Value and the Information Market

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Abstract

In this paper we explore how (micro)economic theory can be used to analyze and model the exchange of information on the Web. More specifically, we consider searchers for information who engage in transactions on the Web. Searchers will engage in web transactions only if they gain something in such a transaction.

To this end we develop a formal model for markets, based on the notions of *value* and *transaction*. This model enables us to examine transactions on an *information market*. In this market we have a dual view on transactions, creating a dichotomy of *transactors* and *transactands*.

1 Introduction

The main topic of interest of *microeconomics* is to explain (the consequences of) different choices given a set of assumptions or, alternatively, to prescribe which course of action should be taken. These assumptions range from scarcity and utility to the labor theory of value, the marginal theory of value, and bounded rationality (See e.g. [Wiki, 2005b]). The assumptions explain, among other things, that an economic agent only participates in a *transaction* if he expects to gain something from this transaction. Put differently, he expects that the *value* of the benefits from this transaction will exceed the value of its costs.

The notion of value is complex, as it is used in many different fields such as economics, marketing, and computer science. Moreover, it has a subjective, personal and volatile nature. When bridging the gap between the different disciplines of economics, marketing, and computer science, we note that the value of Web resources is often difficult to measure. As a consequence, it is hard to put a price on them. Also, it is hard for consumers to asses whether they wish to consume the resource or not: the only way to assess the value is by consuming it. Similarly, it is often unclear why publishers actually publish resources on the Web.

We believe that the notions of value and transaction play a key role on the Web. Before the apparent rise of the Web, an important way of exchanging information was via *books*. If someone wanted to learn about, say, mathematics he could go to a bookstore, examine the available books and buy the one with the most beneficial cost/benefit ratio for his taste. If he were to use the Web, he would have to asses whether he expects to find something (for example a website or a document) which is worth the effort of searching. The cost incurred in making an economic exchange (in this case: the search cost) is called *transaction cost*.

In this article we explore the relation between economic theory and exchange of information on the Web, called the *Information Market*, to stress the relation with economic theory further. With this exploration we try to shed light on *value on the Information Market* to be able to answer questions such as: How do searchers use the Web from an economic point of view? What is value, really, in this context? How can we benefit from economic theory in case of information retrieval on the Web? Some preliminary ideas have been presented in [Bommel et al., 2005].

We discuss several areas of related work (see later sections). In the context of *value of assets*, the surveyed material addresses preferences, such as strict preference, weak preference, and indifference. The notion of preference is important as it helps searchers to determine whether a certain transaction is sufficiently interesting.

Our contribution here is to place value in the framework of transactions in an electronic information market. Also, existing approaches to *consumer value* are augmented with aspects of information, structure, and emotion. We do this using a dual view on transactions, creating a dichotomy of transactors and transactands. We further surveyed material about *pricing and valuing* information, and extend this with a model of satisfaction and cost-benefit on the basis of explicit axioms.

We start off by presenting the core concepts for markets in Section 2 after which we present a formal model for market-thinking in Section 3. The core elements of this model are the notions of players (in different roles), assets, the value of assets and finally transactions. In Section 4 we use this model to describe transactions on the information market. Last but not least, in Section 5 we discuss a multi-dimensional model for value on the information market, followed by an example application of our framework in section 6.

The link between on the one hand sections 4-6 and on the other hand sections 2-3 is as follows. Sections 4-6 give a description of the notion of information market, taking into account current and future possibilities of (electronic) information markets such as the Web. Sections 2-3 give a formalization of the foundations of such markets, including assets, transactions, and value.

2 Assets, transactions, value and players

In this section we introduce the basic concepts for markets in general: assets, transactions, value and players. Each concept is discussed in a separate subsection.

2.1 Assets

In economic markets we observe that assets are being exchanged between players. Different definitions of the notion of an asset are used in literature such as:

> An asset is anything owned, whether in possession or by right to take possession, by a person or a group acting together, e.g. a company, the value of which can be expressed in monetary terms.
>
> — Taken from: [Wiki, 2005a]

This definition seems a little odd since it makes a distinction between monetary assets and 'other' assets. After all, money is also something that is owned by a person or a group. Another definition:

> Assets are goods that provide a flow of services over time. Assets can provide a flow of consumption services, like housing services, or can provide a flow of money that can be used to purchase consumption. Assets that provide a monetary flow are called *financial assets.*
>
> — Taken from: [Varian, 1996]

In this definition it is at least recognized that money (financial assets) is also an asset. In this article we use the following definition:

Definition 2.1 (Asset) *Any thing that can be exchanged in a transaction. This includes things such as goods and services, but also the right on goods and services.*

Assets are involved in exchanges via transactions. Transactions will be further discussed in section 2.2. To be able to exchange the right on goods and services, we distinguish between the following important aspects of assets:

Ownership : Assets are owned by players (either individuals or an organisation). As such, ownership of some asset can be seen as a right to an asset. For example: John may be the owner of a book.

Execution of service : Services can be invoked on assets. Players can execute the right to execute such a service. Examples would be: the painting of a house, treatment of illness, the right to view/read certain information. These can be split futher into:

Transformation of entities : Services which aim to transform some property of an entity. Example: transportation of a chair from a warehouse to someone's room.

Reduction of uncertainty : Services which are typically aimed at reducing some form of uncertainty about the assets and/or players infolved in the transaction. Example: Quality appraisal of some asset.

2.2 Transaction

The definition of assets calls for a clear-cut definition of a transaction. We define this as:

Definition 2.2 (Transaction) *A specific, identifiable exchange between two or more players where each participant in the transaction pays something (cost) and receives something in return (benefit).*

In this definition, the word 'player' refers to persons or organisations that participate in the transaction. The following two examples of transactions are illustrated in Figure 1.

Example 2.1 *We give an example of a transaction between two players, and an example of a transaction between three players. Figure 1a illustrates the situation where two players p_1 and p_2 exchange two assets a_1 and a_2. This occurs when, for example, John (p_1) buys a book a_2 for €20 (a_1) from a bookstore p_2.*

Figure 1b illustrates the case where three players are involved in a single transaction. This illustrates the case where John (p_1) pays the bookstore p_3 a sum of €15 (a_1) to receive a book a_3 directly from a publisher p_2 after being paid a_2 by the bookstore a_3.
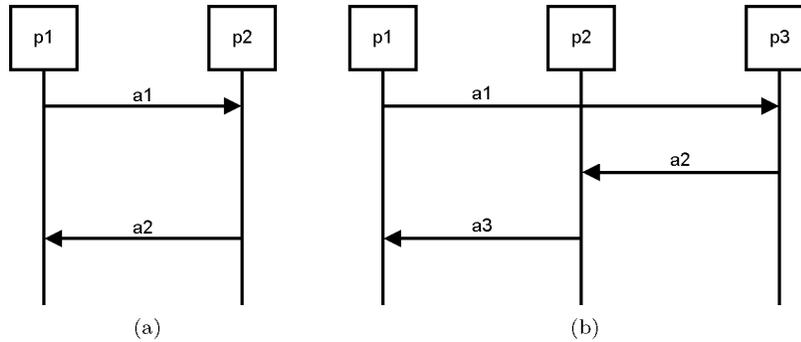

Figure 1: Transactions between two, or three players

The assets that a player receives in a transaction is defined to be his *benefit* and the assets that he pays are defined to be his *cost*:

Definition 2.3 (Benefit) *The assets that a player receives in a transaction.*

Definition 2.4 (Cost) *The assets that a player pays in a transaction.*

Note that these definitions are at the level of transactions; they do not include any valuations. This more refined view is presented in Section 3.2.

2.3   Value

The concept of *value* is the basis for cost / benefit. The value of an asset that has different connotations in different fields such as marketing, computer science, mathematics and even in the context of personal and cultural values. The dictionary definition is: "a fair return or equivalent in goods, services, or money for something exchanged", but also: "relative worth, utility, or importance". In an economic market the notion of value has the following two important characteristics:

- Assets have an intrinsic value which may differ from person to person. In other words: players value assets.

- The value of an asset can be expressed in its comparison to other assets.

The latter aspects refers to the notion of transaction where assets are exchanged. We define the notion of value as follows:

Definition 2.5 (Value of an asset) *The value of an asset is highly personal and can only be expressed in terms of an abstract domain (which is a partial order).*

This notion of value is the basis for making choices. If a player has a choice between several options (i.e. buying (bundles of) assets) he will choose the option with the highest value to him. The fact that asset a_1 has a higher value than a_2 is a complete, transitive and irreflexive relation and is denoted as $a_1 \succ a_2$. Similarly, indifference between two assets a_1 and a_2 (i.e. two assets having the same value) is denoted $a_1 \sim a_2$. Weak preference is then defined as $a_1 \succeq a_2 \triangleq a_1 \succ a_2 \vee a_1 \sim a_2$. For an overview of preference see e.g. [Katz and Rosen, 1994, Varian, 1996].

More elaborate schemes for preference exist as well. For example, [Sugden, 2003] describes reference-dependent approach to utility and preference. The core of the described approach is that preference is dependent on a current position. Strict preference and indifference are defined similarly. Also, the preference relation is defined to be complete and transitive. Even more:

> A decision problem can be described by a reference act and an opportunity set of acts (the set of options from which the agent must choose), of which the reference act is one element. The agent chooses either to stay at the status quo or to move to one of the other options.

In other words, for a decision problem the preference (strict preference, weak preference or indifference) is dependent on the current position.

The value-notion is the basis for decision making of players (cost / benefit analysis). We presume that players of the market behave in a goal-driven manner. That is, they want to satisfy their goals by engaging in transactions. These goals can be either explicit, or implicit based on such things as political situation and mental state.

2.4 Players

Players fulfill different *roles* in a transaction. To understand why this is the case, observe that in a transaction each player always exchanges one asset for another.

Example 2.2 *In Figure 1a, player p_1 exchanges a_1 for a_2. In this case he is the* supplier *of a_1 and the* demander *of a_2.*

So we have the roles of suppliers and demanders. The third role of players is called the *broker*. The role of a broker is complex; we define a broker to be a player that participates in a transaction

- but does not *alter* an asset that is exchanged

- is value adding for the other players involved in the transaction.

Consider the market for antiquities such as paintings.

Example 2.3 *Consumers can either buy a painting from another player, or via an intermediary (broker) at an auction. If the transaction takes place via a broker then this broker must be value adding (by definition):*

From the consumer point of view. *Finding a specific antiquity can be very hard if no intermediary is involved. For example, how would a person in the Netherlands ever find out that a person in the USA is selling a painting by Rembrandt? Furthermore, the fact that a well-established broker (i.e. an auctioneering firm such as Sotheby's) is selling the piece will give the consumer more confidence in its genuineness. He may even be willing to pay an additional fee in return for this added value.*

From the supplier point of view. *The supplier (i.e. the person selling the antiquity) knows that there is a better chance of selling via a broker since all consumers will go there. There is also a better chance of receiving a higher price. Also, the broker will take care of shipping the item, insurance of the item during transportation and so on.*

Note that the broker does not *alter* the asset: an auctioneer will not re-paint a *Van Gogh* painting, he merely facilitates the transaction.

In short, this leads to the following defintions:

Definition 2.6 (Consumer of an asset) *The player receiving the specified asset in a transaction.*

Definition 2.7 (Supplier of an asset) *The player supplying / offering the specified asset in a transaction.*

Definition 2.8 (Broker) *The value adding player involved in a transaction that does not alter the asset in any way.*

2.5 Consumer value

A comprehensive approach to *consumer value* is presented in [Holbrook, 1999]. Even though this work is mainly focussed on the marketing field, the framework presented in it is still worth our consideration. It is interesting to observe that the author points out that "the theory of value is a topic neglected not only by marketers but even by axiologists[1] themselves". After carefully studying the available literature on axiology and marketing the author proposes a framework for the nature and types of consumer value. In this paper we will briefly discuss this framework which is summarized in Figure 2. The framework is built along

		Extrinsic	*Intrinsic*
Self-oriented	Active	EFFICIENCY	PLAY
	Reactive	EXCELLENCE	AESTHETICS
Other-oriented	Active	STATUS	ETHICS
	Reactive	ESTEEM	SPIRITUALITY

Figure 2: Typology of consumer value

the following three dimensions:

1. *Extrinsic* value pertains to a rather functional or utilarian view on value, whereas *intrinsic* value occurs when an artefact or consumption is appreciated as an end in itself.

2. *Self-oriented* value occurs when consumption is down for one's own sake; i.e. is hedonistic. On the other hand, *other-oriented* value looks beyond the self and occurs when consumption is intended to please another.

3. Value is *active* when consumption involves things done by a consumer to the good/service that is consumed, whereas value is *reactive* when it results from things done by a product/service to the consumer.

The framework is mainly used (and validated) in the context of consumers and marketing. These results are, indeed, inspiring but we are interested in a broader, more fundamental understanding of the notion of quality.

3 A formal model for markets

3.1 Players & Transactions

Let $\mathcal{PL}$ be the set of all players and $\mathcal{AS}$ be the set of all assets. In the previous section we have defined the notion of transaction. There are two views on this notion:

- A player exchanges one asset for another.

- Assets are transferred from one player to another.

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[1]Axiology: the study of values and value judgments.

In our formal model we will use two notations, comforming to these views. The notion of a transactor reflects the first view. We use $t : a_1[p]a_2$ to denote the fact that player p exchanges asset a_1 for asset a_2 in transactor t. We model a transaction to be a set of these transactors. Let $\mathcal{TO}$ be the set of all transactors and $\mathcal{TR} \subseteq \wp(\mathcal{TO})$ be the set of all transactions. A transaction is then denoted as $T = \{t_1, t_2\}$. We introduce the following abbreviation:

$$a_1[p]a_2 \in T \quad \triangleq \quad \exists_{t \in T} [t : a_1[p]a_2]$$

Players can participate in a transaction only once, for the transaction would be splittable otherwise. Recall that players pay and receive assets. These assets thus flow from one player to the next, which means that all players in a transaction must be connected:

Axiom 1 (Unsplittable transactions) A transaction spans a connected graph over players and assets.

This axiom 1 of unsplittable transactions immediately results in the fact that, if a person exchanges one asset for another, then they must at least give something to one player and receive something from another player:

Lemma 1

$$a_1[p]a_2 \implies \exists_{a_3,a_4 \in \mathcal{AS}, p_2, p_3 \in \mathcal{PL}} [a_3[p_2]a_1 \land a_2[p_3]a_4 \land p \neq p_2 \land p \neq p_3]$$

We assume that a player can not engage in a transaction with himself:

Axiom 2 (No transaction with self) $a_1[p]a_2 \implies a_1 \neq a_2$

The notion of a transactand reflects the second view. A transactand is defined as the sales of an asset by one participant to another participant. Let transactand $p_1 \xrightarrow{a} p_2$ denote the fact that asset a is transferred from player p_1 to player p_2. A transaction T can, thus, also be seen as a set of transactands. More formally:

$$p_1 \xrightarrow{a_2} p_2 \in T \quad \triangleq \quad \exists_{a_1,a_3} [a_1[p_1]a_2, a_2[p_2]a_3 \in T]$$

Depending on what we are trying to express we will either use transactors or transactands. Transactions can, thus, be expressed as either a set of transactors or a set of transactands.

Example 3.1 *The transaction example presented in Figure 1a can, for example, be represented by the set*

$$\{a_1[p_1]a_2, a_2[p_2]a_1\}$$

using transactors or by the set

$$\{p_1 \xrightarrow{a_1} p_2, \; p_2 \xrightarrow{a_2} p_1\}$$

using transactands.

Recall that (at least) two players are involved in each transaction. The participant in a transactor t is given by $\mathsf{Participant}(t : a_1[p]a_2) \triangleq p$. We use this in the formulation of basic properties of transactions (for example axiom 3 below). Similarly, the set of participants in a transaction T is obtained by the union of the participants of the transactors in T.

Deals such as "p_1 will only exchange a_1 for a_2 with p_2 if p_1 can also exchange a_3 for a_4 with p_3" can certainly happen in the real world. However, these *deals* are not a property of transactions. Transactions denote a unique exchange and a player makes a transaction only once.

Axiom 3 (Unique participation)

$$t_1, t_2 \in T \wedge \mathsf{Participant}(t_1) = \mathsf{Participant}(t_2) \implies t_1 = t_2$$

From the definition of transactor combined with Axiom 3 it follows that in each transaction each participant plays the consumer role and the supplier role exactly once. Let $T : \{p_1 \xrightarrow{a_1} p_2, \ p_2 \xrightarrow{a_2} p_1\}$ be a transaction. In this transaction p_1 is the supplier of asset a_1 and the consumer of asset a_2. To express this formally we use the functions $\mathsf{Buyer}, \mathsf{Seller} : \mathcal{TR} \times \mathcal{AS} \to \mathcal{PL}$ such that

$$p_1 \xrightarrow{a} p_2 \in T \implies \mathsf{Buyer}(T, a) = p_2 \wedge \mathsf{Seller}(T, a) = p_1$$

The fact that a participant in a transaction can not play the buyer and the seller role in one single transaction can be proved using Axiom 3.

Lemma 2 $\mathsf{Buyer}(T, a) \neq \mathsf{Seller}(T, a)$

3.2 Value & Decision Making

As was stated before, the notion of *value* is abstract; it is not apparent in which domain to express the value of an asset to a player. It is, however, the key concept in decision making. For our purposes it is, therefore, sufficient to be able to measure which asset / bundle of assets has higher value. Therefore, let $\mathcal{VD}$ be such an abstract value domain. Since value is personal it is tempting to express the value of an asset to a player using the function $\mathsf{Val} : \mathcal{AS} \times \mathcal{PL} \to \mathcal{VD}$. However, this does not take into account the *goals* of players.

We therefore introduce $\mathcal{GL}$ to be the set of all player goals and $\mathcal{ST}$ to be the set of all states of players. A state is defined to be the present satisfaction of a player with regard to his goals. The function $\mathsf{Id} : \mathcal{ST} \to \mathcal{PL}$ identifies which state belongs to which player. A player in a certain state (as opposed to 'merely' a player) is the basis for the value function: $\mathsf{Val} : \mathcal{AS} \times \mathcal{ST} \to \mathcal{VD}$.

Given the state s of a player $\mathsf{Id}(s)$ we can view the satisfaction of this player's goals (in a certain state) using the function $\mathsf{Satisfaction} : \mathcal{ST} \times \mathcal{GL} \to \mathcal{SD}$. The satisfaction domain $\mathcal{SD}$ is a specialized version of a value domain (i.e. $\mathcal{SD} \subseteq \mathcal{VD}$). We choose the value domain $\mathcal{VD}$ to be defined as the range $[0 \dots 1]$ to reflect that satisfaction can be expressed as a percentage. This situations is illustrated in Figure 3. The value notion can now be extended to include the satisfaction level of a player in a certain state as transactions should be considered in this
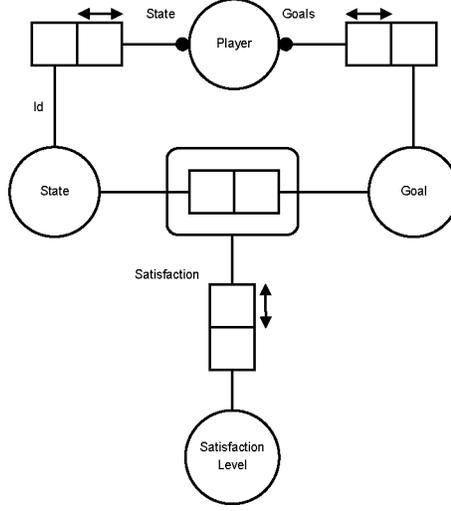
Figure 3: Satisfaction level of goals of players

light. The consumption of an asset by a participant in a transaction will result in a change of state for this participant. If T a transaction and $s \in \mathcal{ST}$ a state then $s \ltimes T$ is the state which results if participant $\mathsf{Id}(s)$ participates in T. To make the discussion of state-changes in transactions easier we introduce the abbreviations:

$$a_1[s]a_2 \triangleq \mathsf{Id}(s) = p \wedge a_1[p]a_2$$
$$s_1 \xrightarrow{a} s_2 \triangleq \mathsf{Id}(s_1) = p_1 \wedge \mathsf{Id}(s_1) = p_2 \wedge p_1 \xrightarrow{a} p_2$$

to denote the fact that an actual transaction will take place between *participants who hold a specific state*. We require the resulting state after a transaction to belong to the original participant.

Axiom 4 (State-change in a transaction) $\mathsf{Id}(s) = \mathsf{Id}(s \ltimes T)$

Players will only participate in a transaction if they (expect to) gain something from it. In other words, if $T = \{a_1[s_1]a_2, a_2[s_2]a_1\}$ then we know that for players $\mathsf{Id}(s_1)$ and $\mathsf{Id}(s_2)$:

$$\mathsf{Val}(a_1, s_1) < \mathsf{Val}(a_2, s_1)$$
$$\mathsf{Val}(a_1, s_2) > \mathsf{Val}(a_2, s_2)$$

A more refined view uses the notions of *cost* and *benefit*. The benefit of a transaction for a participant in a certain state is defined as the positive impact on the satisfaction levels of a participant. Similarly, the cost of an involvement in a transaction is defined to be the negative impact on the satisfaction levels of a participant. More formally[2]: $\mathsf{Benefit}, \mathsf{Cost} : \mathcal{ST} \times \mathcal{TR} \to \mathcal{SD}$ and more specifically:

$$\mathsf{Benefit}(s, T) \triangleq \lambda_{g \in \mathcal{GL}} \bullet \mathrm{MAX}\left(\mathsf{Satisfaction}(s \ltimes T, g) - \mathsf{Satisfaction}(s, g), 0\right)$$
$$\mathsf{Cost}(s, T) \triangleq \lambda_{g \in \mathcal{GL}} \bullet \mathrm{MAX}\left(\mathsf{Satisfaction}(s, g) - \mathsf{Satisfaction}(s \ltimes T, g), 0\right)$$

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[2]We have employed the Lambda calculus notation [Barendregt, 1984] to denote a function ranging over $\mathcal{GL}$.

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It is likely that players have more than one goal at a time, and that they try to satisfy them simultaneously. Even more so, some goals may be more important than others. Given the prioritization of the different goals, a weighted level of satisfaction of (all) goals can be computed. In order to do so we introduce a priority function: $\mathsf{Priority} : \mathcal{ST} \times \mathcal{GL} \rightarrow \mathcal{PR}$. We set the priority domain $\mathcal{PR}$ to $[0 \ldots 1]$ to identify the level of satisfaction for a player in a certain state with respect to *one* goal as a percentage. We presume the priority function to be a distribution totalling to one for each of the states:

Axiom 5 (Rational priorities) $\forall_{s \in \mathcal{ST}} \left[\sum_{g \in \mathcal{GL}} \mathsf{Priority}(s, g) = 1 \right]$

The overal / total satisfaction of a player in a certain state is the sum of the (relative) satisfaction levels of that player towards each of the goals. More formally:

$$\mathsf{TotSat}(s) \triangleq \sum_{g \in \mathcal{GL}} \mathsf{Satisfaction}(s, g) \times \mathsf{Priority}(s, g)$$

The following example illustrates this.

Example 3.2 *Let s be a state of player $\mathsf{Id}(s)$ and $\mathcal{GL} = \{g_1, g_2\}$ be the set of goals. Furthermore,* $\mathsf{Priority}(s, g_1) = 0.4$, $\mathsf{Priority}(s, g_2) = 0.8$, $\mathsf{Satisfaction}(s, g_1) = 0.8$ *and* $\mathsf{Satisfaction}(s, g_2) = 0.7$. *Then the total satisfaction is* $0.4 \times 0.8 + 0.8 \times 0.7 = 0.88$.

Note that if two players are in the same *state* (having the same level of satisfaction) and the same goal(s) then participating in a transaction wil have the same cost/benefit for these players.

We already stated that a player will only participate in a transaction if he expects the value of the benefits of the transaction to exceed its cost. We can now refine this *assumption of rational behavior*. It therefore seems reasonable to presume that the level of satisfaction of all participants should not decrease:

Axiom 6 (Rational behavior) $\mathsf{TotSat}(s) \leq \mathsf{TotSat}(s \bowtie T)$

In Section 2.3 we introduced the notion of preference in economics and explained how it is the basis for decision making. It is not always apparent why some asset is preferred over another. In the real word preference doesn't even follow the transitivity axioms (i.e. $a_1 \succ a_2 \wedge a_2 \succ a_3 \implies a_1 \succ a_3$). We presume the preference relation to be complete, transitive and irreflexive. $p : a_1 \succ a_2$ denotes strict preference for player p, $p : a_1 \succeq a_2$ denotes weak preference and $p : a_1 \sim a_2$ denotes indifference. This allows us to prove that:

Lemma 3 $T \in \mathcal{TR} = \{p_1 \xrightarrow{a_1} p_2, p_2 \xrightarrow{a_2} p_1\} \implies p_1 : a_1 \succeq a_2 \wedge p_2 : a_1 \succeq a_1$

Last but not least, we need to model the value adding nature of brokers. We will discuss this from the *transactor* point of view. Consider the following motivating example:

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Example 3.3 *Consider the market for antiquities such as paintings. Consumers can either buy a painting from another person, or via an intermediary at an auction. In the first case, value is transferred from the seller to the buyer in the form of the painting, and back in the form of a payment. In the latter case, the seller expects that selling his painting at the auction will result in a higher price. Even more, this price has to exceed the fee that hey (probably) has to pay to be able to sell at this auction. Also, from the consumer point of view, buying at an auction may have a higher value, for example because the painting is first checked by experts (is it really a* Van Gogh*), or because of extra insurance.*

The case where a consumer (p_1) buys a painting (a_1) directly from another person (p_2) for a certain amount of money (a_2) can easily be modeled as a transaction $T = \{p_1[a_2]a_1, p_2[a_1]a_2\}$. However, the case where a broker is involved is not as easy to model with the theory introduced so far. Note that:

- Brokers do not alter the asset to be exchanged

- Brokers would not exist if they wouldn't be able to 'get something out of brokering' (See axiom 6).

- Even if a transactions via a broker 'cost more' to the participants involved in the transaction, it must still be value-adding to all these participants. Otherwise the transaction would not be executed.

On the one hand it seems natural to model this situation such that brokers are not part of the actual transaction because they merely facilitate it. This is, however, not very elegant. We consider brokers to be normal, regular players. The following example illustrates a transaction where a broker is involved:

Example 3.4 *Suppose p_1 has a* Van Gogh *(a_1) for sale. To support him in selling it for a proper price (a_2) he asks an acutioneer (p_2) to assist him for a fee (a_3). The execution of this service is denoted a_4. When person p_3 buys the paining for a_5 via this broker then two transactions are completed:*

- $T_1 = \{a_2[p_1]a_1, a_1[p_3]a_5, a_5[p_2]a_2\}$

- $T_2 = \{a_4[p_1]a_3, a_3[p_2]a_4\}$

Note that the broker does not alter the assets a_1 and a_2. The broker merely facilitates the transaction. However, the participants involved do perceive them to be more valueable!

4 The information market

In the previous section we presented our view on market-thinking in general, and clearly positioned our view with regard to economic markets. In this section we will apply our findings to the more specific case of the information market which we define as:

Definition 4.1 (Information market) *The information market is the market where* resources *are exchanged between* searchers *and* publishers*, possibly by means of* brokers*.*

Definition 4.2 (Resource) *Resources are the 'entities' on the Web that make up information supply. The name* resource *was chosen in accordance with [Gils et al., 2005].*

An important observation is that transactions on the information market have a time-aspect and are one-to-many: the moment of publishing a resource and actually consuming (downloading) it may be far apart in time. Also, many searchers may download it. This is illustrated in Figure 4.

Example 4.1 *In Figure 4, the publisher publishes the original resources (denoted by the letter 'o') after which many searchers download copies (denoted by the letter 'c') of it.*
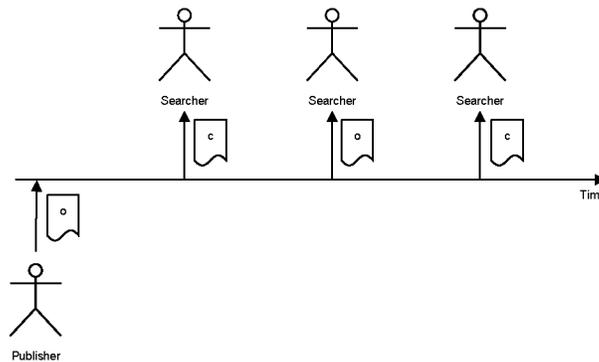

Figure 4: Time aspects of transactions on the information market

Figure 4 illustrates another distinguishing feature of transactions on the information market. Recall that there are two kinds of rights on assets (Section 2.1): ownership & execution of services. On the information market, the ownership right of a resource is not transferred as such; searchers receive a *copy* of the original resource. As such, downloading a (copy of) a resource is the execution of a service, not the transfer of ownership rights.

The value of a resource is difficult to measure. As a consequence, it is hard to put a price on them. Also, it is hard for consumers to asses whether they wish to purchase/consume the resource or not: the only way to assess the value is by consuming it! Similarly, it is often unclear why publishers actually publish resources on the Web. Surely enough, for companies a transaction may increase popularity, or people may even pay to see certain information. Often, however, this is not the case. Consider, for example, the *Wikipedia*[3] case. Wikipedia is a free, online encyclopedia. What do authors, participating in this project gain?

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[3]http://www.wikipedia.org/

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In [Alstyne, 1999] the authors stress that resources typically do not behave like assets and that information quantity can not be used directly to decide which resource is better. The authors observe that two approaches to information should be treated as a dual concept. On the one hand, information can be seen as a reduction in uncertainty (i.e. the Baysian approach). On the other hand, it can be seen as a description of a state transition (i.e. a Turing Machine approach). This observation is the basis for a framework to asses the value of resources. Another approach for pricing and valuing information can be found in [Shannon and Varian, 1999].

Several other approaches relating to the value of resources have been proposed in the literature over the last few years. For example, the work of Gryce (see e.g. [Cruse, 2000, p. 355–358]) focuses on conversations but can also be applied to analyze the value of resources. In this respect Gryce proposes four rules of conduct (also called maxims): the maxim of quantity, the maxim of quality, the maxim of relevance and the maxim of manner. Results from the field of multi-dimensional data modeling can also be used to model the different characterizations of the value of a resource. In [Pedersen and Jensen, 1998] many different dimensional types characterize a fact type; e.g. the fact type *Patient* can be characterized by the dimensional types *Diagnosis*, *Residence*, *Social Security Number*, and *Name*. In [Vishik and Whinston, 1999] the *double coincidence of wants* is described as:

> Double coincidence of wants relates to the fact that both traders involved in an exchange transaction without a recognizable currency should find the other agent's offering useful and desirable.

The authors then observe that this is the core source of inefficiency in resource-based transactions; instead of simply acquiring a desired resource a player has to locate another player that not only offers the desired resource but is also willing to exchange it for the proposed payment. It is argued that the main function of brokers is to eliminate friction in the market by decreasing the search efforts. Brokers are considered to be value adding because most users do not have the expertise to properly asses the quality of resources.

As a consequence of the above it is hard, to say the least, to pick a single value domain for the information market. We therefore adopt a multi-dimensional view on this domain:

Information : the information that may be provided by a resource. This refers to the actual 'content' of a resource.

Structure : concerned with the form (report, audio, summary, outline) and format (PDF, XML, Word) of a resource.

Emotion : dealing with the emotional effect (pretty/ugly/inspiring) that a resource may have when it is consumed.

During a search action and the corresponding transaction, these value domains are often relevant. These domains also closely correspond to three aspects of *architecture* as introduced by Vitruvius, a Roman writer, architect and engineer, active in the 1st century BC. These aspects were called *utilitas* (which corresponds to our informational domain), *firmitas* (which corresponds to our

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structural domain) and *venustas* (which corresponds to our emotional domain). See e.g. [Rijsenbrij, 2004, Vitruvius, 1999, Wiki, 2004] for details.

In general we could use *cost* as a generic dimension, which then is composed of one, two, or three of the above dimensions.

Example 4.2 *Consider as an illustration, the situation depicted in figure 5:*

- *The left "spiderweb" shows an example where the emotional value does not play a very important role, but informational and structural value do. An example would be: searching for a time table for trains on a mobile phone using* WAP. *The constraints on what a resource must be about is high (specificity). Also, the constraints on its form are important, for instance in terms of size or type of resource.*

- *The right "spiderweb" is completely different. In this case the emotional value is important. An example would be (an image of) a painting that inspires people on the work floor, that stimulates them in their creative process. The topic and form are less important in such case.*
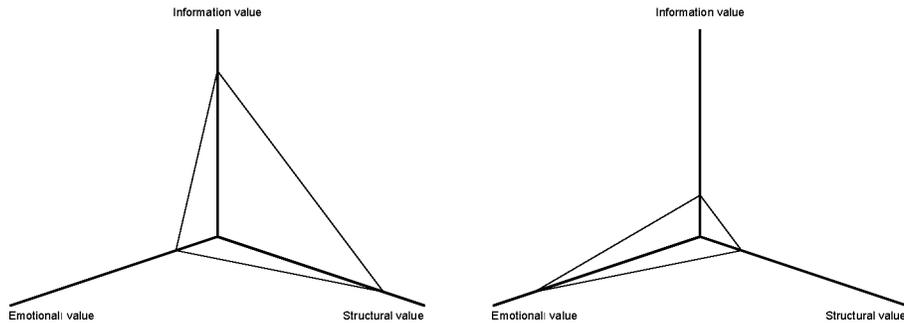

Figure 5: Value on the information market

The costs associated to a resource also fits the above discussed multi-dimensional domain. For a searcher these costs would, for example, include:

Information : The costs of actually obtaining the resource, such as search costs (time and money) and costs for the Web-connection.

Structure : The amount of disk space needed to store the information resources at a convenient location, and the computing capacity needed to display the information resource.

Emotion : The costs associated to actually conceiving the resource (i.e. the cognitive load associated with interpreting and understanding the resource. These are costs from the informational domain. See e.g. [Tardieu and Gyselinck, 2003] for more details.

For a publisher these costs would, for instance, include:

Information The costs associated to creating the resource such as time and effort.

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Structure The costs associated to storing the resource such as disk space, as well as required computing power in creating the resource.

Emotion Intellectual energy needed to create the contents of the resource. This may also be referred to as cognitive load [Bruza et al., 2000].

In summary, the behavior of searchers and publishers on the Web is hard to explain using a (multi dimensional) value domain. Because of the assumption of rational behavior (See Axiom 6) we know that they only participate in transactions if they expect to gain something from these transactions. In case of consumers: they expect to be able to reduce his information need; to "fill his information gap".

5 Value on the information market

In this section we present a more detailed view on how our complex view of value may work in practice. To achieve this we consider each of the value dimensions in turn. Section 5.1 will present *infons* as a conceptual way of looking at information value and includes suggestions on how to implement them. In Section 5.2 we will outline a transformation framework for dealing with structural value. Finally, in Section 5.3 we will discuss some aspects of emotional value.

5.1 Information value

In this section we focus mainly on the informational domain. Our goal is to gain insight in the strategies of information consumers on the information market as well as to show that infon algebras can be used to model the intentional description of the *information gap of searchers* and the *characterisation of resources*. In this section we aim to provide a deeper understanding of the informational value domain and its application in the information market.

What information exactly is has been studied intensively before, see for example [Bruza and Proper, 1996, Devlin, 1990]. Different authors from different fields have provided diverse theories of the nature of information. The notion of information plays an important role in fields such as information retrieval [Rijsbergen, 1975, Salton and McGill, 1983], cognitive science [Stillings et al., 1995, Oostendorp, 2003] database systems [Date, 1986, Codd, 1970], and data modeling [Chen, 1976, Nijssen, 1989, Halpin, 1995, Hofstede, 1993].

In this paper we take a modest approach to information theory, and only assume information to consist of *information particles* called *infons* as well as a *specialisation operator*. Infon theory has been suggested by Barwise [Barwise, 1989, Devlin, 1990], and applied to the field of information retrieval by [Rijsbergen and Lalmas, 1996]. This broad view on information is in line with the approaches taken in [Landman, 1986] and [Barwise, 1989]. Infons can be thought of as imaginary objects in the sense that they cannot be denoted or named explicitly.

An infon algebra is referred to as $\mathcal{IF}$. Formally, it is a structure

$$\mathcal{IF} = \langle \mathcal{I}, \rightarrow, \bot, \top \rangle$$

where $\mathcal{I}$ is the set of all infons. $\bot$ and $\top$ are special infons, corresponding to the least and the most meaningful information particles respectively. Furthermore, $\rightarrow$ is a relation to compare the information content of infons; it denotes the *specialisation* relation.

5.1.1 The specialisation operator

The main property of infons is that they can be compared with respects to their informational content. We use the generic term *specialisation* for such a comparison. If $i \rightarrow j$ then we say that i is a specialisation of j or, j a generalisation of i. The specialisation of infons can be interpreted as either information containment or precognition:

Information containment expressing the fact that some information particles contain more information than others.

> **Example 5.1** *For example, the statement (referred to as i_1)* grass tends to be green, but varies between brown and green *contains more information than the statement (referred to as j_1)* grass is usually green. *Statement j_1 is obviously less informative than i_1. In this case the information of i_1 contains the information of j_1, or:* grass tends to be green, but varies between brown and green *contains* grass is usually green.

> This is denoted as $i_1 \rightarrow j_1$. The specialisation relation is interpreted as an information containment relation.

Precognition expresses the fact that, in order to understand an information particle, another information particle is required.

> **Example 5.2** *Consider the following example: it is impossible to understand* Pythaghoras' Theorem *(referred to as infon i_2) without understanding the concept of* triangle *(referred to as infon j_2). In other words, infon j_2 is a prerequisite for infon i_2.*

> This is expressed as $i_2 \rightarrow j_2$. The fact that *Pythagoras' Theorem* is a specialization of *triangle* is interpreted as a precognition relation.

From a logical point of view, we would express this as: infon i_1 involves infon j_1, or as: infon j_1 is a consequence of i_1. So from having the knowledge *grass tends to be green, but varies between brown and green* we can conclude the knowledge *grass is usually green* as a consequence. This is denoted as $i_1 \rightarrow j_1$. Our second example may be formulated as: if a person has knowledge of *Pythagoras' Theorem* then we can conclude this person has knowledge of *triangle*. This is denoted as: $i_2 \rightarrow j_2$. As an analogy, consider the boolean proposition $p \implies q$. Then it is said that p is a sufficient condition for q, or that q is a necessary condition for p. Using the analogy of this latter formulation is seems reasonable to view j_2 as information that is prerequisite to grasp the infon i_2: knowledge of triangles is prerequisite to knowledge of Pythagoras' Theorem.

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5.1.2 Properties of the specialisation operator

The properties of an infon algebra are described as properties of the relation $\rightarrow$. This is assumed to be a partial order on infons. This is in line with Dretske's Xerox principle ([Barwise and Etchemendy, 1990]).

Axiom 7 (reflexivity) $i \rightarrow i$

Axiom 8 (anti-symmetry) $i \rightarrow j \wedge j \rightarrow i \implies i = j$

Axiom 9 (transitivity) $i \rightarrow j \wedge j \rightarrow k \implies i \rightarrow k$

Two special infons are assumed, a most specific infon ($\bot$) and a least specific (most general) one ($\top$). They are characterized by:

Axiom 10 (top element) $i \rightarrow \top$

Axiom 11 (bottom element) $\bot \rightarrow i$

These properties state that the infon $\bot$ is a specialisation of every infon whereas every infon is a specialisation of $\top$. As such, $\top$ can be interpreted as a *worldview*. An example would be the view that the world consists of keywords and collocations of keywords. Another example would be the view that the world consists of *concepts* (in which case the lattice-structure would be a *concept lattice*). Similarly, $\bot$ can be interpreted as the infon that is so specific that it is no longer meaningful. Figure 6 illustrates how keywords can be used as operationalize an infon algebra in practice.
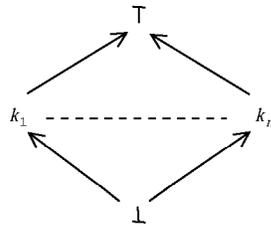

Figure 6: The lattice for keywords

Example 5.3 (Flat keyword lattice) *The most simple indexing mechanism for documents is to use a set of keywords. Each keyword represents some semantical unit. We extend this set with two special 'keywords': $\bot$ and $\top$. In its most simple form, all keywords are assumed to be independent. As a consequence, if $i \rightarrow j$ then either $i = \bot$ or $j = \top$. The resulting structure is called the* flat keyword lattice. *Figure 6 illustrates such a structure.*

Example 5.4 (Extending the basic lattice) *In order to further illustrate the inforn algebra, the flat keyword lattice from figure 6 can be used to build more advanced lattices. This is done by joining two keywords to define a more complex descriptor. For example,* information *and* retrieval *may be used to define* information retrieval. *Figure 7 illustrates the mechanism.*
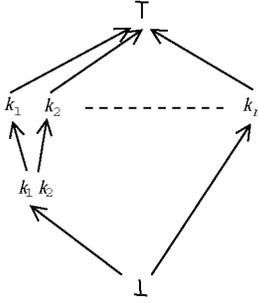
Figure 7: Extending the basic lattice

5.1.3 Infons and information value

In the previous subsection we've presented properties of infon algebras. Resources can be used by using the containment relation: the resource is seen as a big infon which can be decomposed using the specialisation operator. Similarly, the knowledge / information gap of searchers can be expressed as an infon.

Still, we're faced with the problem of 'implementing' infons as they are merely a conceptual construct. Concept lattices [Wille, 1982] or (power)index expressions [Bruza, 1990] seem to be a logical choice. In Section 6 we will present an example that uses index expressions.

5.2 Structural value

As was explained before, the structural value of a resource on the Web has to do with its form and format. We have presented a model for resources / information supply in [Gils et al., 2004, Gils et al., 2005]. To explain the structural value of assets we re-use parts of this model here. Let $\mathcal{RS}$ be the set of all resources, and $\mathcal{IR}$ be the set of all *information resources*. Information resources are 'things' (in the real world) and resources are *about* these information resources (see Section 5.1). The combination of a resource and the information resource(s) it is about is called a *representation*. Let $\mathcal{RP} \subseteq \mathcal{RS} \times \mathcal{IR}$, InfoRes : $\mathcal{RP} \to \mathcal{IR}$ and DataRes : $\mathcal{RP} \to \mathcal{IR}$.

Example 5.5 *In other words, the fact that resource* monalisa.eps *is a representation being about information resource* The Mona Lisa *(the painting) is modeled as follows:*

$r \in \mathcal{RP}$ *such that* InfoRes(r) = The Mona Lisa $\wedge$ DataRes(r) = monalisa.eps

The relation between resources and information resources is many to many (signifying that resources can be about more than one information resource and that an information resource can be represented by more than one resource). Furthermore, representations can be *typed*. The typing of representations deals with the *form* of resources.

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Example 5.6 *For example: resource* monalisa.txt *and* monalisa.eps *are both about information resource* The Mona Lisa. *One, however, is a* textual description *whereas the other is a* picture of.

Similarly, the resources themselves are also typed, signifying the format issues. For example, the resource monalisa.eps *is a* EPS *file (resource type).*

Let $\mathcal{EL} = \mathcal{RP} \bigcup \mathcal{RS}$ be the set of all *elements*. ALso, let $\mathcal{RP}_\tau$ denote the representation types (forms), $\mathcal{RS}_\tau$ denote the resource types (formats) and $\mathcal{TP} = \mathcal{RP}_\tau \bigcup \mathcal{RS}_\tau$ then $\mathsf{HasType} : \mathcal{EL} \to \mathcal{TP}$. Obviously, all elements must be typed:

Axiom 12 (Total typing) $e \in \mathcal{EL} \implies \exists_{t \in \mathcal{TP}} [e \, \mathsf{HasType} \, t]$

This (brief outline of the) model illustrates how the form/ format issues work. It does not, however, explain how (resources with) forms/ formats can be compared in terms of value. For example:

- Is a *PDF* more valueable than a *HTML* file when a searcher really wants a *Word* document?

- Is a *Summary* more valueable than a *keyword-list* when a searcher really wants a *movie*?

One of the tasks of brokers on the information market is to estimate the *aptness* or resources to searchers[4]. Brokers can, however, be value adding by *transforming* resources such that the form/ format is changed according to the searchers desires. In the remainder of this section we will outline a transformation framework (based on our earlier work, e.g. [Gils et al., 2004, Gils et al., 2005]).

Transformations transform one resource into another. More specifically, a transformation transforms instance of an input type to another instance of its output type. More formally, let $\mathcal{TR}$ be the set of all transformations and let $\mathsf{Input}, \mathsf{Output} : \mathcal{TR} \to \mathcal{RP}_\tau$.

Example 5.7 *For example, let $T \in \mathcal{TR}$ be a transformation with* $\mathsf{Input}(T) =$ HTML *and* $\mathsf{Output}(T) =$ PDF. *Applying this transformation to a* HTML *file will result in a* PDF *file. However, if this transformation is applied to a non* HTML *file then the result will be void.*

As an abbreviation we introduce:

$$t_1 \xrightarrow{T} t_2 \triangleq \mathsf{Input}(T) = t_1 \wedge \mathsf{Output}(T) = t_2$$

Note that $T \in \mathcal{TR}$ is merely the name/ placeholder for a transformation. Its actual semantics (what the transformation does) is denoted by $\overrightarrow{T}$ such that the application of this transformation to a resource r_1, resulting in r_2 is denoted as $\overrightarrow{T}(r_1) = r_2$. Lat but not least, (complex) transformations can be constructed from other transformations as long as the input type of one transformation matches the output type of the other transformation. The semantics of the

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[4]We use the term aptness to indicate the valuation of resources on the Web. Aptness is more than just (topical) relevance!

complex transformation, then, is the application of one transformation after the other:

$$t_1 \xrightarrow{T_1} t_2 \land t_2 \xrightarrow{T_2} t_3 \implies \exists_{T_3} \left[t_1 \xrightarrow{T_3} t_2 \land \overrightarrow{T_3} = \overrightarrow{T_2} \circ \overrightarrow{T_2} \right]$$

An example illustrates how this can be used.

Example 5.8 *Let $t_1 \in \mathcal{RS}_\tau$ is the type* HTML *and $t_1 \in \mathcal{RS}_\tau$ is the type* Ascii. *Furthermore, let $t_1 \xrightarrow{T_1} t_2$ and $t_2 \xrightarrow{T_2} t_2$ where T_2 is an abstract generator for* Ascii *files. Suppose a searcher prefers his resource to be an abstract in* Ascii. *If a broker finds a* HTML *file which is not an abstract (full-text) then transforming it will improve the aptness for this specific searcher. So the browser is value adding!*

5.3 Emotional value

In the previous subsections we have addressed informational value and structural value. In this section we (briefly) consider emotional value. Emotional value deals with such aspects as:

- How *pretty* is a resource (e.g. a picture)?

- How *eloquent* is a poem?

- In what *mood* is the searcher?

Surely enough, these influence the search process. For example, if a searcher is in a mood where he's highly motivated to learn about a topic for an examn then he will (mentally) be better equipped to read and study complex material than in other situations (i.e. in a *lazy* mood).

In our multi-dimensional approach to value, the dimension of emotional value is the most difficult to capture in a concrete model. We incorporate emotion in our approach along the following lines. Firstly, we consider emotion in the general context of user models. User modeling is a tool in describing and predicting the cognitive aspects of user behavior.

Secondly, emotion can be considered in the more specific context dealing with emotional aspects such as trust and frustration. It is well-known that personal relations based on trust are important in buyer-seller dyads. See for example [Andersen and Kumar, 2006]. The underlying trust models can be expressed in terms of positive and negative psychological states. Moreover, in the context of a web-oriented information market, negative computing experiences resulting in (immediate or deferred) frustration have to be dealt with. Models of computer frustration are found in for instance [Bessiere et al., 2006].

6 An example application

In previous sections we have outlined a theorie to discuss transactions on the information market from an economic perspective. Our claim is that such a theory not only provides insight in retrieval problems on the Web, but can also be used as an aid for designing and implementing novel search tools. In this

section we will present an example of how a retrieval system could work using our view on *value*. Furthermore, we will show which transactions take place.

Let us provide some more details about the intention of an implementation. A typical context for implementing value-based transactions is a digital warehouse. Such a warehouse may contain digital objects (for example a digital library), or digital descriptions of physical objects. Clearly we can have transactions in a digital warehouse, and these transactions are value-based. In most cases they involve payment. In order to support transactions, the warehouse uses some kind of characterization of the objects at hand. This can for instance be based on keywords or more advanced descriptors such as index expressions and noun phrases. Actually these descriptors deal with the informational value. The search facility of a digital warehouse should not be based solely on informational value. Structural value and emotional value are also relevant here! Different kinds of digital warehouses are found on the Web today. Moreover, traditional search engines build specific environments focussing on a narrow area of interest, such as scientific publications, geographic maps, and dating communities.

6.1   Setting

The setting for our application is a digital library (DL) for scientific papers and data. This DL offers several resources:

- scientific publications and a wide range of meta-data (for example when it was published, by whom, and in which journal),

- relations between publications such as citations/references,

- profiles of authors consisting of a short bio, research interests and a list of past publications,

- a wide range of datasets in either XML or ASCII format.

Each of these resources are available in a variety of forms ($\mathcal{RP}_\tau$) and formats ($\mathcal{RS}_\tau$). To facilitate (potential) customers, the DL offers freebies such as abstracts of scientific articles or a small subset of a dataset.

The DL offers search functionality which is being taken care of by an external player (broker). As such, there is a transaction between the broker and the DL: Let s denote the search service as offered by the broker (denoted B) for a certain period and let p_1 denote the payment for this service by the DL (denoted D):

$$T = \{s[D]p_1, p_1[B]s\}$$

The broker is faced with the problem of characterising the resources offered by the DL. In terms of our model this means that it must be able to calculate the *value* of resources to searchers. Since (it is presumed that) emotion has no place in scientific publications and data sets, this characterisation is based on informational value and structural value. The task of the broker can be summarized as follows:

Compose the true information need of a searcher in terms of informational value and structural value, and present the apt *resources to him.*

6.2 Informational value

In Section 5.1 we have described how infons can be used to represent an informational value domain. However, we observed that infons are intangible, they can not be directly harvested from resources. One of the main properties of the described infon algebra is that it forms a lattice. We propose to use index expressions to construct such a lattice structure which is commonly called a power index expression (See e.g. [Bruza, 1990]). Index expressions have the following syntax:

$$
\begin{array}{lll}
\mathsf{IdxExpr} & \rightarrow & \mathsf{Term}\,\{\mathsf{Connector}\ \mathsf{IdxExpr}\}^{*} \\
\mathsf{Term} & \rightarrow & \mathsf{String} \\
\mathsf{Connector} & \rightarrow & \mathsf{String}
\end{array}
$$

Brackets can be used to disambiguate base index expressions. Also, · denotes the empty connector. An example of such a base index expression is attitudes to (courses of students) in universities. Another example is the expression attitudes of (students of universities) to (war in Vietnam). The lattice structure called power index expression is the set of all index subexpressions including the empty index expression denoted (in conformance to our infon algebra) ⊥. The power index expression of the last example is shown in Figure 8. More details on the construc-
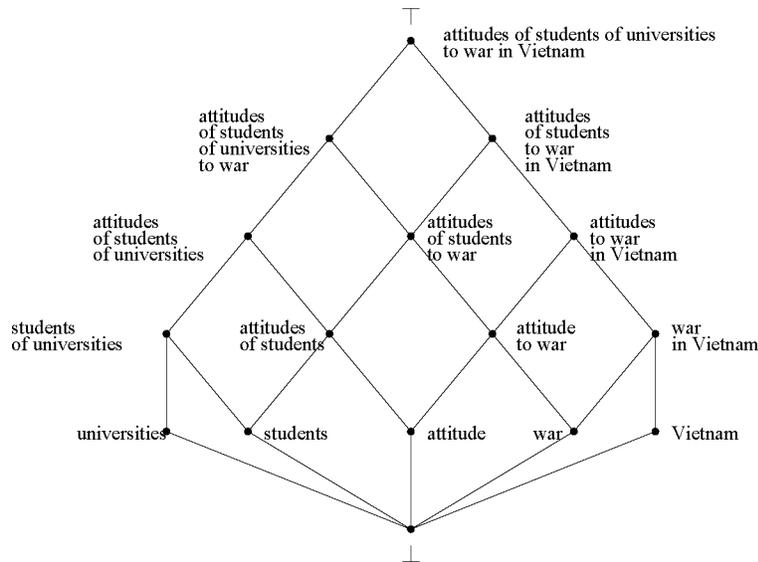

Figure 8: Example of a power index expression

tion of indexexpressions is provided in [Bruza and Weide, 1990, Bruza, 1990].

Simply put, we use (power)index expressions as a representation for infons. For each node in the power index expression the broker records which resources are (topically) relevant, i.e. have a high informational value. Searching can now be implemented using *Query by Navigation*(See e.g. [Bosman et al., 1998, Grootjen and Grootjen, 2000, Hofstede et al., 1996]). This works as follows:

- The searcher gives the broker an index expression to start with (in its shortest form this is a single Term).

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- The broker finds the node in the lattice confirming to this index expression and offers te searcher the opportunity to either specialize or refine his query untill he is satisfied.

- Once the searcher is done specifying (the informational part) of his need the broker 'knows' which resources to work with.

6.3 Structural value

The structural value of resources is put to the fore by their forms, formats and the relations they have with other resources as the following examples of (structural aspects of) queries show:

- The resource must be in the format PDF.

- The resource must be an author profile.

- The resource must have a reference to my own article.

- The resource must be based on dataset x.

In Section 5.2 we presented a framework for transformations. With these transformations we can manipulate form and formats of resources meaningfully; that is, if user preferences are known. In other words, the broker must figure out the user preferences with regard to form and format while composing a query consisting of the true information need. This, obviously, also includes the relational aspects as illustrated in the above example.

To "retrieve" the necessary information from the user (i.e. to construct his information need) the broker can deploy many different ways. For example, the broker may offer a form which must be filled in, or it may engage in a dialog (using some formal language) with the searcher.

6.4 Searching

The search rocess roughly consists of two phases: the *query formulation* phase and the *processing & presentation* phase. During the query formulation phase
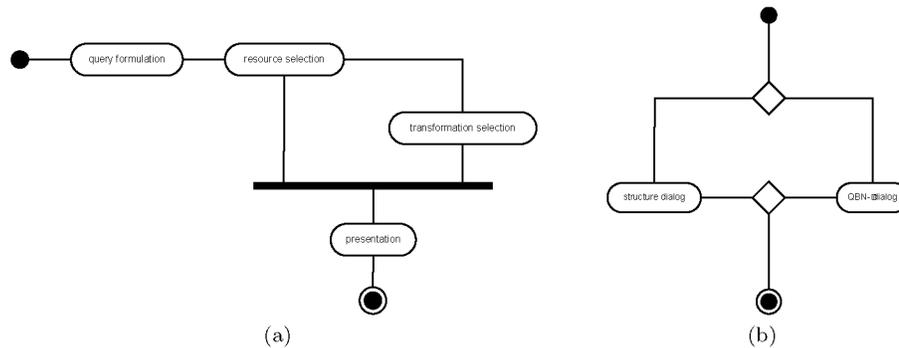

Figure 9: Search process for the broker

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the broker interacts with a searcher to capture his information need. During the processing and presentation phase, the broker selects possible transformations to operate on the resources that were selected during the first face[5]. Last but not least, the final results (that is: with the *apt* resources) are presented to the user. Figure 9a illustrates the overal process, whereas Figure 9b illustrates the query formulation proces. The latter is fairly simple: the user can either start by specifying the informational part of his information need or with the structural part. After that he can go back and forth between the two untill satisfied with his query.

6.5 A search scenario

Searcher J. Random Searcher (JRS), a Ph D student in information retrieval, surfs to the digital library for scientific data, being interested in a certain paper. He has recently read an article and wants to learn more about *index expressions*. He conctacts a search-broker to assist him in his search. A dialog with the broker follows. JRS starts out by specifying the topic of his search: *index expressions*. The broker processes these keywords and presents him with part of the graph shown in Figure 10, showing the power index expression representing the brokers knowledge of the world. Not being completely satisfied with his
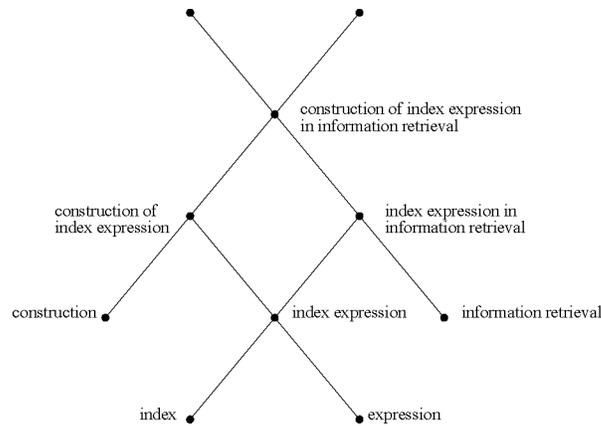

Figure 10: The brokers knowledge of the world (partial)

query, he navigates via index expressions in information retrieval to construction of index expressions in information retrieval. Being satisfied with this part of his query, JRS moves on to specify the structural aspects of his information need. Just to be on the safe side, he indicates the search results must have a reference to [Bruza, 1990]. This also increases the chance of finding scientific papers. Furthermore, he indicates that the results must be available to him in *PDF* the format. As an after thought he indicates that the results must be in the form "scientific paper", just to be sure. This completes the query formulation phase.

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[5]It is beyond the scope of this paper to present the nitty gritty details of a transformation selection algorithm. For details of such an algorithm see [Gils et al., 2005].

The search broker now compiles the query and searches through its resources, finding exactly one relevant resource which is a scientific paper: [Ounis and Huibers, 1997]. Unfortunately this resource is only available in the *Postscript* format. After a check, it turns out that a transformation to *PDF* is available so it prompts JRS with the message that it has found 1 relevant resource. Once he accepts the resource (i.e. indicates that he wants to download it) the broker actually executes the transformation and presents JRS with the mentioned resource in the proper format.

From the perspective of JRS this transaction was successful if the broker did a good job of assessing the value of this resource for him; more specifically, the transaction is succesful if he perceives the resource to be more valueable than the time and effort he spent in getting it. In that case the broker succeeded in being *value adding* while setting up this transaction.

Summarizing, in section 6 we have sketched an attractive implementation strategey for digital warehouses based on our theory of value and transactions. The foundation of such an implementation is the multi-dimensional notion of value. In this way, not only the search process within digital warehouses can be supported, but transactions in an electronic information market can be supported as well. The question whether a given user is interested in a given transaction can now be treated in terms of cost-benefit (section 3.2) using the various value dimensions.

7   Conclusions & future work

In this paper a model was presented which improves our understanding of transactions on the Web. This improved understanding is based on a dual view on transactions with a multi-dimensional notion of value.

The core building blocks of the model are the *players* on the web (suppliers, searchers, brokers) and the notions of *value* and *transaction* and the basic observation is that players engage in a transaction if they expect its benefit to exceed its costs. Two interesting observations about transactions on the *information market* are the fact that transactions have a time-aspect and that they are one-to-many: there may be a large difference in time between publishing a resource and downloading it and many people can download (more specificaly: make a copy of) this resource. Another interesting aspect deals with the notion of value: value is not 'tangible' and seemingly impossible to measure. We propose to use 3 dimensions on this value notion: informational value (dealing with the topic of a resource), structural value (dealing with issues such as form and format of resources) and emotional value (dealing with issues such as beauty of resources, or the *cognitive load* associated with consuming it).

Even though our model is mainly descriptive in nature, some important lessons can be learned from it. First of all, the observation that value is multi-dimensional on the information market suggests that the traditional method for measuring the *topical relevance* of resources is insufficient; there's more to it than that. We propose to use *aptness* instead. Secondly, the role of brokers on the information market is not to be underestimated since (almost) all

transactions are facilitated by brokers. These brokers facilitate in setting up transactions and are value adding for all parties. Note that these brokers should evolve to a sitatuation where they can also use the aptness notion.

Also, the results presented in this paper raise some questions for future research, closely related to the value notion as explained in Section 5 and the search process as outlined in Figure 9:

characterisation of resources : the multi-dimensional value notion works rather nicely in theory. However, implementing in practice may be much more difficult. More specifically: how will the resources on be charactersized? Can the relations (and their types), the attributions (and their types) be recognized automagically? How well will the transformation inferences work in practice? How will emotional value be measured, if at all?

value addition by brokers : in order for brokers to be effective they must be able to asses the value of resources to searchers. Even more, they must be value adding to the publisers of these resources as well. Smart brokers should exploit their unique position on the market to make both parties as well off as possible.

query construction : in the search process there is a query formulation phase which consists of two (repeating) steps. Combining the results of these steps in a proper query is, probably, a challenge in itself.

interface : designing and implementing a user interface for brokers on is, probably, an interesting challenge, especially in the dialog-form.

value dimensions : the use of heterogeneous value dimensions should be considered. As an example, the situation where the producers of information (servers) and the consumers (clients) use different value dimensions may be considered here.

In our future work we will work on solving these interesting puzzles. Currently we are exploring the notion of *quality* which is closely related to that of value. More specifically, we attempt to create a formal model for quality and make it quantifiable so that it can be used in real systems. This will bring us one step closer to dealing with the challenges posed by the information market.

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