entities, and such concepts seem to be tightly interrelated
- Interrelations between theories are notoriously difficult to be manipulated, then it would be an advantage to represent non-physical objects as instances of concepts instead of models satisfying some theory
- For many domains of application, we are faced with partial theories and partial models that are explicated and/or used at various detail levels. Partiality and granularity are two more reasons to have some theories and models manipulated as first-order entities
- Natural languages are able to reify whatever fragment of (usually informal) theories and models by simply creating or reusing a noun. Once linguistically reified, a theory or a model (either formal or informal) enters a life-cycle that allows agents to communicate even in presence of partial (or even no) information about the reified theory or model. The Web contains plenty of examples of such creatures: catalog subjects or topics, references to distributed resources, unstructured or semi-structured (but explicitly referenced) contents, such as plans, methods, regulations, formats, profiles, etc., and even linguistic elements and texts (taken independently from a particular physical encoding) can be considered a further example
- Recent unpublished work by one of the authors reports that more than 25% of WordNet (v1.6) noun synsets [8] can be formalised as non-physical object classes

In general, we feel entitled to say that representing ontological (reified) contexts is a difficult alternative to avoid, when so much domain-oriented and linguistic categorisations involve reification. However, we also want to provide an explicit account of the contextual nature of non-physical entities and thus aim for a reification that accounts to some extent for the partial and hybrid structure of such entities.

From the logical viewpoint, any reification of theories and models provides a first order representation. From the ontological engineering viewpoint, a straightforward reification is not enough, since the elements resulting from reification must be framed within an ontology, possibly built according to a foundational ontology.

We also need specific reification rules for at least some distinct elements of a theory or a model. Moreover, from a practical viewpoint, the actual import of theories and models (when they are used as concepts) into an ontology requires not only reification rules, but also mapping and inheritance rules. This partial and hybrid transformation allows an easy grasp and manipulation of reified theories and models.

2.2 An ontology of descriptions and situations

D&S is intended to provide a framework for representing contexts, methods, norms, theories, situations, and models at first-order, thus allowing a partial specification of those entities.

Partial specification[5] is the usual assumption for cognitive artifacts used in many rational activities: planning, viewpoints, perspectival thinking, modular conceptualizations, naïve theories, granularities, problem solving methods, etc.

D&S axioms try to capture the notion of "situation" as a *unitarian* entity out of a "state of affairs" [2]. The *unity* criterion is provided by a "description".

A *state of affairs* is any non-empty set SoA of assertions $a_{1..n}$ that are individually coherent with the axioms in a first-order theory O, called a "ground ontology". A SoA is a second-order entity, therefore it cannot be represented (as such) as an individual in O. Examples: a clinical data set, a set of temperatures with spatio-temporal coordinates, etc.

A *description* is an entity that *partly represents* a (possibly formalized) theory T (or one of its elements) that can be "conceived" by an agent: either human, collective, social, or artificial. A description can be an individual in O. Examples: a diagnosis, a climate change theory, etc.

A *situation* is *constituted by* the entities and the relations among them that are mentioned in assertions $a_{1..n}$ from a SoA, and it is an entity in O that *partly represents* a (possibly formalized) model M for T, according to the axioms in O. A situation can be an individual in O. $a_{1..n}$ must be systematically related to

[5] Any axiomatic theory and its models are partial, since they usually formalize only part of the assumptions or facts in a domain of interest. This can be called external incompleteness, and should be taken for granted, at least for the well known logical reasons. On the other hand, internal incompleteness can be considered for entities that represent only some of the elements of a theory or a model. Internal incompleteness is assumed for D&S descriptions and situations.

the components of a description in order to constitute a situation.[6] Example: a clinical condition, a climate change history, etc.

Intuitively, when a description is applied to a state of affairs, some *structure* (a “situation”) emerges (this reflects the cognitive structuring cognitive process [6]). The emerging structure is not necessarily equivalent to the actual structure.

Due to its neutrality with respect to realism, D&S can generalize the distinction between state of affairs and description, in order to obtain an epistemological layering. Epistemological layering consists of assuming that any logical structure L_i (either formal or capable of being at least partly formalised) is built upon a structure SoA that it describes according to a theory T_i (either formal or capable of being at least partly formalised). In other words, T_i describes what kind of ontological commitment L_i is supposed to have within the epistemological layer that is shared by the encoder of an ontology.

Epistemological layering reflects the so-called *figure-ground* shifting cognitive process [6]. For example, a functional biological theory can assume a molecular biological theory as ”data” in a SoA, instead of including it, or a legal norm can overrule a social practice without including it.

A ground ontology O is here restricted to be a foundational ontology that in its signature contains at least one unary predicate P and one n-ary predicate R whose universe is restricted to P. D&S adds to O by inserting two unary predicates: D (Description) and S (Situation), and a binary predicate $satisfies$, holding between S and a subset of D, called SD (Situation Description):

$$SD(x) \rightarrow D(x) \tag{1}$$
$$satisfies(x, y) \rightarrow S(x) \land SD(y) \tag{2}$$
$$satisfiedBy(y, x) \leftrightarrow satisfies(x, y) \tag{3}$$
$$\forall x.S(x) \rightarrow \exists y.SD(y) \land satisfies(x, y) \tag{4}$$

D is inserted under one of the predicates P_i in O, provided that D instances are unitarian, non-physical entities depending on the intentionality of an agent. *Unitarian* entities, *non-physicality* and *intentionality* are introduced in [2]. For example, in DOLCE D is inserted under the predicate ”Non-physical Endurant”. If no P_i can subsume D, D is inserted as a new most general predicate. O enriched with D&S is called $O+$.

A further transformation induced by D&S on O is the so-called *functional* (or “selectional”) *structure*. For each most general predicate P_i in $O+$, there exists a predicate P_i^D subsumed by D (but disjoint from SD), and between each

[6] Other names have been proposed for these concepts, for example flux, unstructured world, or data for “state of affairs”, conceptualization, representation, schema, or function for “description”, setting, Gestalt, configuration, or structure for “situation”. Context is a word used for all three concepts, thus reaching a very high ambiguity score. “Situation” in D&S is not related to “situations” in situation calculus: these are independent punctual entities used to assemble fluents, while in D&S situations are not bound to temporal instants, and depend on an s-description.

pair P_i, P_i^D the *selects* binary predicate may hold when an instance of P_i is a constituent of a situation:

$$P_i^D(y) \rightarrow D(y) \tag{5}$$
$$\neg(P_i^D(y) \wedge SD(y)) \tag{6}$$
$$selects(x, y) \rightarrow P_i^D(x) \wedge P_i(y) \tag{7}$$

For example, in DOLCE a "Perdurant" can be "selected by" a "Course", an "Endurant" can be selected by a "Functional Role", and a "Region" can be selected by a "Parameter".

The functional structure in $O+$ requires that a P_i^D is a *(temporary) component of* an SD_i, and for each P_i in the *setting* of an S_i that *satisfies* an SD_i, a P_i is *selected by* a P_i^D.

$$\forall x.P_i^D(x) \rightarrow \exists y.SD(y) \wedge t\_component(y, x) \tag{8}$$
$$\forall x.SD(x) \rightarrow \exists y.P_i^D(y) \wedge t\_component(x, y) \tag{9}$$
$$\forall x.S(x) \rightarrow \forall y.part(x, y) \rightarrow S(y) \tag{10}$$
$$settingFor(x, y) \rightarrow constituent(x, y) \wedge S(x) \wedge P_i(y) \tag{11}$$
$$\forall x.S(x) \rightarrow \exists y.P_i(y) \wedge settingFor(x, y) \tag{12}$$
$$settingFor(x, y) \rightarrow \exists zw.P_i^D(z) \wedge SD(w) \wedge t\_component(w, z) \wedge satisfies(x, w) \wedge selectedBy(y, z) \tag{13}$$

"Component" and "setting for" binary predicates can have various names. These ones are used in the extension of DOLCE (DOLCE+). *T_component* is the non-transitive, systemic restriction of "(temporary) part", while *setting for* is a "constitution" relation holding between a situation and its constitutive elements. "Part" and "constitution" are defined in [2].

Functional structure in $O+$ allows to maintain a dependency of the constituents of a situation, on the components of an s-description (cf. Ax.13). Such dependency is the analytic motivation for a situation to "satisfy" an s-description. Since situations and s-descriptions are partial representations of models and theories respectively, this notion of satisfaction "mirrors" the satisfiability relation between models and theories.

Realistic uses of D&S that empower ground ontologies have richer structures. For example, extending DOLCE with D&S requires finding a component of SD for each most general concept in DOLCE. DOLCE features four such categories: Endurant, Perdurant, Quality, and Abstract. Abstract includes one major subconcept: Region. Qualities in most applications are mediated by a position in some (dimensional) region. DOLCE+ currently simplifies DOLCE's ontological commitment by considering only regions within abstracts, and ignoring qualities.

Figure 1 shows a UML class diagram of the full ontology, with the following semantics: generalization is interpreted as subsumption, tagged associations are interpreted as binary predicates, classes as unary predicates, and cardinalities as generalized quantifications on axioms that use binary predicates and their inverses.

DOLCE+ s-description components have the following types: "Course (of events)" for Perdurant, "Function(al role)" for Endurant, and "Parameter" for Region. The relation "selects" is specialized for c-descriptions accordingly:

$$SD(x) \rightarrow \exists y.COU(y) \vee FR(y) \vee PAR(y) \wedge t\_component(x,y) \tag{14}$$
$$COU(x) \rightarrow \exists y.SD(y) \wedge t\_component(y,x) \tag{15}$$
$$FR(x) \rightarrow \exists y.SD(y) \wedge t\_component(y,x) \tag{16}$$
$$PAR(x) \rightarrow \exists y.SD(y) \wedge t\_component(y,x) \tag{17}$$
$$sequences(x,y) \rightarrow selects(x,y) \wedge COU(x) \wedge Perdurant(y) \tag{18}$$
$$playedBy(x,y) \rightarrow selects(x,y) \wedge FR(x) \wedge Endurant(y) \tag{19}$$
$$valuedBy(x,y) \rightarrow selects(x,y) \wedge PAR(x) \wedge Region(y) \tag{20}$$
$$PAR(x) \rightarrow \exists y.Region(y) \wedge valuedBy(x,y) \tag{21}$$

It is easy to notice that, while in general s-descriptions require at least one component (a c-description, cf. Ax.9), no further specification can be given of what c-description is required. For example, in DOLCE+, an s-description can be composed of functions only, of courses only, of parameters only, or of a mixture of them (cf. Ax.14). This is quite natural, since the requirement comes from D&S functional structure, but further distinctions derive from the categories in the ground ontology.

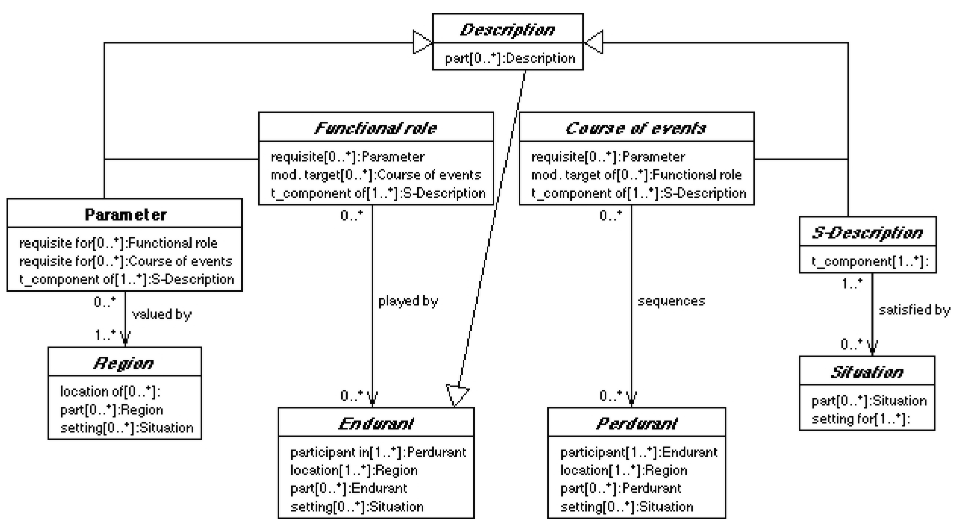

Fig. 1. UML model of the D&S ontology and its relations to the top-level of DOLCE

C-description types can be related one to another in peculiar ways. For example, *inter-categorial* relations (holding within different kinds of c-description) have the following argument restrictions:

$$modalityFor(x, y) \rightarrow FR(x) \wedge COU(y) \tag{22}$$

$$requisiteFor(x, y) \rightarrow PAR(x) \wedge (COU(y) \vee FR(y)) \tag{23}$$

"Modality for" is the functional counterpart of the "participation" relation from DOLCE ground ontology: in analogy with endurants participating in perdurants, functions have a way of participating to courses (according to a certain s-description). For example if a person p participates in an event e according to a mental plan, a social habit, a legal norm, etc., then the function f played by p can respectively be "willing", "hopeful", "cautious", "obliged", "allowed", etc. with reference to a course c that sequences e. Modalities and functions can be also used to characterize special participation relations, e.g. so-called "thematic roles".

"Requisite for" is the functional counterpart of the "localization" relation from DOLCE: in analogy with regions being the localizations of endurants or perdurants, parameters give requisites to functions and courses for endurants or perdurants to be localized (according to a certain s-description).

Examples of descriptions and situations in DOLCE+ include: a clinical condition (situation) with a diagnosis (s-description) made by some agent (functional-role), a case in point (situation) constrained by a certain norm (s-description), a murder (situation) reported by a witness (functional role) in a testimony (s-description), a 40kmph (region) as the value for a speed limit (parameter) in the context of an accident (state of affairs) described as a speed excess case (situation) in an area covered by traffic code (s-description) etc.

D&S is currently employed in various academic and industrial domains, including legal norm dynamics, services, financial risk, biological pathways, fishery information, etc. In the following, we will demonstrate the use of D&S through the development of an ontology of communication. While this is an instantiation of the D&S schema, the observant reader may note that the ties between the two ontologies run deeper: interpretation logically depends on the notion of a description, which on its turn depends on an intuitive notion of referencing to (having an intention towards) some configuration. Such referencing requires a communication setting including information objects. A communication setting can be understood only within a semiotic framework, and the circle is complete.

3 Modelling ontology-based communication with D&S

In the previous work of a survey of ontology-based systems, we have shown that all proposed application scenarios of ontologies in information systems build upon the primitive notion of ontology-based communication [10]. To our knowledge, no formal descriptions of this process has been given so far; even though such formalization would allow us to reason about the workings of our systems.

In the following, we describe the creation of an ontology of communication using the D&S framework. Theories of communication and interpretation lend naturally to be modelled as descriptions. While disjoint from the actual setting of interaction, they have the power to bring structure to a state of affairs consisting of primitives such as the rise and fall of electrical signals over a wire. The contextual nature of these theories is also reflected by the fact that multiple descriptions of communication may be mapped to a given state of affairs. Multiple situations present in the same state of affairs, however, do not necessarily constitute a contradiction and in fact, are a natural phenomenon in scientific work.

The generic schema for our communication ontology combines two skeletal descriptions as shown in Figure 2. The description for communication consists of communication parameters valued by communication regions, communication roles played by endurants and communication turns that sequence a communication event according to some method of communication. The description for interpretation concerns semiotic parameters, roles and semiotic tasks according to some interpretation method.

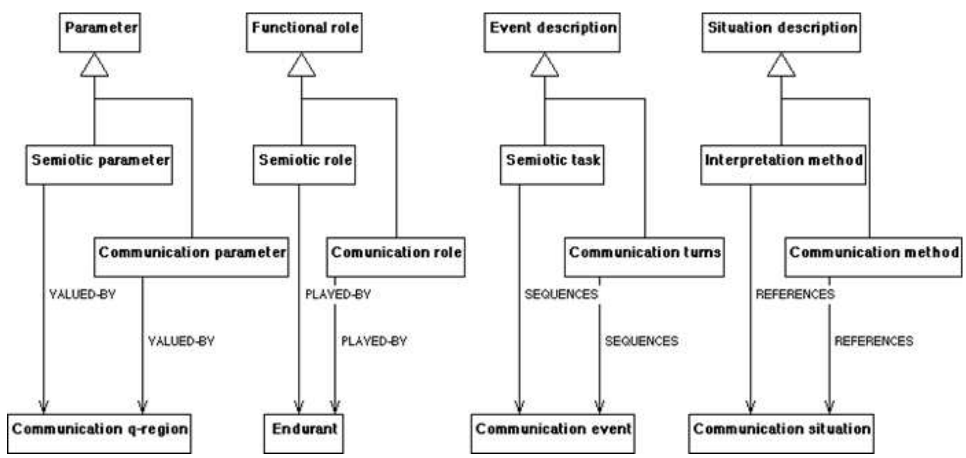

Fig. 2. The schema for communication and interpretation descriptions

Beyond the fact that the two descriptions reference the same situation (albeit from different perspectives), we will see that they are also interrelated in more intricate ways. We consider these connections particularly important, as there is a tendency in the Semantic Web community to dismiss questions of interpretation as external to the system. In this respect the community follows the tradition of symbolic AI, ignoring the fact that ontologies are social artifacts.

While tenable in closed environment, this attitude quickly leads to practical problems in heterogeneous contexts, such as the one known as the Web's identity crisis [11]. This crisis resulted from the vague definition of Universal Resource

Identifiers (URI). In practice, symbols of Semantic Web ontologies are often used to denote documents, in other cases documents containing definitions of concepts or the concepts themselves. A further difficulty with the URIs of the last type is that they cannot be denoted (resolved) by machines. As there is no authority provisioning such identifiers, individuals or communities may take the authority upon them to use the same URIs to denote different real world entities (not to mention fictitious ones). Without accessing and processing the interpretation context, such cases may not be disambiguated by a machine.

In the words of John Sowa, "... meaningless data cannot acquire meaning by being tagged with meaningless metadata. The ultimate source of meaning is the physical world and the agents who use signs to represent entities in the world and their intentions concerning them." [12]. Coupling our theories of communication with theories of interpretation will allow us to map the connections between elements of the communication system and those external to it, such as the agents who (re)create meaning.

To demonstrate the use of this template, we will fill our schema by modelling a communication theory developed by Roman Jakobson and a theory of semiotics originating from the work of Ferdinand de Saussure. This combination results in a simple, but generic model that can provide systematic account of communication acts regardless whether direct (oral) or mediated (as in the case of an information system), independently from a particular encoding.

The ontology of communication may be used in two ways. By mapping it to elements of a model of an information system such as the SWAP environment, it allows us to understand states of affairs as a communication situation, i.e. to check whether our respective theories of communication are upheld by the system.

While the descriptions obtained by instantiating the ontology are very fine grained (and therefore of low expressivity), they may be collected in the form of a knowledge base and interpreted later on according to additional heuristics (e.g. by detecting that communications are part of the same dialogue or broadcast). These heuristics may also be captured in an extended description which is able to express more complex patterns of interaction, such as communications involving multiple peers. We will demonstrate this method by modelling the resolution of queries in the peer-to-peer network. This description is naturally related to the previous one in that activities may be translated to the message exchanges of the previous example.

3.1 Theories of communication and interpretation

Jakobson's model of communication and the functions of language had a decisive impact on linguistic theory ever since its original publication over 40 years ago. As he writes in "Linguistics and Poetics: Closing Statement" all acts of communication are contingent on six constituent elements [13]: the addresser or encoder [speaker, author], a message [the verbal act, the signifier), the addressee or decoder (the hearer or reader), a context[7] (a referent, the signified), a code (shared mode of discourse, shared language) and a contact or channel.

Using the ontology of descriptions, all six constituents are modelled as functional roles: the encoder and decoder are agentive roles, while the other elements of theory are non-agentive functional roles. The method of communication is represented as a course.

Missing from Jakobson's model is a theory of interpretation: his model gives no indication as to how meaning is constructed from messages. To find such a theory and fill the missing gap one may turn to the models of semiotics.

Semiotics is the science of signs. While deriving from linguistics, semiotics is an application of linguistic methods to objects other than natural language; it is a way of viewing any system as constructed and functioning similarly to language. Semiotics was independently developed by the logician and philosopher Charles Sanders Peirce and the linguist Ferdinand de Saussure in the second half of the 19th century. For our purposes of extending our communication description with an interpretation theory, we will commit to the Saussurean idea of interpretation, shared by Jakobson himself.

Ferdinand de Saussure was the first to describe scientifically the interaction between the two distinct but interoperating structures of language (at the level of meaning: the lexical structure, and at the level of expression: the phonologic structure), and the interaction between the emergent linguistic structure (morpho-syntactic), and the underlying linguistic structure (conceptual or paradigmatic) [14]. Meaning in Saussurean terms is created by (morphosyntactic, lexical) Expressions in (a conceptual) Context, i.e. by the interpretation function $I : (e, c) \rightarrow m$. Thus the semiotic roles of this theory are the expressions, contexts and meanings used to fill the domains and the range of the interpretation function.

Again using our ontology of descriptions, expressions are modelled as functional roles played by information objects and are equivalent to the message communication function.

S-Contexts are played by S-Descriptions. These descriptions are reifications of the various contexts affecting communication and interpretation of knowledge.

While the ontology is open at this point to further modelling, we note that related work exists in several communities. For example, the so called organizational context of knowledge (agents and their groups or communities, and the task and processes they perform) have been extensively studied in Knowledge Engineering [15]. Context modelling is also relevant to the effort of ontology mapping. Here, the most widely used contexts are the instance context and the natural language context. Algorithms using the first type of context build on the ability to compare concrete instances of classes even if the classes themselves represent external or abstract concepts. Algorithms of the second kind attempt to interpret symbols of the ontology as (particular senses of) natural language terms and map them to standard linguistic dictionaries. (Better mappings can

[7] One should note that by "context" Jakobson means referent, i.e. what the message is about and not the circumstances of utterance.

be established by using 'ontologised' dictionaries such as the DOLCE-enhanced version of WordNet [9]).

Meanings are played by descriptions whatsoever and are not equivalent to any communication function. Descriptions playing the role of meaning have different natures according to the situation referenced by S-Contexts: legal cases, narrative worlds, planned procedures, clinical conditions, telephone calls, etc.

Our description for ontology-based communication, based on Jakobson's model of communication combined with a Saussurean interpretation theory is shown in the upper half of Fig. 3.

3.2 Communication in a Semantic Web environment

The European SWAP project aims to develop a distributed knowledge sharing solution using ontology-based methods in a peer-to-peer environment. The SWAP system is an extension of centralized ontology-based Knowledge Management solutions to decentralized scenarios.

The knowledge of peers is maintained and managed locally in the form of knowledge sources (e.g. documents, emails etc.) and an ontology used to organize those sources. Autonomy on the local level is complemented by coordination in the form of mappings between the ontologies of individual peers. Organizational knowledge networks subsequently emerge through the bottom-up process of making the connections between the ontologies of single nodes. An advantage of this network construction is that it is dynamically reconfigures itself as the underlying ontologies evolve. Furthermore, since the network is invoked on the basis of need for cooperation, its structure reflects the goals and interests of the various groups in the network. For more information on the SWAP system, we refer the reader to the project website[8].

The lower half of Fig. 3 shows a simple ontology of the SWAP system developed using DOLCE. In applying our description of communication and interpretation to the SWAP environment, we have to map the elements of the theories to the elements of this setting through the predicates *valued-by*, *played-by* and *sequences* as shown in Fig. 1.

In this case, the abstract Channel role is realized by a physical connection between the parties involved. Messages are played by information objects, which are realized by a physical stream of bytes going through the network. The encoder and decoder roles are played by SWAP peers, which stand in a direct relation with the human agents controlling them.[9] The encoding and decoding agents, the physical channel and the message are all *participant-in* the message transfer activity, which is sequenced by the communication method.[10]

[8] `http://swap.semanticweb.org`

[9] For the purposes of this example (and without entering the debate whether intentionality can be attributed to software agents) we suppose that peers are agentive, but receive their intentionality from a natural person.

[10] Omitted from the figure are participation relations (between endurants and perdurants) and setting relations (between the elements of the model and the situation object).

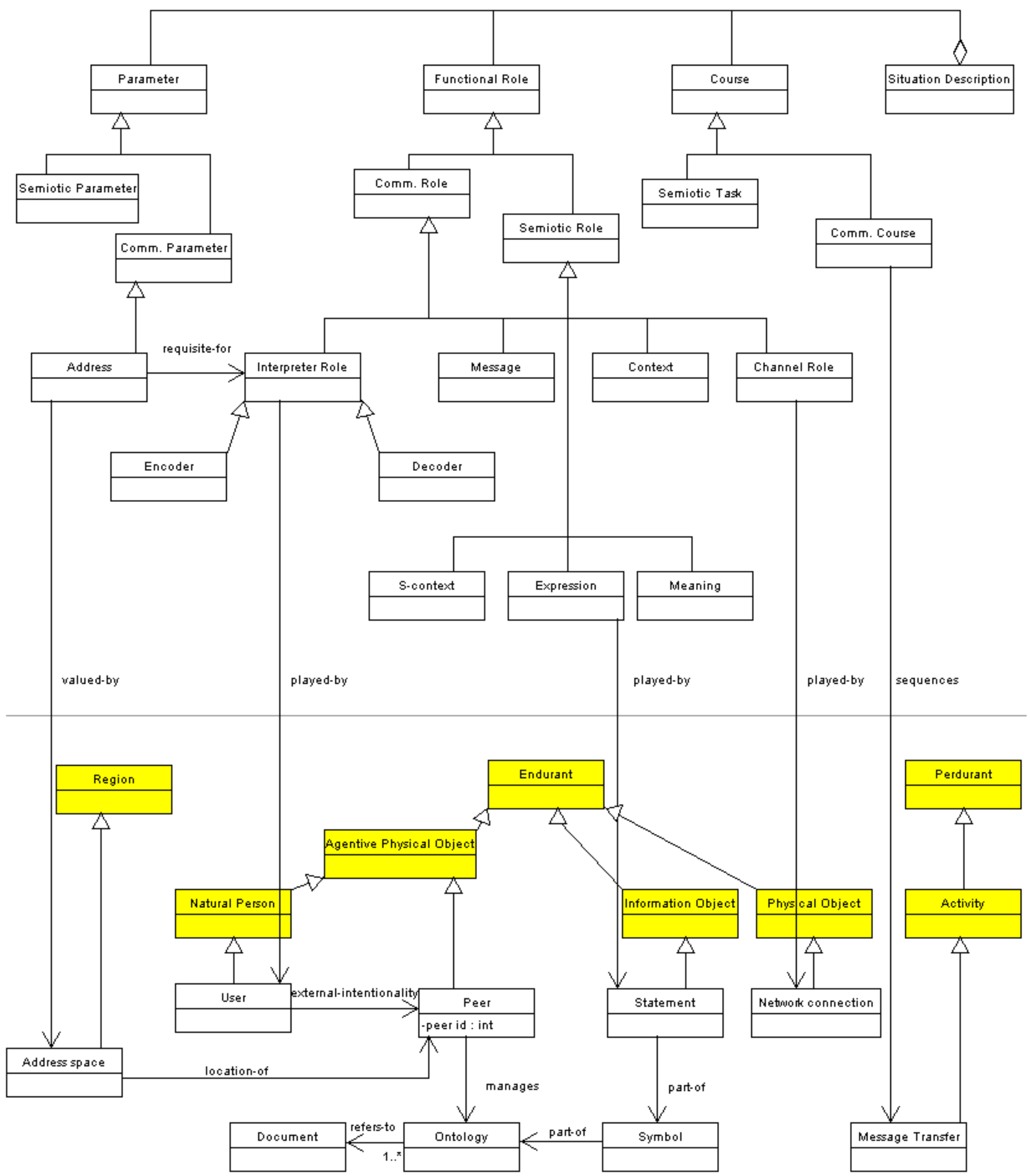

Fig. 3. The description of communication and interpretation (upper half of the picture) and its mapping to elements of the SWAP system (lower half). Shaded classes are defined in basic DOLCE.

The semiotic role of expressions are also played by the information objects. Interpretation is carried out by an element external to the information system, namely the human agent who manages his knowledge in the form of an ontology. She is the one who evaluates her personal interpretation function, which takes into account the expressions (along with axiomatization of the ontology as constraints on the possible models) and the contexts in which the communication takes place. In the end, an interpretation of the expressions results in meaning, which may or may not cover the intended meaning for the expression. In case a software agent has reasoning capabilities, it can use ontologies as the interpretive context, and the meaning will be the axioms for a given term e.g. in a query an agent tries to expand or to satisfy.

This modelling also shows how the previously mentioned dependency on interpretation translates into the system design of SWAP. Specifically, our theory suggests that the system should retain as much contextual information regarding its users as possible. In fact, there is no shared interpretation outside of local groups without an inherent community, i.e. a shared background of the users regarding the interest or task at hand. Matching the social contexts of the communicating parties, for example, may significantly increase the chance of successful interactions.

In our second example we provide a description for the query resolution process of the SWAP system as shown in Fig. 4.

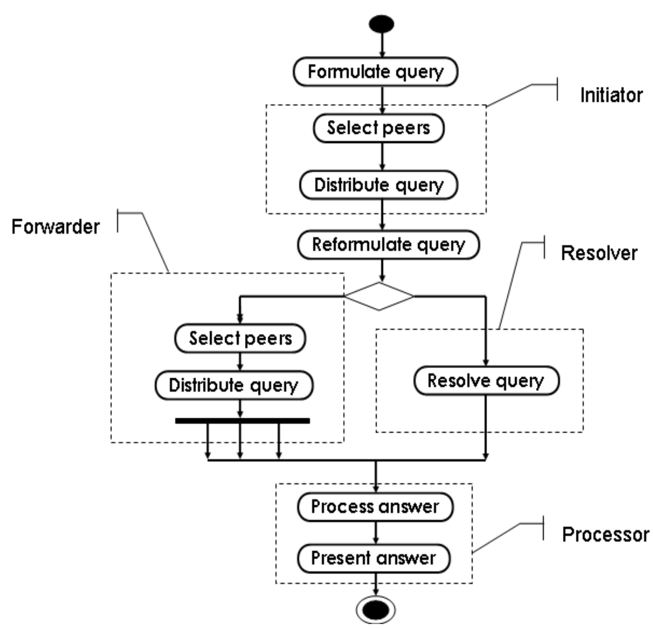

Fig. 4. The query resolution process of SWAP.

This process is started by a user creating a query using the interface of the system [16]. This query is handed to the Peer Selector which decides which peers to contact among those known locally. The Peer Selector takes into consideration the content of the query and tries to select those peers that are rated highly as expert on the subject and are also trusted. Then the query is wrapped in a message (which also contains relevant parts of the local ontology) and distributed over the peer network.

When the message arrives to a peer, the query is reformulated in terms of the local ontology of the receiving peer. Subsequently, a decision is made whether the query can be resolved based on local knowledge or it needs to be forwarded to other known experts. In the latter case, the query is carried out iteratively, i.e. a new query process is initiated whose results provide feedback to the original query.

In the meantime, the initiating peer waits for the incoming results and processes them asynchronously until a certain timeout is reached. Processing entails maintaining the rating system used for peer selection and carrying out updates to the local ontology.

Creating a formal description from this process model starts with attributing a number of the activities depicted to certain functional roles. In this case, the informal description suggests the three roles of Initiator, Resolver, Forwarder and Processor as shown in Fig. 4. Functional roles in query resolution are also systematically related to the simpler roles identified in the communication description (see Fig. 5). Initiators play the role of encoders, Processors play the role of decoders, while Forwarders and Resolvers play both roles with respect to different messages. This mapping to the communication description also results in the constraint that all four roles are played by SWAP peers in the system.

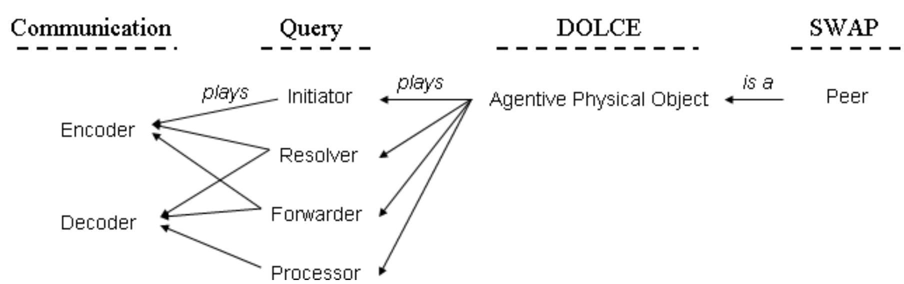

Fig. 5. Mapping of roles between descriptions.

Once the functional roles and their parameters have been found, the process diagram is modelled as the course of the query resolution. (For the representation of processes another extension of DOLCE is used.) The course, as mentioned before, defines the succession relations that prefigure the temporal relations which may exist between activities in the situation. Elements of the course are said to sequence the communication activities.

The refined description (omitted for brevity) may be mapped to actual settings as before. However, the expressive power of this mapping is greater than in the previous case as we are now able to understand patterns at a larger granularity. This process of refinement may be continued in a similar way and its gradual, cumulative nature makes sure that agents who do not commit to more refined descriptions of the system may still use less expressive theories.

4 Related and Future Work

In the previous sections we described the Descriptions and Situations framework and applied D&S to create an ontology of communication based on Jakobson's theory and Saussurean semiotics. We also showed how this ontology may be used as a basis for a more expressive description which models the query process in the peer-to-peer ontology-based system developed within the European SWAP project.

Our contribution is thus twofold:

Descriptions and Situations. The D&S framework is an ontology of descriptions based on the fundamental distinction between the flux (an unstructured world) and logos (an intentionality). D&S provides a number of reification rules for various kinds of non-physical contexts and offers a template for complex descriptions based on theories such as laws, plans, norms etc.

Descriptions as contexts are first-order entities, but themselves may have a structure consisting of other referenced descriptions. D&S thus provides a middle ground between the formal, analytic treatment of context [17, 18] and practical applications based on the structural investigation of particular contexts (such as the social context or workflow setting) and their effect on information systems.

The D&S ontology will be further developed and maintained within WonderWeb. In particular, D&S forms the backbone of an ontology of services, which takes into account the multitude of views on a service: the offering of the provider, the expectations of the requestor, the contract agreed, the service norms etc.

An ontology of ontology-based communication. The description of communication is an application of the D&S framework. This ontology is of particular interest to the Semantic Web community as it makes an attempt to formalize the first time the workings of communication using ontologies. The community is expected to gain from this formalization by reaching a shared understanding over the workings of its models and in particular the dependence of communication on interpretation. In short, this ontology should serve as a reference point in arguments both within the community and externally.

We also demonstrated how this ontology may be specialized to provide useful descriptions of specific ontology-based communication methods, by encoding additional knowledge about tasks or control mechanisms. The ground level of this ontology, namely the elements of the communication context could be modelled in more detail. This amounts to developing a formal description of the Semantic Web, which might be challenging at times when so many contrasting visions exist side-by-side. Nevertheless, the rewards would outweigh the benefits: even if ontologies will become a black box similarly to content today, information on the broader context of an ontology may be used to help answer questions of relevancy and legitimacy and thus might be a factor in partitioning the web in communities of practice or interest.

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