Increasing Bid Expressiveness for Effective and Balanced E-Barter Trading

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Abstract. We present a novel knowledge-based approach for automated electronic barter trade systems. An e-barter is basically a closed e-marketplace, where agents may exchange (buy/sell) goods –or equivalent trade dollars– only with other participants to the e-barter. Obviously, in such systems one of the major issues is keeping exchanges as balanced as possible. If the description of goods or services to be exchanged is simple and limited to a well defined set, *e.g.*, oil, wheat, transport, etc., then an exchange based only on price and quantity is enough. But, what if goods or services to be exchanged are described in a complex way? Is it a suitable exchange the one involving *mobile phones supporting video streaming with a QWERTY keyboard* if the agent is looking for *smart phones*? Those two descriptions, although very different form a syntactic point of view, are very similar with respect to their meaning (semantics). How could an agent manage and exploit the knowledge on a given domain to deal with such a semantic information and optimize exchanges?

We focus on how to find most promising matches, in a many-to-many matchmaking process, between bids (supplies/demands), taking into account not only the price and quantities as in classical barter trade systems, but also a semantic similarity among bid descriptions while keeping exchanges balanced.

To this aim we use a logical language to express agent preferences, thereby enhancing bid expressiveness. We also define a logic-based utility function that allows to evaluate the semantic similarity between bids. Finally we illustrate the optimization problem we solve in order to clear the market.

1 Introduction

An electronic marketplace can be basically described as a system that facilitates business activities by providing users with one, or more, added value services, usually including: discovery/matchmaking (finding partners to engage in a commercial interaction), negotiation and deal (establishing trust, negotiating and agreeing on terms of business transaction), exchange (payment and actual execution of the business transaction) [29]. The main interest of the service provider is obviously to maximize successful transactions (*i.e.*, what is usually termed as clearing the market). The service

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provider revenues depend in fact either on charges placed on each successful transaction or on fixed fees paid for membership required to benefit of offered services. Successful and renowned existing e-marketplaces are either person-to-person auction sites such as EBay (www.ebay.com) or business-to-business (B2B) marketplaces such as Covisint (www.covisint.com) or Alibaba.com (www.alibaba.com), or procurement services such as CombineNet (www.combinenet.com).

In this paper we focus on a particular –and definitely ancient– form of commercial interaction, namely barter trade exchange. Historically barter trade was a bilateral form of exchange of goods and services without currency. Obviously, we refer here to a *modern multilateral* barter trade [14], where traders do not exchange goods directly, but use a form of private label currency, named *trade dollar*. Therefore if they sell a good they receive credits in trade dollars, that can be used to purchase other goods. An electronic barter trade system is then basically a *closed* B2B e-marketplace, where the trade of goods/services among companies is managed by an intermediary (broker). In automated *e-barter* exchange agents play the role of managers (acting on behalf of companies) or brokers (acting on behalf of the trade exchange system).

Usually, commercial e-barter systems make money by charging a commission on each transaction done, so the revenue of the system is higher the more the e-marketplace is lively. Therefore the role of the broker agent is to stimulate trade exchanges, recommending possible promising exchanges given a set of demands and supplies from the *barter pool* (the set of companies involved in the e-marketplace).

One of the aims of the barter trade broker is maintaining exchanges as far as possible balanced, so that the total income of trade dollars by a company equals to the amount bought by the company itself. In fact maintaining the balance of trade helps the traders to make purchases in the future increasing the trade volume over the long run [14]. Furthermore, given a demand (supply), there are typically several possible supplies (demands) to choose from, so the pivotal question in an e-barter system is: how can the broker choose and consequently suggest an exchange to the other agents? The obvious answer is: by finding the most *promising* matches such that agents can be equally satisfied by the exchange. Obviously, price cannot be the only parameter when goods to be exchanged are not simply undifferentiated ones, and moreover traders do not make their decision based only on price [14]. Usually price is negotiated later between buyer and seller, so price other than not being the only criterion, might not be the most important one. Other parameters to take into account are, *e.g.*, similarity between demand and supply descriptions, quantity and trade balance.

We introduce logical languages, in particular Description Logics [4], to model bids. In this way we enhance bid expressiveness, and are able to catch relations among features, exploiting basic inference services such as satisfiability and subsumption. Yet our aims are manifold and go well beyond simple matchmaking:

- Maximize utilities of each agent finding the best *overall semantic match* among several demands and supplies;
- Maintain the balance of trade;
- Maximize the trade volume.

While achieving these goals separately can be straightforward, it is quite challenging trying to fulfill all of them at the same time; contributions of this paper therefore include a many-to-many matchmaking process between bid descriptions modeling both mandatory requirements and preferences, taking into account not only price and quantities as in classical barter trade systems; a logic-based utility function that allows to evaluate the semantic similarity between bids; the optimization problem we solve in order to clear the market keeping exchanges balanced. The rest of the paper is structured as follows: in the next section we illustrate features and motivations for e-barter trading outlining the scenario we refer to; then we illustrate the logical language we adopt to model agents bids. In Section 4 we define the logic-based utility function we introduce to catch the semantic similarity between bids. Section 5 outlines the optimization problem we solve to clear the market, taking into account both quantity constraints (balance of trade) and utility function. Related work and conclusion close the paper.

2 The Barter Trade Scenario

The World Trade Organization estimated in 2004 that 15% of international trade was conducted on non-cash basis, and approximately \$8.25 billion was traded through reciprocal trade companies [16]. It should be noted that the interest for bartering does not depend on the possibility to avoid/reduce value added taxes (VAT), as practically all countries have long ago introduced specific legislation that make barter income equal to cash-based income; the reciprocal trade among firms is considered appealing as it allows the exchange of unproductive assets and surplus inventory for valuable products or services, opening at the same time new outlets for excess inventory and unused capacity [16]. Noteworthy examples of working e-barter marketplaces, among many others, are `www.tradia.net`, `www.U-Exchange.com`, `www.trashbank.com`, `www.tradefirst.com`, `www.barterbart.com`, and BizXchange[1]. The range of products/services that it is possible to buy/sell is very wide; among many others: administrative services, business consultation, legal and accounting services, automotive services, computer and technology services, telephone and telecommunication systems, commercial furniture.

Let us consider the following scenario[2]: A chain of hotels needs to buy mobile phones for a large number of its employees. The company has two choices: the first one is simply buy the mobile phones in the open market, the second one is pursuing an exchange of accommodations for mobile phones. Their occupancy rate is about 60%. The chain of hotels therefore may trade hotel stays for a complete mobile phone supply and increase its occupancy. This is accomplished without the use of cash, and with mutually benefical results. Hence, the idea is that barter exchange enables a company to use its excess capacity to finance its purchases.

An e-barter system shares several characteristics with generic B2B e-marketplace, where agents enter their demands/supplies (*bids*) to search for potential commercial partners. Differently from a peer-to-peer (P2P) e-marketplace, and similarly to an auction-based market, there is a central entity, the *broker*, which finds, on behalf of the company agents, most promising transactions based on some constraints, as will be

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[1] `www.bizx.bz`

[2] This scenario is inspired by an example found on the web site http://www.tradia.net/

discussed later on. In this paper we model the trade balance problem extending the approach by Haddawy et al. [14], who modeled the setting as a minimum circulation problem [2] on a network, considering expressive demand/supply descriptions referred to a common ontology, similarity among goods, preferences and utilities of buyers/sellers. As in [14] we consider the trade occurring in business cycles: agent's bids are entered in the system, a matching is determined and then the market is cleared, and the cycle repeats.

In our proposed framework a transaction in the e-barter trade system is therefore initiated by the following phases:

- Agents enter the e-marketplace and submit a bid description, modeled using a logical language(*supplies*/*demand*).
- Supply and demand descriptions are effectively matched trying to maximize agent utilities, taking into account (semantic) similarity between bid descriptions, the market price of each good and the barter trade constraints.
- Given the quantities and the type of good supplied/requested as well as the market price of each product, the broker tries to maintain the balance of trade, as requested in an e-barter system, solving an optimization problem, see Section 5.
- The broker finds the most promising matches among bids and proposes them to the agents in the e-marketplace. While finding the most promising matches, the broker has to take into account the utility of each agent. Such a utility is related to preferences that each agent expresses using our logical language (see Section 3).

In such a way it is possible both to balance the trade (as required by a barter trade system) and also find for each agent the most promising counterpart, based on the semantic similarity between bids.

3 The Logical Setting

In the rest of the paper we refer, for the sake of clarity and without loss of generality, to a mobile phone domain. Clearly, in an e-barter marketplace several categories of goods/services will be traded, and an agent looking for mobile phones will probably sell at the same time another good in the trade system. We assume the background knowledge $\mathcal{T}$(*i.e.*, an ontology) be modeled using Description Logics (DL) [4].

3.1 Basic of Description Logics

Here, we provide a little survey on DLs, referring to [4] for a more comprehensive description. Description Logics (DLs) are a family of logic formalisms for Knowledge Representation, whose basic syntax elements are *concept names*, *properties* and *individuals*. Concepts names stands for set of objects in the domain (`WindowsMobile`, `Bluetooth`, `WebBrowser`) while properties link (sets of) objects in the domain (`hasOS`, `supportedNetwork`, `hasComponent`). Individuals are used for special named elements belonging to concepts (`NokiaN80`, `MotorolaRazor`).

Description Logics are usually endowed with a model theoretic formal semantics. A semantic *interpretation* is a pair $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$, where $\Delta^{\mathcal{I}}$ represents the *domain* and $\cdot^{\mathcal{I}}$

is the *interpretation function*. This function maps every concept to a subset of $\Delta^{\mathcal{I}}$, and every property to a subset of $\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$. Then, given a concept name A and a property name R we have:

$$A^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$$
$$R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$$

The two symbols $\top$ and $\bot$ are used to represent the most generic concept and the most specific one respectively. Hence their formal semantics correspond to $\top^{\mathcal{I}} = \Delta^{\mathcal{I}}$ and $\bot^{\mathcal{I}} = \emptyset$.

Properties and concept names can be combined using *existential role quantification*, *e.g.*, $\texttt{MobilePhone} \sqcap \exists\texttt{supportedNetwork}.\texttt{3G}$ describing the set of mobile phones supporting at least 3G (third generation) networks, and *universal role quantification e.g.*, $\texttt{MobilePhone} \sqcap \forall\texttt{hasOS}.\texttt{Symbian}$ describing the set of mobile phones having only Symbian operating system installed. The formal semantics of universal and existential quantification is as follows:

$$\exists R.C = \{x \in \Delta^{\mathcal{I}} \mid \exists y, (x, y) \in R^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\}$$
$$\forall R.C = \{x \in \Delta^{\mathcal{I}} \mid \forall y, (x, y) \in R^{\mathcal{I}} \to y \in C^{\mathcal{I}}\}$$

Well formed formulas in DLs (in DLs jargon knows as **concept expressions**) can be written using *constructors* to write concept and property *expressions*. Based on the set of allowed constructors we can distinguish different Description Logics. Basically, every DL allows one to form a *conjunction* of concepts, usually denoted as $\sqcap$; some DL include also disjunction $\sqcup$ and complement $\neg$ to close concept expressions under boolean operations.

$$(C \sqcap D)^{\mathcal{I}} = C^{\mathcal{I}} \cap D^{\mathcal{I}}$$
$$(C \sqcup D)^{\mathcal{I}} = C^{\mathcal{I}} \cup D^{\mathcal{I}}$$
$$(\neg C)^{\mathcal{I}} = \Delta^{\mathcal{I}} \backslash C^{\mathcal{I}}$$

The Description Logic closed under Boolean operators is referred as $\mathcal{ALC}$. Depending on the adopted Description Logic one is also allowed to use construct involving concrete domains as $\texttt{Camera} \sqcap \geq_2 \texttt{megaPixel}$ describing a camera with at least 2 megapixel of resolution. Notice that while properties, as `hasOS`, are mapped to a subset of of $\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$, concrete properties, as `megaPixel` are mapped to a subset $\Delta^{\mathcal{I}} \times D$ where D is a concrete domain.

$$(\leq_k R)^{\mathcal{I}} = \{x \in \Delta^{\mathcal{I}} | R^{\mathcal{I}}(x) \leq k\}$$
$$(\geq_k R)^{\mathcal{I}} = \{x \in \Delta^{\mathcal{I}} | R^{\mathcal{I}}(x) \geq k\}$$
$$(=_k R)^{\mathcal{I}} = \{x \in \Delta^{\mathcal{I}} | R^{\mathcal{I}}(x) = k\}$$

Actually, more espressive operators can be added to this logic as number restrictions, transitive roles and inverse roles just to cite a few [4]. The expressiveness of a DL depends on the type of constructors allowed; we point out that our approach is completely independent of the particular DL chosen to describe the domain knowledge.

In order to formally represent the domain knowledge and constraints intercurring among elements of the domain, we can model an Ontology $\mathcal{T}$(for Terminology) containing axioms $D \sqsubseteq C$ where D and C are well formed formulas in the adopted DL and $R \sqsubseteq S$ where both R and S are properties. The formal semantics of such axioms is:

$$(C \sqsubseteq D)^{\mathcal{I}} = C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$$
$$(R \sqsubseteq S)^{\mathcal{I}} = R^{\mathcal{I}} \subseteq S^{\mathcal{I}}$$

We can also write $C \equiv D$ to represent both $C \sqsubseteq D$ and $D \sqsubseteq C$.

In the rest of the paper we refer to the Ontology $\mathcal{T}$depicted in Figure 1.

$$\begin{aligned}
\mathtt{W\text{-}CDMA} &\sqsubseteq \mathtt{3G} && (1)\\
\mathtt{WindowsMobile} &\sqsubseteq \neg\mathtt{Symbian} && (2)\\
\mathtt{MobileOS} &\equiv \mathtt{WindowsMobile} \sqcup \mathtt{Symbian} && (3)\\
\mathtt{Camera} &\sqsubseteq \mathtt{Component}\\
\mathtt{Display} &\sqsubseteq \mathtt{Component}\\
\mathtt{Keyboard} &\sqsubseteq \mathtt{Component}\\
\mathtt{Display} &\sqsubseteq \neg\mathtt{Camera}\\
\mathtt{Display} &\sqsubseteq \neg\mathtt{Keyboard}\\
\mathtt{Camera} &\sqsubseteq \neg\mathtt{Keyboard}\\
\exists\mathtt{type} &\sqsubseteq \mathtt{Component} && (4)\\
\top &\sqsubseteq \forall\mathtt{hasComponent}.\mathtt{Component} && (5)\\
\mathtt{SmartPhone} &\equiv \mathtt{MobilePhone} \sqcap \exists\mathtt{hasSoftware}.\mathtt{WebBrowser} \sqcap && (6)\\
&\quad \exists\mathtt{hasComponent}.(\mathtt{Display} \sqcap \exists\mathtt{type} \sqcap\\
&\quad \forall\mathtt{type}.\mathtt{Graphical}) \sqcap \exists\mathtt{supportedNetwork}.\mathtt{3G} \sqcap\\
&\quad \exists\mathtt{hasComponent}.(\mathtt{Keyboard} \sqcap \exists\mathtt{type}.\mathtt{QWERTY})\\
\exists\mathtt{hasOS}.\mathtt{Symbian} &\sqsubseteq \exists\mathtt{supports}.\mathtt{MPEG4} && (7)
\end{aligned}$$

Fig. 1. Reference Ontology

In axiom (1) a simple subclass relation is represented (*W-CDMA is a 3G technology*). Axiom (4) forces the domain of `type` to be a `Component`while axiom 5 forces the range of `hasComponent` to be a `Component`. Noteworthy are also axiom (2) and axiom (3). The first one represents a disjointness relation (*a Symbian OS is not a Microsoft Windows Mobile OS and vice versa*). Together with axiom (3) (*Mobile operating systems are Microsoft Windows Mobile or Symbian ones*) they represent the complete partition of `MobileOS` [3]. Using axioms in the ontology we can also relate properties. This is the case of axiom (7) where it is stated that *a mobile phone equipped with Symbian Operating System supports the MPEG-4 mutimedimedia format*. Finally, axioms

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[3] This is a simplified model of the mobile phones domain where many other operating systems exist.

can be used to define terms to be used as synonyms of complex descriptions as in axiom (6) where a *smart phone* is defined as *a mobile phone supporting web browsing, provided with a graphical display, 3G connectivity and a QWERTY keyboard*.

Using concepts and roles defined within the ontology $\mathcal{T}$, it is possible to describe items to be sold as well as items to be bought with corresponding preferences. As an example, consider three agents in the e-marketplace selling mobile phones[4] (for the sake of conciseness we translate in DL only the first description):

[S^1 – **LG enV VX9900**:] Mobile phone with a digital camera, 2 mega pixels and 4X digital zoom, W-CDMA network technology, supported media format: MPEG-4, 3gp, MP3.

$$\begin{aligned}
\textbf{LG enV VX9900} &= \\
\texttt{MobilePhone} \sqcap \exists \texttt{hasComponent}.(\texttt{Camera} \sqcap \\
=_2 \texttt{megaPixel} \sqcap =_4 \texttt{zoom}) \sqcap \\
\exists \texttt{supportedNetwork}.\texttt{W-CDMA} \sqcap \exists \texttt{supports}.\texttt{MPEG4} \sqcap \\
\exists \texttt{supports}.\texttt{3GP} \sqcap \exists \texttt{supports}.\texttt{MP3}
\end{aligned}$$

[S^2 – **Nokia N95**:] Mobile phone with Digital Camera, 5.0 mega pixels and 10X zoom, WCDMA and GSM network technology, supported media format: WMA, AAC, MP3. Infrared, Wi-Fi and Bluetooth wireless technology, phone endowed with Symbian OS.

[S^3 – **Samsung BlackJack SGH i607**:] Smart phone with digital camera, 1.3 mega pixels and 2X digital zoom, supporting the MP3 format. Bluetooth wireless technology, phone endowed with Microsoft Windows Mobile Operating System.

On the other hand, let us suppose an agent **i** enters the e-marketplace looking for a "*mobile phone with a digital camera with at least 2 mega pixel resolution and digital zoom at least 4X, supporting MP3 format and optionally the MPEG-4, Bluetooth connection and infrared port, endowed preferably with a Symbian operating system, and a 3G mobile telephony communications protocol*". Clearly, in such a bid it is possible to distinguish ***strict requirements***, features the agent wants to be specified in the description of the item to be bought, *i.e.*, they have to be provided by the seller, and ***preferences***, features that, although not strictly necessary, make the agent more satisfied and happier.

Strict requirements**:** "*mobile phone with a digital camera, supporting MP3 format, Bluetooth, endowed with a 3G mobile telephony communications protocol*"

Preferences**:** " *at least 2 mega pixel resolution and digital zoom at least 4X, supporting MPEG-4 format, infrared port, endowed with a Symbian operating system*"

We can represent both strict requirements and preferences as DLs formulas.

$$\begin{aligned}
B^{\mathbf{i}} = {} & \texttt{MobilePhone} \sqcap \exists \texttt{hasComponent}.\texttt{Camera} \sqcap \\
& \exists \texttt{supports}.\texttt{MP3} \sqcap \exists \texttt{connections}.\texttt{Bluetooth} \sqcap
\end{aligned}$$

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[4] The mobile phone descriptions we refer to have been taken from the web site: `http://shopping.yahoo.com` Category: Electronics → Cell-Phones.

$\exists$`supportedNetwork.3G`
(“*mobile phone with a digital camera, supporting MP3 format, Bluetooth connection, endowed with a 3G mobile telephony communications protocol*”)

$P_1^{\mathbf{i}}$ = $\geq_2$ `megaPixel`$\sqcap$ $\geq_4$ `zoom`
(“*at least 2 mega pixel resolution and digital zoom at least 4X*”)

$P_2^{\mathbf{i}}$ = $\exists$`supports.MPEG4`
(“*supporting the MPEG-4 format*”)

$P_3^{\mathbf{i}}$ = $\exists$`connections.Infrared`
(“*infrared port*”)

$P_4^{\mathbf{i}}$ = $\forall$`hasOS.Symbian`
(“*endowed with a Symbian operating system*”)

Which will be the supply most suitable for the buyer’s agent? How can we determine the items more appealing for the agent **i**? Looking at formulas, we can say that offer $S^{\mathbf{1}}$ does not satisfy the strict requirement for *Bluetooth*, while $S^{\mathbf{2}}$ and $S^{\mathbf{3}}$ fulfill all the strict requirements $B^{\mathbf{i}}$. Hence offer $S^{\mathbf{1}}$ has not to be considered as a promising partner for agent **i**. Notice that because of the axiom in the ontology $\exists$`hasOS.Symbian` $\sqsubseteq$ $\exists$`supports.MPEG4` we know that the mobile phone described by $S^{\mathbf{2}}$ supports MPEG-4 format, even if this is not explicitely stated. Similarly, we know the same phone supports a 3G protocol because $\mathcal{T} \models$ `W-CDMA` $\sqsubseteq$ `3G`. For what concerns $S^{\mathbf{3}}$ description, thanks to the axiom in the ontology relative to *smartphone* we know that the phone described by $S^{\mathbf{3}}$ supports a 3G communication protocol. Given the ontology $\mathcal{T}$, in formulas we have the following relations: $\mathcal{T} \not\models S^{\mathbf{1}} \sqsubseteq B^{\mathbf{i}}$, $\mathcal{T} \models S^{\mathbf{2}} \sqsubseteq B^{\mathbf{i}}$, $\mathcal{T} \models S^{\mathbf{3}} \sqsubseteq B^{\mathbf{i}}$ Similarly to the one for strict requirements, we can establish a criterion to decide, between offers $S^{\mathbf{2}}$ and $S^{\mathbf{3}}$, which is the one better fulfilling the buyer preferences. In other words we are going to define a logic-based utility function that allow to measure the satisfaction degree of an agent (see Section 4.1).

4 Bid Expressiveness

Let $\mathcal{L}$ be a Description Logic and $\mathcal{T}$an ontology expressed as a set of formulas over $\mathcal{L}$.

We name the n agents of the e-barter as $\{ \mathbf{1},\ldots,\mathbf{n} \}$, and use **i** as a variable over $\{ \mathbf{1},\ldots,\mathbf{n} \}$. Hereafter, whenever we use indexes is with the following meaning: in $\bullet_k^{\mathbf{i}}$, **i** represents an agent, while k, the k-th element of a set. Each agent **i** looks for (“buys”) some good $B^{\mathbf{i}}$, and offers (“sells”) some other good $S^{\mathbf{i}}$. Both $B^{\mathbf{i}}$ and $S^{\mathbf{i}}$ are formulas in $\mathcal{L}$. We also let $\min QB^{\mathbf{i}}$, $\max QB^{\mathbf{i}}$, $\min QS^{\mathbf{i}}$, and $\max QS^{\mathbf{i}}$ be the *minimum and maximum quantities* that agent **i** is willing to buy and to sell, respectively. For the sake of simplicity, we assume that each agent “buys” only items of one type of good and “sells” items of only one other type of good.

4.1 Preferences and Utility Functions

If the agent **i** is willing to buy a certain quantity of a good, then it can formulate its request setting some characteristics as *strict* and others as *preferred*. *Strict* characteristics represent what has to be specified in a good description $S^{\mathbf{j}}$ in order to be considered by **i**. *Preferred* characteristics make **i** happier if $S^{\mathbf{j}}$ exposes them. Hence, if **i** is looking for some good to be traded, it expresses its request as a set of formulas:

$B^{\mathbf{i}}$: a Description Logic formula representing strict requirements;
$\{P_k^{\mathbf{i}}\}$: a set of Description Logic formulas representing preferred requirements.

The preferences of each agent $\mathbf{i}$ are formalized by a utility function $\mathsf{U}^{\mathbf{i}} : \mathcal{L} \mapsto \Re^+$, assigning a worth to $B^{\mathbf{i}}$ and to each formula in $\{P_k^{\mathbf{i}}\}$.

Of course, we assume that $\mathsf{U}^{\mathbf{i}}$ is very sparse, and only a few number of formulas in $\mathcal{L}$ have a non-zero utility, corresponding to those characteristics—single concept names, or generic Description Logics formula—an agent considers important. $P_k^{\mathbf{i}}$ are formulas to which agent $\mathbf{i}$ assigns some worth (*i.e.*, a non-zero utility). In formulas:

$$u^{ij} = \mathsf{U}^{\mathbf{i}}(B^{\mathbf{i}}) + \sum\{\mathsf{U}^{\mathbf{i}}(P^{\mathbf{i}}) \mid \mathcal{T} \models S^{\mathbf{j}} \sqsubseteq P^{\mathbf{i}}\} \tag{8}$$

where u_{ij} is the utility gained by agent $\mathbf{i}$ when buying good $S^{\mathbf{j}}$ from agent $\mathbf{j}$, computed as the sum of utilities set by $\mathbf{i}$ of characteristics which are fulfilled by good sold by $\mathbf{j}$.

We now explain why we require agents to put a utility over their strict requirements. In Classical Negotiation Theory [20], the existence of a *disagreement payoff* is always hypothesized. Such a payoff is the minimum utility each agent requires to pursue the negotiation, and usually represents both the attitude of an agent towards negotiation—a high disagreement payoff models the fact that the agent is rather unwilling to negotiate at all—and some fixed costs which be repaid by the agreement. Since the behavior of our agents is that if at least the strict requirements are fulfilled, they may accept the barter, it follows that such strict requirements should have a utility which is equal to, or greater than, the disagreement payoff hypothesized by the theory.

4.2 Prices

Prices could be set in two ways: we call them *exogenous* prices and *endogenous* prices.

In exogenous prices, we suppose that every offered good—whoever offers it—has a market price, given by the value of a global function $p(S^{\mathbf{i}}) \in \Re^+$, in barter dollars. This price is set by the barter autonomously with reference to the market price, and we require that whenever two agents $\mathbf{i}$ and $\mathbf{j}$ sell the same good—that is, when $\mathcal{T} \models S^{\mathbf{i}} \equiv S^{\mathbf{j}}$—then $p(S^{\mathbf{i}}) = p(S^{\mathbf{j}})$[5].

On the other hand, endogenous prices are fixed by the well-known result by Arrow and Debreu [3] that states that there exists a unique price vector $\boldsymbol{p}$ such that if every agent maximizes her own utility, the market clears, subject to the constraints that every agent cannot spend more than the worth she initially owes. Deng et al. [8] proved that the result can be extended to indivisible goods—as in our case—and that one can find a price that minimizes the deficiency of the market, although that price is hard to approximate.

We now discuss the two options. Endogenous prices are advisable for a *closed* market; one in which no other agent can enter in the future, and that must find an equilibrium in itself. In fact, Arrow& Debreu's result does not take into account any intrinsic value of the bartered objects—*e.g.*, their production cost. So it may happen that an agent

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[5] Observe that since in $\mathcal{L}$ there could be more than one way of describing the same good—*e.g.*, in the simplest case, two synonyms, made equivalent by a formula in $\mathcal{T}$—we use logical equivalence $S^{\mathbf{i}} \equiv S^{\mathbf{j}}$ to express the fact that agent $\mathbf{i}$ and agent $\mathbf{j}$ sell in fact the same good.

selling a good which is not required by other agents at a given moment of the e-barter marketplace gets a very low price for it, because the utility that the other agents assign to the good is very low. However, the situation might change when another agent, requiring exactly that good, enters the marketplace. These considerations suggest us to opt for exogenous prices. Hence, from now on, we assume that every good has a price which is fixed by the barter independently of the market status.

5 The Barter Trade Optimization

Our optimization problem is finding non-negative integral values for n^2-n variables q^{ij} $i, j \in \{\mathbf{1}, \ldots, \mathbf{n}\}, \mathbf{i} \neq \mathbf{j}$, representing the quantity of good sold by agent $\mathbf{j}$ to agent $\mathbf{i}$, at the price of $p(S^{\mathbf{j}})$ barter dollars. Each variable q^{ij} is subject to the following constraints:

$$\min QB^{\mathbf{i}} \leq \textstyle\sum_j q^{ij} \leq \max QB^{\mathbf{i}} \tag{9}$$

$$\min QS^{\mathbf{j}} \leq \textstyle\sum_i q^{ij} \leq \max QS^{\mathbf{j}} \tag{10}$$

These constraints express the fact that globally, the quantities traded by agents should be within the range they specified. Intuitively, an agent might not want to exchange a good below a given minimal quantity in order to, say, reduce its marginal costs, or reduce packaging and shipping costs. Analogously, an upper bound on the quantity could model production/consumption physical limits.

Moreover, we force $q^{ij} = 0$ if the strict characteristics of the good required by agent $\mathbf{i}$ are not implied by the ones offered by agent $\mathbf{j}$, *i.e.*, if $\mathcal{T} \not\models S^{\mathbf{j}} \sqsubseteq B^{\mathbf{i}}$.

To ease summations, we also let $q^{ii} = 0$ for n "fake" variables. Then, we let n new variables $b^{\mathbf{i}}, \ldots, b^{\mathbf{n}}$ ("balances") be defined by

$$b^{\mathbf{i}} = \sum_j q^{ji} \cdot p(S^{\mathbf{i}}) - \sum_j q^{ij} \cdot p(S^{\mathbf{j}}) \cdot (1/u^{ij}) \tag{11}$$

We now explain Formula (11). The balance of an agent is usually made by the barter dollars gained by giving (several items of) good $S^{\mathbf{i}}$ minus the barter dollars it owes the barter exchange to get (several items of) good $B^{\mathbf{i}}$. Hence, one would expect the balance for the agent $\mathbf{i}$ to be defined simply by $b^{\mathbf{i}} = \sum_j q^{ji} \cdot p(S^{\mathbf{i}}) - \sum_j q^{ij} \cdot p(S^{\mathbf{j}})$ However, we have to remember that the items that Agent $\mathbf{i}$ gets might not be exactly the ones it looked for: some preferred characteristics might not be satisifed by the items it buys. We have to weigh the barter dollars spent with "how bad" are the bought items w.r.t. $\mathbf{i}$ preferences. This is the reason why, in Formula (11), barter dollars spent by $\mathbf{i}$, *i.e.*, $\sum_j q^{ij} \cdot p(S^{\mathbf{j}})$, are scaled by its corresponding utility. This allows us to compare different matches and hence discover the most promising ones, as the higher is the value of the logic-based utility function the higher will be the semantic similarity between the two bids.

Let us clarify the idea behind the flow of barter dollars with the aid of a graph representation. Starting from $B^{\mathbf{i}}$ and $S^{\mathbf{j}}$, with $i, j \in \{\mathbf{1}, \ldots, \mathbf{n}\}, \mathbf{i} \neq \mathbf{j}$, we can build a weighted directed graph (see Figure 2) following these simple rules:

— for each agent, draw a node and label it with its name;
— given two nodes $\mathbf{i}$ and $\mathbf{j}$, if $\mathcal{T} \models S^{\mathbf{j}} \sqsubseteq B^{\mathbf{i}}$ then draw an edge from node $\mathbf{i}$ to node $\mathbf{j}$;

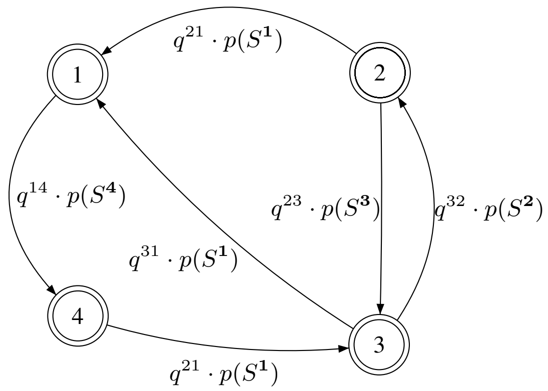

Fig. 2. The flow of *barter dollars*: Nodes correspond to agents, edges **(i,j)** to barter dollars agent **i** will pay to agent **j** in exchange of q^{ij} items of Supply $S^{\mathbf{j}}$

— assign to each edge from node **i** to node **j**, a label $q^{ij} \cdot p(S^{\mathbf{j}})$ representing the barter dollars **i** will pay to **j**.

Given an agent **i**, the corresponding balance $b^{\mathbf{i}}$ is computed as the summation of weights asociated to the edges (i, j) and (j, i). Weights labelling (i, j) edges represent barter dollars **i** pays to **j** —their value is considered negative in the summation in equation (11)— while the ones labelling (j, i) edges represent barter dollars that **i** receives from **j** —their value is considered positive in the summation in equation (11).

We impose that the balances are "close enough" to zero with the following constraints:

$$-\varepsilon \leq b^{\mathbf{i}} \leq \varepsilon \quad \text{for } \mathbf{i} = \mathbf{1}, \ldots, \mathbf{n} \tag{12}$$

for a suitable value for ε. When the exchange of goods lasts several rounds (possibly, forever) we record in each round the value of each agent's balance $pb^{\mathbf{i}}$, and modify (12) as $-\varepsilon \leq b^{\mathbf{i}} + pb^{\mathbf{i}} \leq \varepsilon$, in order to make compensations for unbalanced agents in subsequent rounds.

Finally, our *objective function* is: $\max \sum_{ij} q^{ij}$, in order to maximize the barter capabilities of the barter exchange.

Taking the overall system of disequations (9)–(12), we get a Mixed-Integer Programming, solvable with standard techniques [15].

We remark the fact that our framework is a true extension of the proposals for barter exchange regarding fixed goods, as the one of Haddawy et al. [14]: in fact, it is sufficient to set the utility of each $B^{\mathbf{i}}$ to 1, and to let every agent have no preferences. In this case, Formula (11) becomes the usual balance for trade dollars.

6 Related Work

Literature on e-marketplaces is huge and ever increasing, we refer the interested reader to [29,19] and focus this section on works having some relationship with our approach.

With reference to logic-based matchmaking, there has been a growing interest, motivated by the Semantic Web initiative. Matchmaking as satisfiability of concept conjunction in DLs was first proposed in the same venue by Gonzales-Castillo et al. [12] and by Di Sciascio et al. [11], and precisely defined by Bartolini et al. [28]. A specific language for agent advertisement in the framework of the Retsina Multiagent infrastructure was proposed in [26]. A matchmaking engine was developed [27,22], which carries out the process on five possible levels. Such levels exploit both classical text-retrieval techniques and semantic match using Θ-subsumption. Nevertheless, standard features of a semantic-based system, as satisfiability check were unavailable. It is noteworthy that in this approach, the notion of *plug-in* match was borrowed from research on matching software components [30], to overcome in some way the limitations of a matching approach based on exact matches. Two new levels for matching classification, along with properties that a matchmaker should have in a DL-based framework, and algorithms to classify and semantically rank matches within classes were introduced by Di Noia et al. [10]. The Difference Operator in DLs for semantic matchmaking was proposed by Benatallah et al. [5]. The approach uses Concept Difference, followed by a covering operation optimized using hypergraph techniques, in the framework of web services discovery. An initial DL-based approach adopting penalty functions ranking was proposed by Calí et al. [6], in the framework of dating systems. An extended matchmaking approach, with negotiable and strict constraints in a DL framework has been proposed by Colucci et al. [7], using both Concept Contraction and Concept Abduction [9]. Matchmaking in DLs with locally-closed world assumption applying autoepistemic DLs has been proposed by Grimm et al. [13]. The need to work in someway with approximation and ranking in DL-based approaches to matchmaking has also recently led to adopting fuzzy-DLs, as proposed by Ragone et al. [24] and in Smart [1] or hybrid approaches, as in the OWLS-MX matchmaker [17]. Lukasiewicz and Schellhase propose [18] a language able to express conditional preferences to matchmake in Description Logics based on *strength* values (*i.e.*, weights) assigned to preferences. A ranking procedure was also proposed. The main aim of the approach was to retrieve a set of appealing available resources with respect to a request.

Nevertheless in all such approaches the matchmaking process is defined according to one player's perspective, according to a different purpose. Namely, the purpose is to rank a set of promising offers according to buyer's preferences or viceversa. In our framework we model the matchmaking process as a many-to-many one, taking into account both buyers' and sellers' preferences.

As first pointed out by Segev and Beam [25] the role of an electronic mediator in marketplaces is becoming increasingly important, as the broker can help agents to *search* for potential partners as well as to *negotiate*. Moreover, being a trusted third party, it can collect information from the agents and then suggest to the parties win-win solutions otherwise difficult to discover by agents themselves. Segev and Beam assumed in their model that for each product the quantity requested/supplied is equal to one. The negotiation process is based on price, basically the seller's bid with a price lower than the buyer's one is chosen. So they do not consider in their analysis either the problem of different quantities that can be requested/supplied or the semantic similarity between bids. Haddawy et al. [14] modeled the trade balance problem as a minimum cost circulation problem (MCC) on a network. They addressed the typical problem in a barter exchange: matching buyers and sellers such that the trade volume is maximized while the balance of trade is maintained as much as possible. Furthermore the matching algorithm presented by Haddaway et al. is a *quantitative* one; they suppose that goods requested/supplied in the e-marketplace are exactly the same. Therefore no semantic relation among goods is taken into account, neither are agents' preferences, while it is intuitive that, as long as the market does not deal only with undifferentiated goods, structured and complex descriptions should be taken into account, and preferences handling allows one to find many more possible matches and business opportunities.

Núñez et al.[21] modeled an e-barter system using a hierarchical structure. Agents are grouped in local markets and when, in turn, each market gets completed, an agent, representing the whole market, is created and it is grouped in a new market. A utility function models agents preferences on basket of goods, hence only quantitative preferences are taken into account and no semantic relations among attributes are modeled. In our framework we define a *logic-based* utility function, thus taking into account both qualitative and quantitative preferences. The use of a logical language enhances the bid expressiveness and it allows one to catch semantic relations between attributes, through basic inference services such as subsumptions and satisfiability. Ragone et al. [23] modeled a negotiation process among agents in an open e-marketplace and semantic relations among attributes are taken into account, using a propositional logic to model preferences. Here we use much more expressive DLs and introduce an approach to deal with quantities and to balance the (closed) barter market.

7 Conclusion

We presented a knowledge-based approach to e-barter trading, exploiting a broker. In particular we focused here on an approach to find most promising matches, in a many-to-many matchmaking process, between supplies and demands, taking into account not only the price and quantities as in current barter trade systems, but also a semantic similarity among bid descriptions, while keeping exchanges balanced.

We proposed the use of a logical language to express agent preferences, thereby enhancing bid expressiveness and defined a logic-based utility function that allows to evaluate the semantic similarity between bids. Finally we outlined the optimization problem to be solved in order to clear the market.

A future development of this research is the adoption of a fuzzy DL for modeling the partial fulfillment of a preference [24] as fuzzy subsumption. An evaluation, to numerically support our approach is currently under way with selected SMEs in the framework of Apulia Region DIPIS project, while future research work will be devoted to extend our framework to a *call market*, and generally speaking to auction-based markets.

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