
Intelligent Brokerage of Learning Resources in Electronic Markets

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Abstract: This paper discusses issues related with modeling of learning resources brokerage systems. It introduces a market-oriented analysis of a learning resources brokerage system, where interactions are mediated by brokering entities. Moreover, it proposes an agent-based design of the market model and presents a prototype implementation. In the implemented system, artificial agents represent the human users and participate in virtual auctions where learning objects are traded between learning resources producers and consumers.

Keywords: digital learning resources, electronic market, multi-agent system

1 Introduction

The education and learning sector is a major producer and consumer of digital learning resources with intellectual properties. Standardization initiatives around the world strive towards the design and development of learning resources metadata models, so that learning content can be efficiently described, archived, reused and traded. Towards this direction, a number of initiatives have been launched around the world developing learning content repositories that can collect learning objects produced from different actors -e.g. [PADL04], [SeSD04], [CARE04], and [CELE04]. Their general goal is to facilitate learning resources
publication, search, identification and delivery, in an effective and efficient manner. In order to achieve this goal, a number of important issues have to be addressed:

- Development of technologically advanced architectures and systems for learning resources indexing, storing, search, retrieval and delivery.
- Development of interoperability frameworks to bring together heterogeneous learning resources repositories that use different educational metadata models and/or that are implemented using different technologies.
- Development of intelligent mechanisms that will support automation of activities related with learning resources management and that require a great amount of human effort (e.g. providing personalized search and delivery of learning resources).
- Development of mechanisms for addressing the commercial aspect of learning resources trading, such as billing and digital rights management.

For this, several architectures and systems have been introduced. Learning resources management systems (e.g. [SaKa04]), learning resources brokerage systems (e.g. [Nils04] & [Ter’02]), personalized access infrastructures (e.g. [Gut’03]), and electronic marketplaces for exchanging and trading learning resources (e.g. [Bra’01]), attempt to address one or more of the above issues.

In the field of learning resources brokerage systems, there are still open issues to be furthermore explored. For example, in a typical learning resources brokerage system, human effort is required to perform tasks such as comparing provision and delivery costs or negotiate upon specific provision terms that can affect pricing. Moreover, although in several existing systems users are profiled (in order for personalized services to be provided) consumer-related preferences are not modeled. On the other hand, mechanisms for the management of property rights and their effects in the pricing of learning resources are yet not fully deployed. The need for the development of architectures and frameworks that can encapsulate the complexities of the scenarios described (and moreover of other ones envisaged) in the sector of online learning resources brokerage and trading, is therefore clearly identified [Iane02].

In this paper, we address modeling of a learning resources brokerage system from a game-theoretic perspective using the virtual market metaphor – where producers and consumers of digital learning resources participate. Additionally, we introduce the concept of mediating entities that act as brokers, so that tasks related with the above mentioned issues can be delegated from human users to system components. In order to achieve automation of brokering and trading tasks, we also introduce the advantages of an agent-based analysis and design of the brokerage system. Finally, we present the case study of an auction-based multi-agent market, where learning objects are traded in virtual sealed-bid auctions.
2 Rationale for agent-mediated market modelling

A huge amount of educational content is produced every year, by numerous educational software tools and environments, used by different actors and applied in several different contexts. This fact represents a substantial commercial opportunity to be exploited and provide the so much expected return-on-investment of the e-learning industry [Ham’96]. A key development will therefore be the deployment of technologies and systems that will effectively address issues such as: billing and pricing; intellectual properties management; negotiation upon the various terms of learning resources provision; and automation of brokerage and trading mechanisms.

In the design of a brokerage system, a general model that will define the roles participating in the system, their interactions, their strategies and the outcomes of their actions is required. Widely applied approaches in modeling complex systems supporting multiple actors adopt principles from game-theory. Such approaches model the system and its actors as a game where different players participate, each one following its own rational strategy and aiming in the maximization of its goals. Specifically in the case of the resources management and allocation problem, market-based approaches, a mix of economic and social/political sciences, have been applied. The main issue in a market model definition is to identify the participating actors and the mechanism design of the market (sometimes called inverse game theory) [RuNo94]. The mechanism design will specify the roles each actor plays in the context of the market, how goals and objectives are modeled, strategies that represent the rational behaviors of the actors, and the outcomes of the strategies in the form of actions and related consequences. Market-based modeling fits the learning resources brokerage problem since it allows for:

- Representing consumers and producers preferences and requests;
- Representing consumers and producers behaviors and strategies;
- Modeling complex mechanisms for digital rights management in the form of billing policies;
- Modeling desired activities such as advertising, searching, negotiation, multiple offers evaluation and selection of the most appropriate.

In order to develop the technological framework that will support such a multi-entities community and its interactions, an appropriate software engineering approach has to be adopted. Agent-based engineering seems to be the most appropriate choice, since it allows for analyzing, designing, and implementing complex software systems as a collection of interacting, autonomous agents [Jenn01]. In general, agents can be identified such as:
• Problem-solving entities with well-defined boundaries and interfaces that are situated in a particular environment;
• They can receive inputs related to the state of their environment through sensors and act on the environment through effectors;
• They are designed to fulfill a specific role with particular objectives to achieve; they are autonomous in the sense of having control of their internal state and their behavior;
• They are capable of exhibiting flexible problem-solving behavior in pursuit of their design objectives, being both reactive (able to respond in a timely fashion to changes that occur in their environment) and proactive (able to opportunistically adopt goals and take the initiative).

Such characteristics have made agent-based software engineering widely applied in electronic commerce applications, and more specifically in virtual electronic markets of producers and consumers where participating entities are represented with interacting agents [He’03]. Multiagent technology also facilitates the development of automated negotiation procedures and the automation of trading and brokering tasks that can save labor time of human negotiators [Sand99]. In addition, agent-based engineering has other kinds of benefits in the market context: computational agents can be more effective at carrying out beneficial transactions than humans are in strategically and combinatorially complex settings.

In the next section, we will introduce a general market model where actors are represented as ‘producers’ of learning resources and ‘consumers’ of learning resources. Moreover, we will introduce the role that mediators (brokers, facilitators, matchmakers) can play, and define an agent-based architectural model of a virtual market of learning resources.

3 Agent-based Virtual Market Model

The generic model of a microeconomic market for mediated learning resources brokerage and exchange is presented in Figure 1 [MaSa03b]. The proposed market model is based on interactions between three types of actors: consumers, producers and mediators.

Producers are learning resources providers who offer digital learning resources to consumers. In order to advertise their goods, producers publish learning resources descriptions (values upon a set of attributes for the resources) to the virtual market participants, and more specifically to the mediator role. The producers can use different strategies to achieve their goals, affecting the way they interact with other actors in the market. They can therefore follow different communication and
interaction protocols. They way producers are expected to act in the virtual market is reflected on the market mechanism design (for example, they make offers to all consumers entering the virtual market and/or wait until a request is published by a consumer).

**Consumers** are learners, tutors or other content users who are searching for learning resources. Consumers have a preference model that allows assessment of offered learning resources so that the most appropriate can be selected. The consumers can also engage different strategies in order to find the desired content and follow different communication and interaction protocols in searching and locating learning resources (for example, they make specific requests to the mediator role and collect offers from interested producers, or search throughout the advertisements until they locate content that suits their needs).

**Mediators** are the main brokerage entities and play different roles. The actual role of the mediating entities is dependent on the market mechanism design: they can be simple facilitators of the interactions of the producers and consumers (providing a simple directory service to consumers or producers); or they can play an active role in the market mechanism (acting as proactive brokers carrying out many of the tasks that facilitate trading of digital learning resources, such as search, comparison and selection).

![Figure 1: Learning Resources Virtual Mediated Market Reference Model](image-url)
Mapping the participating actors to respective system entities, we follow the first steps of an agent-oriented approach [Woo’00] to develop an agent-based analysis of a brokerage system. In the proposed market model, the following agent types can be identified:

- **Assistant Agents:** The assistant agents are responsible for user requests elicitation, and formulation of offers and requests into messages understandable by the virtual market brokers. The assistant agents are not physically part of the virtual market model but they are necessary for the proper operation of the brokerage system. We can identify two categories of assistant agents: Consumer Assistants and Producer Assistants.

- **Broker Agents:** The broker agents represent users in the virtual market and facilitate collection and evaluation of requests and offers. The Broker agents interact among each other in the virtual market and are also responsible for negotiation among the participating parties. We can identify two categories of broker agents: Consumer Brokers and Producer Brokers.

- **The Matchmaker:** This facilitator agent provides mediating services, by informing agents about other agents of the virtual market, their roles and their availability. An advanced Matchmaker can also be able to interfere in the inter-agent relations, make attempts to balance the workload among them, and coordinate a centralized digital rights management mechanism, in cooperation with the broker agents.

### 4 Case-study: Auction-based Learning Objects Brokering

In this section, we present a prototype implementation designed to support automation of trading tasks in a learning resources brokerage system. More specifically, based on the market model presented in the previous section, a virtual market with mediating agents has been implemented. The mediating agents represent the human users (producers and consumers) in virtual auctions where learning objects are traded.

Within the market mechanism design, auctions provide a special setting which is important and often relatively easily analyzable. Auctions have many practical computer science applications and several successful web brokerage systems exist for buying and selling items using auction protocols [He’03].

In its most common form, an auction is a mechanism for selling some goods to members of a pool of bidders. The strategies are the bids and the outcome determines who gets the goods and how much they pay. For the case study
presented, a set of conditions hold: there is only one type of goods, that is learning objects described with an IEEE Learning Object Metadata standard (http://ltsc.ieee.org); each bidder has a single utility value \( u_i \) for the good, which might represent different concepts such as a single value attribute like price (cost) or the global utility of a multi-attribute model; these values for each good are known only to the bidders.

### 4.1 Auction Protocol

There are several types of auctions. A very well known type of auction is the English auction, in which an auctioneer announces the desired price of the good and gradually increments it. In each round, bidders express if they are still interested in the good (e.g. producers express that they are interested in providing the good in the current price), until only one bidder is left.

An alternative mechanism that requires less interaction rounds (and therefore has less communication costs) is the sealed bid auction. Here, each bidder makes a single bid and communicates it to the auctioneer, and the higher bid wins. A variation in the rules for sealed bid auctions produces the sealed bid second-price auction, also as a Vickrey auction. In this auction, the auctioneer pays the price of the second higher bid, rather than paying the bid of the actual higher bidder. This simple modification eliminates the complex deliberations required for standard (or first-price) sealed bid auctions, because the dominant strategy is to bid the actual value. The utility of a good for player \( k \) in terms of his bid \( b_k \), his expected value \( u_k \), and the best bid among the other players, \( b_m \), is:

\[
\begin{align*}
  u_k(b_k, b_m) &= \begin{cases} 
    (u_k - b_m), & \text{if } b_k > b_m \\ 
    0, & \text{otherwise}
  \end{cases}
\end{align*}
\]

(1)

As mentioned above, in the Vickrey auction the best strategy for bidders is to bid their actual desired utility value for the good (e.g. producers bid the actual expected price). To see that \( b_k-u_k \) is a dominant strategy, note that when \( (u_k-b_m) \) is positive, any bid that wins the auction is optimal, and bidding \( u_k \) in particular wins the auction. On the other hand, when \( (u_k-b_m) \) is negative, any bid that loses the auction is optimal, and bidding \( u_k \) in particular loses the auction. So bidding \( u_k \) is optimal for all possible values of \( b_m \), and in fact, \( u_k \) is the only bid that has this property. Because of its simplicity and the minimal computation requirements for both sellers and buyers, the Vickrey auction is widely used in distributed market-based systems [RuNo94] [Sand99]. In the prototype system we implemented a reverse version of the Vickrey auction, where the auctioneer is the buyer (consumer) and the bidders are the sellers (producers). The utility \( u \) of an offered learning object can either be the value of a single attribute (such as cost) or be calculated using a multi-attribute function synthesizing the values that each offered product has upon multiple attributes.
## 4.2 Prototype implementation

A prototype implementation of the described multi-agent auction market has been developed in Java, presenting the main functionalities of a learning resources brokerage system based on this market model. The prototype is currently implemented in a local system, in order to provide a controlled environment to study the discussed model. At the lower level dealing with safe and reliable communication and administration of the developed agents, JADE agent development platform has been used [JADE04]. The reverse Vickrey auction protocol between one consumer agent and multiple producer agents in the prototype agent system follows the following stages:

1. The user expresses the learning object request to the Consumer Assistant.
2. The Consumer Assistant communicates the request to the Consumer Broker.
3. The Consumer Broker requests from the Matchmaker the contact addresses of Producers Brokers that can serve this request.
4. The Consumer Broker communicates with all Producer Brokers and initiates the auction. Each Producer Broker replies with an offer (sealed bid) for the request of the consumer.
5. The Consumer Broker selects the best offer and requests delivery settlement from the Producer Broker.
6. The Producer Broker provides the delivery details (location of the learning object) to the Consumer Broker. The Consumer Broker forwards it to the Consumer Assistant.

Figure 2 presents the auction stages versus time progress diagram of an example auction where one (1) consumer and five (5) producers are participating. Figure 3 presents an instance of the monitoring screen JADE’s environment, where the interactions between the agents of the market are recorded.

An extension to the description of the learning objects so that the utility value is calculated upon multiple attributes that describe the learning content can also been introduced, without altering the auction interaction protocol. For example, an additive value function could be used to calculate the total utility value for each offer. Such an approach is based on multi-attribute utility theory (MAUT) and uses an additive value function with different weights associated with each bid’s attributes, assuming that the utility function of each individual attribute (criterion) is known. In the case study we would assume that there is no uncertainty during the decision making, and the total utility of a bid could be expressed as:

\[
u(a) = \sum_{i=1}^{n} f_i(x_i) \times w_i\]  

(2)
where $x_i$ is the value of attribute $i$ for the bid, $w_i$ is a weight indicating the importance of the attribute $i$ to the user, and $f_i$ is the utility function for the $i$th attribute. A further discussion on how a multi-attribute utility approach can be engaged for the selection of learning objects is found in [MaSa03a] and [KaSa04].

Figure 2: Stages vs. progress of auction with one (1) Consumer and five (5) Producers

Figure 3: Instance of Auction Communication Steps
5 Conclusions

In this paper we discuss issues related with engaging market modeling mechanisms and agent-oriented technologies in designing and developing intelligent brokerage systems. We introduced an agent-based analysis and design of an auction-based virtual market, and presented a prototype implementation using a reverse version of the Vickrey auction for learning objects trading. In its current version, a single-attribute utility auction model is implemented but other approaches are also studied in the context of the proposed market model.

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