Chapter 7
Semantics in Multi-Agent Systems

Nicoletta Fornara, Gordan Ježić, Mario Kušek, Ignac Lovrek, Vedran Podobnik, Krunoslav Tržec

Abstract In this chapter we discuss how semantic technologies in general and specific Semantic Web standards in particular can contribute to the goal of achieving interoperability between independent, loosely coupled, heterogeneous, autonomous software components (i.e., agents) and for the realization of open interaction systems. In particular we will discuss how those technologies have been used for the definition of the semantics of agent communication languages, for the definition of norms and policies used to regulate interactions in open frameworks, and for defining efficient mechanisms for matching demands (i.e., content they need) to supplies (i.e., available content) in Telecommunication networks. In particular regarding this last type of application we describe a techno-economic approach for solving the matching problem, by means of a multi-agent system representing an electronic marketplace. Its functionality is realized by applying a semantic-aware content discovery model with two-level filtering in order to finally recommend a ranked set...
of eligible content to the users in response to their requests. The filtering processes not only consider the semantic information associated with the available content, but also ratings regarding the actual performance of businesses that act as content providers as well as the prices paid by businesses for advertising their content.

7.1 Introduction

In this chapter we discuss and report some examples of how semantic technologies in general and specific Semantic Web standards in particular can contribute to the goal of achieving interoperability between independent, loosely coupled, heterogeneous, autonomous software components (that we call agents). These components need to interact, negotiate, compete, or collaborate in order to reach their own goals in an open framework, that is, in a framework where those software agents dynamically start or stop to interact with other agents without being specifically programmed for interacting with a specific counterpart. Examples of application domains where this ability is fundamental are eCommerce and eProcurement (for example for the specification of B2B or B2C electronic auctions or e-markets where different parties may buy or sell products in [34, 23]), eBusiness (for example for the dynamic creation of supply chains or virtual enterprises [28, 5]), and resource sharing systems (for example systems for data, video, audio, or photo sharing [4, 26]).

The problem of interoperability between autonomous components in an open framework has the following two crucial characteristics:

- no assumptions can be made about the internal structure of the interacting parties and about their willingness to satisfy the rules, the norms, the interaction protocols, or the agreements reached with other agents;
- the interacting agents for planning their future communicative and non communicative actions need to have an expectation on the future actions of the other agents and therefore they need to be able to assume that every agent will derive the same conclusions from the information received. Therefore they need to share a common semantics for the meaning of the exchanged messages.

In order that the interaction among autonomous parties may lead to states having some global desirable properties, it is crucial to constrain agents’ actions with a set of norms, rules, or protocols.

In this chapter in Section 7.2 we will present and discuss how Semantic Web Technologies are used for modeling and reasoning on the content of agent communicative acts, on the specification of Artificial Institutions, and on norms and policies definition and enforcement (see Chapter 18 and Part III for more details on these concepts). In Section 7.3 we will present and discuss how Semantic Web Technologies are used for tackling one of the fundamental problem of open B2C e-markets: the problem of searching for possible matches between requested and available products, where products consists of content delivered over a network by telecommunication services.
7.2 Semantic Technologies for ACL, Institutions, and Norms

specification

One possible proposal, for the realization of interoperability in an open framework, is to define an application-independent format for the communication of information (abstract and concrete syntax), as for instance the one proposed in FIPA-ACL\(^1\) (Agent Communication Language) and most importantly a commonly accepted semantici. Usually the semantics of messages is defined compositionally by combining the semantics of the type of the message (as for instance promise, request, inform, agree, refuse) that is application independent, with the semantics of the content of the message that may be partially application independent and partially application dependent.

In the definition of the semantics of those components an important role may be played by semantic technologies. One important advantage of adopting Semantic Web technologies is that they are increasingly used in Internet applications and therefore it would be easier to achieve a high degree of interoperability of data and applications. Moreover, given that Semantic Web technologies are becoming widely used in innovative applications it will become much easier to teach them to software engineers than convince them to learn and use a logic language adopted by a limited group of researchers. One important standard Semantic Web language is OWL Description Logic (DL)\(^2\). The adoption of this language as a formal language for the specification of messages and their semantics has many advantages: thanks to the fact that it is decidable it is supported by many reasoners (like FaCT++\(^3\), Pellet\(^4\), Racer Pro\(^5\), HermiT\(^6\)), there are many tools for OWL ontology editing (like Pro\-tégé, NeOn), and there are libraries for automatic OWL ontology management (like OWL-API, KAON)\(^7\).

Examples of existing approaches that use semantic technologies for the formalization of the content language of FIPA-ACL are: the proposal of using RDF as content language of FIPA-ACL [10], the proposal of using the Darpa Agent Markup Language (DAML) language for expressing the content of messages [43], the proposal of using OWL DL as content language of FIPA-ACL [35], and the proposal of using OWL DL as content language of a commitment-based ACL whose syntax is compatible with FIPA-ACL [15].

A crucial requirement in open system is that the semantics of different types of communicative acts and of their content part has to be strongly independent of the internal structure of the interacting agents. The semantics of FIPA-ACL presents the

\(^1\) http://www.fipa.org/repository/aclspecs.html
\(^2\) http://www.w3.org/2007/OWL/wiki/OWL_Working_Group
\(^3\) http://owl.man.ac.uk/factplusplus/
\(^4\) http://clarkparsia.com/pellet/
\(^5\) http://www.racer-systems.com/products/racerpro/
\(^6\) http://hermit-reasoner.com/
\(^7\) W3C list of reasoners, editors, development environments, APIs: http://www.w3.org/2007/OWL/wiki/Implementations
problem of relying heavily on the BDI model of agents and of not taking into account the normative consequences of message exchanges. A successful approach to solving this problem consists in formalizing the effects of making a communicative act under specified conditions with the creation of a new object: the social commitment between the speaker and the hearer having a certain content and condition. Formal proposals to treat communicative acts in terms of commitments and to monitor their state on the basis of the agents’ actions can be found in [6, 37, 12, 40]. In particular in [15] a proposal of using OWL DL as content language of a commitment-based ACL and for expressing the semantics of promise communicative acts is presented.

However, expressing the meaning of certain types of communicative acts in terms of social commitments is not enough for completely representing their semantics, that is, for representing all the consequences of sending or receiving certain communicative acts for the future actions of the agents. The point is: why an agent that is a debtor for certain social commitments should plan its actions in order to fulfill or violate them? One possible answer to this question could involve proposing to formalize the institutional framework where the interaction takes place, and therefore specify the consequences in terms of reward or sanctions for the fulfilment or violation of social commitments. It is important to remark that in order to be able to apply those rewards or sanctions, it is also necessary to define and realize a monitoring component able to detect the fulfilment or violation of social commitments.

The definition of a shared institutional framework is also a requirement for defining the meaning of an important type of communicative act: the declarations. For example in an electronic auction the agent playing the role of auctioneer may declare open a run of an auction or declare the winner of the run. The institutional framework can be used to define institutional attributes (for example the state of an auction) and to define the semantics of a declarative communicative act by means of the changes brought about by this act in the value of institutional attributes, if certain conditions (for example having the required institutional power) hold [13].

Nevertheless, for effectively realizing interoperability among autonomous software agents in open, distributed, and competitive scenarios, the definition of a commonly accepted communication language and of an institutional framework that specifies sanctions and institutional concepts may not be enough. As previously remarked, in order to plan their actions the interacting agents need to have an expectation of the future evolution of the state of the interaction. This is possible if the interacting parties commonly accept a set of rules or norms used to define the obligations, prohibitions, permissions of the interacting parties. Some of them may be created and negotiated at run-time by interacting agents with enough reasoning capabilities, but given that negotiating all those rules from scratch may be very expensive in terms of the number of interactions required, and it can be done only by very complex agents, the more complex norms may be completely or partially (at least their structure or template) specified at design time.

It is fundamental to express those norms using a declarative formal language because this makes it possible to represent them as data, instead of coding them in the software, with the advantage of making it possible to add, remove, or change
the norms that regulate the interaction both at design time or at run-time, without the need to reprogram the interacting agents. Moreover this makes it possible, in principle, to realize agents able to automatically reason about the consequences of their actions and able to interact within different systems without the need to be reprogrammed. Finally their formal specification makes it possible to realize an application-independent monitoring component able to keep track of the state of norms on the basis of the events that happen in the system, and an enforcement component capable of reacting to norms fulfillment or violation on the basis of specific enforcement rules.

Semantic Web languages play a crucial role as languages for the declarative specification of norms. For example in [14, 11] OWL 2 DL and SWRL rules are used to represent and monitor norms and obligations. In those works given that Semantic Web technologies are not devised for modelling and monitoring the state of dynamic systems two problems are tackled: one is related to performing temporal reasoning an important problem given that OWL has no temporal operators; another one is related to successfully monitoring obligations with deadline, that is deducing that when the deadline has elapsed an obligation has to be permanently fulfilled or violated despite the open-world assumption of OWL logic. In [20] Semantic Web languages are used to represent norm-governed organizations allowing norm conflict (i.e., an action being simultaneously obliged and prohibited), to be captured and studied. Another example is the OWL-based representation of policies presented in [36], it enables both policy-governed decision making and policy analysis within the bounds of decidability.

A crucial open problem related to the choice of using Semantic Web Technologies, and in particular OWL, as formal languages for the specification and development of fundamental components of agreement technologies is the problem of understanding what part of those components it is better and possible to represent in ontologies in order to be able to reason on it and what part of those components it is better to represent in an external application because current semantic web standards do not support its representation. In what follows, some of the issues raised in this section are illustrated by an application in the domain of semantic-aware content discovery.

7.3 Semantic-aware Content Discovery in Telecommunication Environment

Discovery is the process of searching for possible matches between requested and available products. It is especially important for efficient trading when products do not represent commodities, i.e., their value is not characterized only by their price. An example of such product is content. Efficient discovery processes should identify all the supplies that can fulfill a given demand to some extent, and then propose the most promising ones [24, 32, 30]. Just a few years ago, discovery relied on simple keyword matching. However, nowadays discovery is becoming grounded on novel
mechanisms which exploit the semantics of content descriptions. Since these novel mechanisms may lead to a plethora of possible matches, mediation between content requesters (users) and content providers (businesses) is one of the most difficult problems faced in real world B2C e-markets [27, 31]. Thus, the notion of match ranking becomes very important, so matches can be ordered according to some criteria. If supplies and demands were described by simple strings, the only possible match would be identity, resulting in an all-or-nothing approach to matchmaking and ignoring the fact that supplies and demands also have a semantic dimension. This semantic dimension of content could be exploited in order to evaluate “interesting” inexact matches [24]. Exact (full) matches are usually rare and the true discovery process is aimed at providing a ranked list of the most eligible matches, thus leveraging further interaction [7]. Most approaches suggested for semantic discovery to use standard DL reasoning to determine whether one description matches another. None of these solutions exploit implicit semantics, i.e., patterns and/or relative frequencies of descriptions computed by techniques such as data mining, linguistics, or content-based information retrieval. In order to exploit these techniques, Klusch et al. use the OWLS-MX [18, 19], a hybrid semantic matching tool which combines DL-based reasoning with approximate matching based on syntactic information retrieval (IR) similarity computations.

Telecommunication services can be defined as a service which consists of content delivered over network resources. Today, a remarkable selection of diverse content is offered in form of various telecommunication services to users. Consequently, users require efficient mechanisms which can match demands (i.e., content they need) to supplies (i.e., available content) [29]. Here we describe a techno-economic approach to solving this problem, implemented through a multi-agent system representing an electronic marketplace. Stakeholders and processes on the electronic marketplace are based on Telco 2.0 [41] business model – users act as content buyers, content providers as content sellers and telecommunication operators (i.e., telcos) as brokers. The functionality of presented agent-mediated electronic marketplace is realized by applying a semantic-aware content discovery model which uses two-level filtration of available content before a final ranked set of eligible content is recommended to users in response to their requests. The filtration processes do not only consider the semantic information associated with available content, but also consider ratings regarding the actual performance of businesses that act as content providers (with respect to both price and quality) and the prices paid by businesses for advertising their content.

By introducing SPPCA (Semantic Pay-Per-Click Agent) auction, we enable content providers to contact telcos and advertise semantic descriptions of the content they provide. Consequently, users can utilize the telco’s service of two-level filtration of advertised content to efficiently discover the most suitable. In the first level of filtration, the broker (i.e., the telco) applies a semantic-based mechanism which compares content requested by users to those advertised by content providers (i.e., ranked semantic matchmaking). The content which pass the first level of filtration is then considered at the second level. Here information regarding the actual performance of content providers with respect to both price and quality is considered.
in conjunction with the prices bid by content providers in the SPPCA auction. At the end, a final ranked set of eligible content is chosen and proposed to the user. The following question may arise here: why does the broker propose the ranked set of eligible content to the user and not just the top-ranked eligible content (or, in other words, why not select just the first content from the top of the list representing the ranked set and then buy that content from corresponding content provider)? Although the latter could be a possible solution, this would violate the CBB (Consumer Buying Behavior) model [16] for transactions in the B2C e-markets because it omits the negotiation phase which should happen after the brokering phases and before the purchase and delivery phase. Therefore, the broker proposes the ranked set of eligible content to the user to enable the user to contact more than one content provider and negotiate the terms of purchase with them. When the negotiation phase is completed, the user chooses one content provider and buys the content from it. The chosen content provider can be the content provider of the top-ranked content in the ranked set of eligible content proposed by the broker, but can also be the content provider of lower-ranked content (e.g., the content provider of third-ranked content offers the user the lowest purchase price during the negotiation and the user chooses this content provider because for him/her it is only important that the content is similar to the requested one and that the price is as low as possible). As it is going to be later explained, we are using Contract-Net protocol for the negotiation between users and content providers.

It is important to highlight the fact that telcos, who represent brokers in the proposed service e-market, do not base their recommendations solely on semantic matchmaking, but they also consider the actual performance of businesses which act as content providers, with respect to both price and quality. The performance model of content providers is founded on research regarding trust and reputation in e-business [8, 33, 38, 39, 42].

### 7.3.1 The agent-based architecture of electronic market for telecommunication services

A description of the Telco 2.0 service e-market architecture follows along with a demonstration of how it operates. The proof-of-concept prototype is implemented as a JADE (Java Agent DEvelopment Framework) multi-agent system [2]. In the prototype agents communicate by exchanging ACL (Agent Communication Language) messages. Coordination between agents is achieved by applying FIPA (Foundation of Intelligent Physical Agents) interaction protocols. Two types of pre-defined FIPA conversation protocols (FIPA Request and FIPA Contract-Net) are used.

Figure 7.1 illustrates the Telco 2.0 service e-market architecture. There are three stakeholders in service e-market: content providers, users and telcos. These stakeholders are in our proposal of service e-market represented with three types of agents: Content Provider Agents, User Agents and Telco Agents, respectively.

In the Figure 7.1 also four different interactions can be identified:
1. SPPCA auction interaction: between Content Provider Agent and Telco Agent, used for advertising content at the broker;
2. FIPA Contract-Net interaction: between User Agent and Telco Agent, used for discovery of eligible content;
3. FIPA Contract-Net interaction: between User Agent and Content Provider Agent, used for negotiation about content purchase, and;
4. FIPA Request interaction: between Content Provider Agent and Telco Agent, used for requesting content delivery (in form of telecommunication service) to the user.

A more detailed description of agents and interactions follow.

Fig. 7.1: A Telco 2.0 service e-market
7.3.1.1 The Content Provider Agent

In the service e-market agents trade with various types of content $C$:

$$C = \{ c_1, c_2, \ldots, c_{|C|} \}, c \subset C, c_i \subset C : |c_i| = 1$$

which is provided by different content providers $CP$:

$$CP = \{ cp_1, cp_2, \ldots, cp_{|CP|} \}, cp \subset CP, cp_i \subset CP : |cp_i| = 1$$

Content providers are represented in the e-market by Content Provider Agents $A_{CP}$:

$$A_{CP} = \{ a_{cp_1}, a_{cp_2}, \ldots, a_{cp_{|CP|}} \}, a_{CP} \subset A_{CP}, a_{cp_i} \subset A_{CP} : |a_{cp_i}| = 1$$

An $a_{cp_i}$ represents a content provider which offers a certain content $c_i$. Initially, $a_{cp_i}$ advertise its content (advertised $c_i$ is denoted as $c_{adv(i)}$) at the broker (i.e., the Telco Agent). An $a_{cp_i}$ accomplishes that by participation in the SPPCA auction (interaction 1 in Figure 7.1), which enables $cp_i$ to dynamically and autonomously advertise semantic descriptions of its content.

After successfully advertising its $c_{adv(i)}$, an $a_{cp_i}$ waits to be contacted by an user (i.e., an User Agent) which is interested in the content it is providing. If user purchases the content from $a_{cp_i}$, the $a_{cp_i}$ requests from user’s telco content delivery (in form of telecommunication service) to that user (interaction 4 in Figure 7.1).

7.3.1.2 The User Agent

Users of telecommunication services $U$:

$$U = \{ u_1, u_2, \ldots, u_{|U|} \}, u \subset U, u_i \subset U : |u_i| = 1$$

are represented in the Telco 2.0 service e-market by agents $A_U$:

$$A_U = \{ a_{u_1}, a_{u_2}, \ldots, a_{u_{|U|}} \}, a_U \subset A_U, a_{u_i} \subset A_U : |a_{u_i}| = 1$$

An $a_{u_i}$ acts on behalf of its owner (i.e., user) in the discovery process of suitable content and subsequently negotiates the utilization of that content. An $a_{u_i}$ wishes to get an ordered list of ranked advertised content which is most appropriate with respect to its needs (requested $c_i$ is denoted as $c_{req(i)}$). It uses the FIPA Contract-Net interaction protocol (interaction 2 in Figure 7.1) to contact the broker (i.e., the Telco Agent). After an $a_{u_i}$ receives recommendations from the broker, it tries to contact a desired number of proposed $a_{cp}$ and find the one which offers the best conditions (e.g., the lowest price) for the requested content (interaction 3 in Figure 7.1).

After the selected content is delivered to the user (in form of telecommunication service), the $a_{u_i}$ sends a feedback message to the broker with information about
its level of satisfaction regarding the proposed $a_{CP}$ (completion of interaction 2 in Figure 7.1).

### 7.3.1.3 The Telco Agent

The telco $t$ is represented in the e-market by the Telco Agent $a_t$. An $a_t$ is the only Telco Agent “visible” from outside of telco system and represents a broker between the remaining two types of agents, i.e., $A_U$ and $A_{CP}$. An $a_t$ enables $A_{CP}$ to advertise their content descriptions (interaction 1 in Figure 7.1) and recommends ranked sets of eligible content to $A_U$ in response to their requests (interaction 2 in Figure 7.1). It is assumed that $a_t$ is trusted party which fairly intermediates between content requesters (i.e., users) and content providers.

It is important to highlight the fact that the $a_t$ serves as manager agent which coordinates telco’s brokering services and represents the telco in communication with all non-telco agents (i.e., the $A_U$ and $A_{CP}$). The telco brokering services are in presented proof-of-concept implementation facilitated by three other Telco Agents which are not “visible” from outside the telco system: the SPPCA Auction Agent ($a_{SAA}$), the Matching Agent ($a_{MA}$) and the Discovery Agent ($a_{DA}$).

### 7.3.2 Content discovery in telecommunication electronic markets

Figure 7.2 shows a more detailed architecture of a broker in the service e-market. Note that the $a_t$ serves as an interface agent between $A_U/A_{CP}$ and the telco. The SPPCA Auction Agent ($a_{SAA}$), the Matching Agent ($a_{MA}$) and the Discovery Agent ($a_{DA}$) enable the broker functionalities. These agents are allowed to make queries to the telco’s databases. The $a_{SAA}$ is in charge of conducting the SPPCA auction. Interaction 1.1 is used for registering/deregistering $CP$ in the auction and placing new bids, while the $a_{SAA}$ uses interaction 1.2 to announce a new auction round. The $a_{MA}$ facilitates semantic matchmaking which corresponds to the first level of filtration ($f_1$) in the content discovery process. It receives semantic descriptions of requested content through interaction 2.1 and forwards a list of semantically suitable content $c_{f_1}$ through interaction 2.2 to the $a_{DA}$ which carries out second-level filtration ($f_2$) and recommends a ranked set of eligible advertised content $c_{f_2}^{-\rightarrow}$ (interaction 2.3). Sometime later, after the selected content is delivered to the user (in form of telecommunication service), the $a_{DA}$ receives feedback information from the $a_{user}$ (through the $a_t$) regarding the performance of the $c_{f_2}^{-\rightarrow cp}$ (cp which offer $c_{f_2}^{\rightarrow}$) (interaction 2.4).

There are two databases at the broker (i.e., telco): the **Content Database** and the **Provider Database**. The Content Database contains information about all the $c$ whose bids are currently active and which therefore participates in SPPCA auction running at this broker. The Provider Database contains information regarding all the $cp$ whose $c$ is advertised at this broker.
Figure 7.3 in more details describes the communication between the three parties involved in the discovery process: $u_i$ (i.e., $a_u$) as content requester, telco (i.e., $a_t$) as broker and $cp_i$ (i.e., $a_{cp}$) as content provider. The presented interactions facilitate a discovery process. The specific parameters in the exchanged messages are described in the following subsections to help clearly present the advertising concept, matchmaking mechanisms and performance evaluation techniques used for designing our content discovery model in the Telco 2.0 service e-market.

Fig. 7.3: Communication between the User Agent, Telco Agent and Content Provider Agent enabling discovery
Figure 7.4 presents interactions between $a_u$ and $a_t$ which enable content discovery in the proposed service e-market, while Figure 7.5 explains how the SPPCA auction, which is part of the discovery process, operates.

![Diagram](https://example.com/diagram.png)

**Fig. 7.4:** The User Agent discovers the most eligible content advertised at the Telco Agent

The $a_u$, by sending CFP (Call for Proposal) to $a_t$, requests two-level filtering of advertised content descriptions to discover which is the most suitable for its needs. Along with the description of requested content $c_{req}$, the CFP includes the set of matching parameters (to be explained later) that personalize the discovery process according to the user preferences. First-level filtering ($f_1 : C \rightarrow C$) is based on semantic matchmaking between descriptions of content requested by $u_i$ (i.e., $a_u$) and those advertised by $c_p$ (i.e., $a_c$). Content which pass the first level of filtering ($c_{f_1} \subseteq C$) is then considered in the second filtering step. Second-level filtering ($f_2 : C \rightarrow C$) combines information regarding the actual performance of $c_{p_f}$ (which offer $c_{f_1}$) and prices bid in SPPCA auction by corresponding $a_{Cp_f}$ ($a_{Cp}$ that represent $c_p$ which offer $c_{f_1}$). The performance of $c_{p_f}$ (with respect to both price and reputation) is calculated from the previous $A_{U}$ feedback ratings. Following filtration, a final ranked set of eligible content ($c_{f_2} \subseteq c_{f_1}$) is chosen. This set is then recommended to the $A_{U}$ in response to their requests.

The SPPCA auction is divided into rounds of a fixed time duration. To announce the beginning of a new auction round, the $a_t$ broadcasts a CFB (Call for Bid) message to all the $a_{Cp}$ which have registered their $c_{adv}$ for participation in the SPPCA auction. Every CFB message contains a status report. In such a report, the $a_t$ sends to the $a_{Cp}$ information regarding events related to its advertisement which occurred during the previous auction round. The most important information is that regard-
Fig. 7.5: The SPPCA auction

ing how much of the \( a_{cp_i} \) budget\(^8\) was spent (the cost of certain advertisement in one auction round is equal to this advertisement’s bid price \( bid_{c_{adv}} \), multiplied by the number of recommendations of corresponding \( c_{adv} \) to various \( a_i \)). In response to a CFB message, an \( a_{cp_i} \) sends a BID message. In doing so, the \( a_{cp_i} \) assures that its \( c_{adv} \) will be considered in the discovery processes which will occur during the next auction round. In addition to referencing the corresponding content description \( c_{adv} \), a BID message also contains information specifying the value of the bid \( bid_{c_{adv}} \) and information regarding the \( a_{cp_i} \) budget.

### 7.3.2.1 Semantic matchmaking of content descriptions

In the MAS implementing the proposed service e-market, the Semantic Web technology [1, 21] is used to describe content. By applying the Semantic Web concepts [3, 17, 9], content can be described by OWL\(^9\) (Web Ontology Language), a semantic mark-up language based on DL. OWL provides a reasonable level of flexibility

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\(^8\) The notion of budget is very important in the SPPCA scenario because it enables content providers to specify their spend limits for the current auction round. Note that one content provider can have multiple content advertisements simultaneously participating in the same SPPCA auction. If such is the case, all advertisements of the same content provider potentially have different bid values since a content provider can advertise only one content advertisement per BID message, and yet all the advertisements share the same budget. Thus, when multiple BID messages for the same auction round from a single content provider are received, budget values are cumulatively added to a budget balance unique for all advertisements originating from the same content provider. This way, content providers do not need to use complex optimization techniques to optimally distribute their budget among their multiple content advertisements. The advertisements of every content provider are monitored during the auction round and potentially all advertisements of a certain content provider become inactive until the end of that round if this content provider’s budget is spent before the auction round is over. Consequently, this content provider’s advertisements are not considered in any of the subsequent content discovery processes during that round.

\(^9\) [http://www.w3.org/TR/owl-features/]
and extensiveness while keeping a balance between expressiveness and decidability. OWL ontology describing content is shown in Figure 7.6: Content is defined by its Category, its InformationType and its Theme. The Category can be one of the following: News, Music, Movies. Furthermore, the InformationType is defined as Data, Audio or Video, where Audio is Voice or HighFidelityAudio (also referred as CDAudio) and Video is HighDefinitionVideo or InteractionVideo. The Theme is hierarchically organized structure, here represented through hierarchy of continents and countries. The OWL-S\(^{10}\) (Web Ontology Language for Services) is an OWL-based technology originally designed for describing the semantics of services in an unambiguous, computer interpretable mark-up language, but can also been used for describing the semantics of products such as content. The three main parts of an OWL-S ontology are: a service profile for advertising and discovering service (the service profile is defined by four parameters: input, output, precondition and effect); a service model, which gives a detailed description of a service’s operation; and a service grounding, which provides details on how to interoperate with a service via messages. In our proposal of autonomous content discovery in Telco 2.0 service e-market we use only service profile for description of content: thus, hereafter, the OWL-S service profile will be referred as OWL-S content profile. The OWL-S content profile is defined by two parameters: input and output, which are described by the ontology in Figure 7.6. The input is described by hasCategory and hasTheme properties, and output is described by hasInformationType property.

The \(a_{UA}\) uses OWLS-MX [19], a hybrid semantic matching tool which combines logic-based reasoning with approximate matching based on syntactic information retrieval similarity computations. As the notion of match rankings is important, OWLS-MX enables computation of the degree of similarity between compared content descriptions, i.e., the comparison is assigned a content correspondence factor (M), which we use as one of the parameters for calculation of a ranked final set of eligible content \(c_f\) in. Such a similarity ranking is highly relevant since it is unlikely that there will always be a content available which offers the exact features requested. Namely, the OWLS-MX matchmaker takes as input the OWL-S content profile of \(a_{UA}\) desired content \(c_{req}\) (the \(c_{req}\) parameter in Figures 7.3 and 7.4), and returns a set of relevant content which match the query: \(c_f\). Each relevant content is annotated with its individual content correspondence factor \(M_{c_{req},c_{adv}}\). There are six possible levels of matching. The first level is a perfect match (also called an EXACT match) which is assigned factor \(M = 5\). Furthermore, we have four possible inexact match levels which are as follows: a PLUG-IN match \((M = 4)\), a SUBSUMES match \((M = 3)\), a SUBSUMES-BY match \((M = 2)\) and a NEAREST-NEIGHBOUR match \((M = 1)\). If two content descriptions do not match according to any of the above mentioned criteria, they are assigned a matching level of FAIL \((M = 0)\). The EXACT, PLUG-IN and SUBSUMES criteria are logic-based only, whereas the SUBSUMES-BY and NEAREST-NEIGHBOUR are hybrid due to the additional computation of syntactic similarity values required. A \(a_{UA}\) specifies its desired matching degree threshold, i.e., the \(M_{min}\) parameter (one of the matching

\[^{10}\text{http://www.daml.org/services/owl-s}\]
Fig. 7.6: Ontology describing content
parameters in CFP message from Figures 7.3 and 7.4), defining how relaxed the semantic matching is.

A illustration of the hybrid content matching with OWLS-MX by means of simple example follows. Figure 7.7 shows four OWL-S content profiles: the required content description \( c_{req} \), and three different advertised content descriptions \( c_{adv_1} \), \( c_{adv_2} \), and \( c_{adv_n} \). When OWLS-MX semantic matchmaking rules are applied, bearing in mind that OWL-S content profile is defined by input and output parameters (which are described by ontology in Figure 7.6), the result is EXACT match between \( c_{req} \) and \( c_{adv_1} \) (i.e., \( M_{c_{req},c_{adv_1}} = 5 \)), PLUG-IN match between \( c_{req} \) and \( c_{adv_2} \) (i.e., \( M_{c_{req},c_{adv_2}} = 4 \)) and NEAREST-NEIGHBOUR match between \( c_{req} \) and \( c_{adv_n} \) (i.e., \( M_{c_{req},c_{adv_n}} = 1 \)).

### 7.3.2.2 The performance model of content providers

A performance model tracks the past performance of \( CP \) in the service e-market. This information can then be used to estimate its performance with respect to future requests [22]. Our approach monitors two aspects of a \( cp_i \) performance – the reputation of the \( cp_i \) and the cost of utilizing the \( c \) that \( cp_i \) is offering. The reputation of a \( cp_i \) reveals its former cooperative behavior and thus reduces the risk of financial loss for \( U \) [25]. Additionally, the reputation of the \( cp_i \) is a measure for quality of the \( c \) provided by that \( cp_i \). On the other hand, information regarding the cost of utiliz-
ing the offered $e$ enables $U$ to find the best-buy option and helps prevent them from spending their money where it is not necessary.

An $a_i$ gives an $u_i$ feedback regarding all $c_{p_i}$ from $c_{p_f}$, both from reputation viewpoint called the quality rating ($Q \in [0.0, 1.0]$) and the cost viewpoint called the price rating ($P \in [0.0, 1.0]$) (the FEEDBACK ($c_{p_f}$) parameter in Figures 7.3 and 7.4). A rating of 0.0 is the worst (i.e., the $c_{p_i}$ could not provide the content at all and/or utilizing the content is very expensive) while a rating of 1.0 is the best (i.e., the $c_{p_i}$ provides a content that perfectly corresponds to the $u_i$ needs and/or utilizing the content is very cheap).

EWMA-based (Exponentially Weighted Moving Average) learning is used for calculating the overall ratings of $c_{p_f}$\textsuperscript{11}. It is computationally simple since the new overall rating can be calculated from the previous overall rating and the current feedback rating (i.e., there is no need to store old ratings which is desirable due to scalability issues). EWMA is defined as follows:

$$\tilde{x}_t = \xi x_t + (1 - \xi) \tilde{x}_{t-1} \quad \text{for } t = 1, 2, \ldots$$

where $\tilde{x}_t$ is the new forecast value of $x$; $x_t$ is the current observation value (in our case, the new feedback rating); $\tilde{x}_{t-1}$ is the previous forecast value; $0 \leq \xi \leq 1$ is a factor that determines the depth of memory of the EWMA. As the value of $\xi$ increases, more weight is given to the most recent values. Every broker (i.e., telco) sets this factor value according to its preferences.

### 7.3.2.3 Calculating a recommended ranked set of eligible content

After an $a_i$ receives a discovery request message (the CFP ($c_{req}$, matching parameters) message in Figures 7.3 and 7.4) from an $a_{u_i}$, the broker (i.e., telco) calculates a ranked set of the best-suitable content $c_{p_f}$. An ordered set $c_{p_f}$ is then recommended to the $a_{u_i}$ in response to its request (the PROPOSE ($c_{p_f}$) message in Figures 7.3 and 7.4). The matching parameters in CFP message are defined as: $\{\alpha, \beta, \gamma, M_{\min}\}$.

Since the performance model monitors two aspects of the $c_{adv}$ (i.e., its quality and price), the $a_i$ defines two weight factors which determine the significance of each of the two aspects in the process of calculating the final proposal ($\beta$ represents a weight factor describing the importance of content quality at $c_{adv}$ while $\gamma$ represents a weight factor describing the importance of content prices at $c_{adv}$). Furthermore, an $a_i$ can specify whether information regarding the semantic similarity of $c_{req}$ and $c_{adv}$ is more important to it or information regarding a $c_{adv}$ performance.

\textsuperscript{11} EWMA-based learning cannot calculate the overall ratings when a content provider is participating for the first time and does not have a history of customer feedback (i.e., there is no entry for the content provider in the Provider Database). Therefore, when a content provider sends a BID message for the first time, the broker not only puts the information about new content advertisement into the Content Database, but also creates a new entry in the Provider Database where the initial quality and price ratings of this new content provider are set to the average values of quality and price ratings of all content providers whose entries already exist in the Provider Database. In such a manner we counter the problem of cold start inherent to EWMA-based learning method.
Thus, the $a_u$ also defines parameter $\alpha$ which is a weight factor representing the importance of the semantic similarity between $c_{req}$ and $c_{adv}$. The $M_{min}$ parameter is already explained: with it a $a_u$ specifies its desired matching degree threshold, i.e., defining how relaxed the semantic matching is.

The final rating $R_{c_{adv}}$ of a specific $c_{adv}$ at the end of discovery process is given by:

$$R_{c_{adv}} = \frac{\alpha \cdot M_{c_{req},c_{adv}} + \beta \cdot Q_{c_{adv}} + \gamma \cdot P_{c_{adv}} \cdot \text{bid}_{c_{adv}}}{\alpha + \beta + \gamma}$$

A higher rating means that this particular $c_{adv}$ is more eligible for the user’s needs (i.e., $c_{req}$); $\alpha$, $\beta$ and $\gamma$ are weight factors which enable the $a_u$ to profile its request according to its owner $u_i$ needs regarding the semantic similarity, quality and price of a $c_{adv}$, respectively; $M_{c_{req},c_{adv}}$, represents the content correspondence factor $M$, but only $c_{adv}$ with $M$ higher than threshold $M_{min}$ are considered; $Q_{c_{adv}}$ and $P_{c_{adv}}$ represent the quality and price ratings of a particular $c_{p_{adv}}$, respectively; $\text{bid}_{c_{adv}}$ is the bid value for advertising a $c_{adv}$ in the SPPCA auction.

An illustration of the content discovery process by means of simple example shown in Figure 7.8 follows. The input for the discovery process is the CFP message sent by the $a_u_i$ where the following matching parameters, along with the $c_{req}$, are defined: $\alpha = 5$, $\beta = 2$, $\gamma = 8$ and $M_{min} = 1$. The required content description ($c_{req}$) and three different advertised content descriptions ($c_{adv_1}$, $c_{adv_2}$ and $c_{adv_n}$) are the same as shown in Figure 7.7. The $Q_{c_{adv}}$, $P_{c_{adv}}$ and $\text{bid}_{c_{adv}}$ for all the $c_{adv}$ are randomly defined as shown in Figure 7.8. Thus, $c_{adv_1}$ is advertised by $c_{p_1}$ with a high quality rating, but expensive, opposite of $c_{adv_2}$ which is advertised by $c_{p_2}$ with a lower quality rating, but very cheap. The $c_{adv_n}$ is advertised by $c_{p_3}$ with both quality and price rating somewhere between ratings for $c_{p_1}$ and $c_{p_2}$ and $c_{adv_2}$. Additionally, the $a_{c_{adv_n}}$ made the highest bid in the SPPCA auction, while the $a_{c_{adv_2}}$ made the smallest bid. The $R_{c_{adv}}$ calculation shows that the best final rating does not achieve the $c_{adv_1}$ whose description is semantically exact in relation to the required content description ($c_{req}$), but $c_{adv_2}$ whose description is semantically similar to the required content description ($c_{req}$). This is the consequence of the fact how the $a_u_i$ has set the matching parameters (i.e., $\{\alpha, \beta, \gamma, M_{min}\}$): it was looking for a cheap $c_{adv}$ and it was not very concerned with the $c_{adv}$ quality, while semantic matchmaking was rather relaxed.

### 7.3.3 Conclusion

An agent-based approach for modeling and analysis of telecommunication e-markets based on Telco 2.0 paradigm is proposed. In particular, B2C e-market for content trading by creating a novel auction, SPPCA auction, which merges together provider’s content advertising and user’s content discovery is presented. The SPPCA auction is modeled to reward low cost and high quality of content providers.
(i.e., content providers with better performance rating can put smaller bids and stay competitive). By contrast, the SPPCA auction punishes high cost and low quality of content providers (i.e., content providers with lower performance rating must place higher bids to stay competitive). The autonomous semantic-based content discovery based on the SPPCA is a better solution within the telecom sector compared to the keyword-based discovery based on the classic PPC auction which has several shortcomings. First of all, there is a scalability problem. Namely, there are a huge number of syntactically valid combinations which result in a vast number of concurrent PPC auctions (a separate PPC auction runs for each particular character sequence and, thus, for every possible character sequence there is a separate auction). Another problem is that separate auctions are held for synonyms. From the content providers’ point of view, it can be very complex and expensive for them to
bid in auctions for all synonyms. From the content requesters’ (i.e., users’) point of view, it is very complicated to search all synonymous words when they require a particular content. The last disadvantage of the classic PPC auction model we consider here is competitor click fraud. This occurs when one company clicks on a competitor’s advertisement to spend their budget with the long term aim of making PPC advertising too expensive for them and therefore removing them as a competitor from the search engine’s results. The auction model proposed here, SPPCA auction, solves the shortcomings described above. The first problem of a vast number of concurrent auctions is solved by having one broker (i.e., telco) running only one SPPCA auction and connecting content provider agent’s bids with their OWL-S descriptions and not a specific keyword. The second problem of running separate auctions for synonyms is solved by introducing the Semantic Web technology which uses OWL-S descriptions to characterise advertised services. The third problem of competitor click fraud cannot occur in the SPPCA auction model since a requester cannot predict which advertised content will be recommended as response to a request. Namely, the answer to each new discovery request is calculated dynamically and depends on fast-changing variables which are unknown to all entities outside the broker (i.e., telco). Hence, a user cannot purposely cause the broker to charge the targeted content provider by making a discovery request without the intent of utilizing any content.

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References


