

# Trusting Advice from Other Buyers in E-Marketplaces: The Problem of Unfair Ratings

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## ABSTRACT

In electronic marketplaces populated by self-interested agents, buyer agents would benefit by modeling the reputation of seller agents, in order to make effective decisions about which agents to trust. One method for representing reputation is to ask other agents in the system (called advisor agents) to provide ratings of the seller agents. The problem of unfair ratings exists in almost every reputation system, including both unfairly high and unfairly low ratings. We begin by surveying some existing approaches to this problem, characterizing their capabilities and categorizing them in terms of two main dimensions: public-private and global-local. The impact of reputation system architectures on approach selection is also discussed. Based on the study, we propose a novel personalized approach for effectively handling unfair ratings in an enhanced centralized reputation system. Experimental results demonstrate that the approach effectively adjusts the trustworthiness of advisor agents according to the percentages of unfair ratings provided by them. We then argue for the merits of our model as the basis for designing social networks to share reputation ratings of sellers in electronic marketplaces.

## Categories and Subject Descriptors

I.2.11 [ARTIFICIAL INTELLIGENCE]: Distributed Artificial Intelligence—*Intelligent agents, Multiagent systems*

## General Terms

Algorithms, Experimentation

## Keywords

Trust, Buyer and Seller Agents, Private and Public Reputation, Unfair Ratings in Social Networks, Electronic Marketplaces

## 1. INTRODUCTION

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As the enterprise of electronic commerce becomes increasingly popular, worldwide, one challenge that arises is to ensure that organizations participating in e-commerce have sufficient trust in order to bring their businesses on-line. In order to assist both individual buyers and business organizations in conducting both B2B and B2C e-commerce, researchers in artificial intelligence have been designing intelligent agents to perform the tasks of buying or selling, on behalf of their human clients. While these agents assist in offloading the processing required by people in order to find the best business partnerships, it then becomes critical for these agents to make effective decisions, in order to engender the trust of their users.

In this paper, we examine one particular problem that arises when buyer agents elicit opinions about seller agents from other buyer agents in the marketplace: the issue of possible unfair ratings. To explain, in an agent-based electronic marketplace, agents are self-interested. They interact with each other to achieve their own goals. Seller agents sell products to buyer agents and try to maximize their profit. Buyer agents try to gain good products in terms of, for example, high quality and low prices. To ensure good interactions amongst agents, a reputation mechanism provides important social control in electronic marketplaces. In a reputation system, agents can rate each other. Agents estimate each other's reputation according to those ratings and choose the most reputable ones to interact with. However, a reputation system may be deceived by unfair ratings for an agent's personal gain. The problem of unfair ratings is fundamental and exists in almost every reputation system. A well-known example of this problem is that on the eBay system three men highly rate each other and later sell a fake painting for a very high price [4].

Dellarocas [3] distinguishes unfair ratings as unfairly high ratings and unfairly low ratings. Unfairly high ratings may be used to increase seller agents' reputations. They are often referred as "ballot stuffing". Unfairly low ratings of a seller agent may be provided by buyer agents who cooperate with other seller agents to drive the seller agent out of the market. They are often referred as "bad-mouthing". In bi-directional rating schemas where buyer and seller agents can rate each other, buyer agents may provide unfairly high ratings in hope of getting high ratings in return. This behavior is based on a social dictum, "be nice to others who are nice to you" [7]. Unfairly high ratings may also be given because agents tend to give high ratings as long as other agents pay for products or deliver the products requested [2]. Agents may also provide unfairly low ratings to retaliate against

other agents for being rated low.

To ease the problem of unfair ratings, the eBay system only allows agents to provide ratings after their transactions have succeeded [5]. It also adds a cost for each transaction. However, this approach still cannot stop fraudulent attempts.

Many researchers have proposed different theoretical approaches to handle unfair ratings. However, these approaches are only effective in limited situations. Dellarocas [3] proposes the *Cluster Filtering* approach to separate unfairly high ratings and fair ratings. This approach is unable to handle unfairly low ratings. Whitby et al. [10] extend the beta reputation system proposed by Jøsang and Ismail [4] to cope with unfair ratings by filtering out the ratings that are not in the majority amongst other ones. This approach is only effective when the majority of ratings are fair. The *GM-GC* approach is developed by Chen and Singh [2] to compute reputations of agents based on their ratings. The computation of this approach is quite time consuming. Teacy et al. [8] propose the *TRAVOS* model to cope with inaccurate reputation opinions. This model does not deal with changes of agents' behavior.

In this paper, we first survey different approaches for handling unfair ratings, and their advantages and disadvantages. We list the capabilities that an effective approach should have and compare these approaches based on their capabilities. We categorize these approaches in terms of two dimensions, a "public-private" dimension and a "global-local" dimension. We also discuss the impact of reputation system architectures on the selection of approaches for handling unfair ratings.

Based on the study, we propose a personalized approach for effectively handling unfair ratings in enhanced centralized reputation systems. We consider the scenario where buyer agents elicit reputation ratings of seller agents from other buyer agents, known as advisor agents. The personalized approach first calculates what we refer to as the "private reputation" of an advisor agent, based on the buyer and advisor agents' ratings for commonly rated seller agents. When the buyer agent is not confident in its private reputation ratings it can also use what we refer to as the "public reputation" of the advisor agent. This public reputation is estimated based on the advisor agent's ratings for all seller agents in the system. The personalized approach ultimately computes a weighted average of private and public reputations to represent the trustworthiness of the advisor agent.

Experimental results demonstrate the effectiveness of the personalized approach in terms of adjusting advisor agents' trustworthiness based on the percentages of unfair ratings they provided. Our personalized model can therefore be seen a valuable approach to use when introducing social networks in order to model the reputations of sellers in electronic marketplaces.

The rest of the paper is organized as follows. In Section 2, we will survey different approaches for handling unfair ratings. In Section 3, we propose a personalized approach for handling unfair ratings in an enhanced centralized reputation system. Section 4 provides examples that go through each step of our approach. Experimental results are presented in Section 5. Conclusions and future work are outlined in Section 6.

## 2. RELATED WORK

In this section, we summarize approaches used in different reputation systems, list their capabilities, present our proposed categorization of those approaches, and discuss the impact of reputation system architectures on the selection of approaches for handling unfair ratings.

### 2.1 Different Approaches

Different approaches have been proposed for handling unfair ratings. Those approaches are used in different reputation systems. We briefly summarize these systems and focus on their approaches for handling unfair ratings. Advantages and disadvantages of these approaches will be pointed out as well.

Dellarocas [3] simplifies the problem of unfair ratings by introducing the mechanism of controlled anonymity to avoid unfairly low ratings and negative discrimination. To reduce the effect of unfairly high ratings and positive discrimination, Dellarocas first uses collaborative filtering techniques to identify the nearest neighbors of a buyer agent based on their preference similarity with the buyer agent on commonly rated seller agents. He then proposes the *Cluster Filtering* approach to filter out unfairly high ratings provided by those neighbors. The idea of this approach is to apply a divisive clustering algorithm to separate the neighbors' ratings into two clusters, the lower rating cluster and the higher rating cluster. Ratings in the lower rating cluster are considered as fair ratings. Ratings in the higher rating cluster are considered as unfairly high ratings, and therefore are excluded or discounted. To deal with the situation where ratings vary over time, the *Cluster Filtering* approach considers only the ratings within the most recent time window whose width is influenced by the frequency of fair ratings. The *Cluster Filtering* approach copes with unfairly high ratings, takes into account preference similarity between buyer agents and advisor agents, and deals with changes of agents' ratings. One problem about this approach is that it does not handle unfairly low ratings. Dellarocas points out that the mechanism of controlled anonymity cannot avoid unfairly high ratings and positive discrimination because of identity signals between buyer and seller agents, for instance, seller agents may use a particular pattern in the amounts of their products. Identity signaling may not be able to avoid unfairly low ratings as well because buyer agents may rate against all other seller agents except their partners. In addition, controlled anonymity may only work in a sufficiently large system. In many smaller systems, however, it cannot be used due to the fact that agents may easily locate their conspirators' identity signals.

The beta reputation system (BRS) proposed by Jøsang and Ismail [4] estimates reputations of seller agents using a probabilistic model. This model is based on the beta probability density function, which can be used to represent probability distributions of binary events. This model is able to estimate the reputation of a seller agent by propagating ratings provided by multiple advisor agents. Ratings are combined by simply accumulating the amount of ratings supporting good reputation and the amount of ratings supporting bad reputation. To handle unfair feedback provided by advisor agents, Whitby et al. [10] extend the BRS to filter out those ratings that are not in the majority amongst other ones by using the *Iterated Filtering* approach. More specifically, feedback provided by each advisor agent consists of ratings supporting both good reputation and bad

reputation of a seller agent, and is represented by a beta distribution. If the cumulated reputation of the seller agent falls between the lower and upper boundaries of feedback, this feedback will be considered as fair feedback. However, the *Iterated Filtering* approach is only effective when the significant majority of ratings are fair. This approach also does not consider buyer agents' personal experience with advisor agents' feedback.

Chen and Singh [2] develop a general method, *GM-GC*, to automatically compute reputations for raters based on all the ratings given to each object. More specifically, the *GM-GC* approach computes a rater's reputation through three steps. The first step is to compute quality and confidence values of each of the rater's ratings for each object in a category. The quality value, called local match (LM) is calculated based on the frequency distribution of all ratings given to the same object. The confidence level, called local confidence (LC) is determined by a piecewise function. LC is the same for all ratings for the same object. The second step is to compute the cumulated quality and confidence values of all ratings for each category of objects, which are called global match (GM) and global confidence (GC) respectively. GM and GC are computed by combining LM and LC for each object in the category. Finally, the *GM-GC* approach computes the rater's reputation based on the rater's GM and GC for each category. The *GM-GC* approach is different from filtering approaches. It explicitly computes reputations for raters to cope with unfair ratings. Ratings from less reputed raters will carry less weight and have less impact on accumulated reputations of seller agents. However, the computation of *GM-GC* is quite time consuming.

Teacy et al. [8] propose the *TRAVOS* model, which is a trust and reputation model for agent-based virtual organizations. This model copes with inaccurate reputation advice by accomplishing two tasks. The first task is to estimate the accuracy of the current reputation advice based on the amount of accurate and inaccurate previous advice which is similar to that advice. The second task is to adjust reputation advice according to its accuracy. The aim of this task is to reduce the effect of inaccurate advice. This task is necessary because it can deal with the situation where an advisor agent untruthfully rates a seller agent a large number of times, also known as the problem of advisors "flooding" the system [3]. Experimental results show that the *TRAVOS* model outperforms the *Iterated Filtering* approach. However, this model also has some problems. It assumes that seller agents act consistently. This assumption might not be true in many cases. The second problem is that this model repeatedly goes over an advisor agent's past advice at each time when estimating accuracy of this advisor agent's current advice. This could be a problem when the number of advisor agents is large and/or the amount of past advice provided by each advisor agent is large.

Wang and Vassileva [9] propose a *Bayesian network*-based trust model in a peer-to-peer file sharing system. In this system, file providers' capabilities are evaluated by different aspects, including download speed, file quality, and file type. A naïve Bayesian network is constructed to represent conditional dependencies between the trustworthiness of file providers and the aspects. Each user holds a naïve Bayesian network for each file provider. If a user has no personal experience with a file provider, it may ask other users (advisors)

for recommendations. A recommendation provided by an advisor will be considered by the user according to the trust value it has of the advisor. The trust value is updated by a reinforcement learning formula. More specifically, it will be increased/decreased after each comparison between the naïve Bayesian networks held by the user and the advisor for the file provider. The *Bayesian network*-based trust model takes into account preference similarity between users and advisors. However, this approach assumes that the aspects of file providers' capabilities are conditionally independent. This assumption is unrealistic in many systems. For instance, users may prefer high quality video and picture files, but do not care much about the quality of text files.

Buchegger and Boudec [1] propose a robust reputation system for mobile Ad-hoc networks (*RRSMAN*). *RRSMAN* is a fully distributed reputation system that can cope with false disseminated information. In *RRSMAN*, every node in the network maintains a reputation rating and a trust rating about every node else that it cares about. The trust rating for a node represents how likely the node will provide true advice. The reputation rating for a node represents how correctly the node participates with the node holding the rating. A modified Bayesian approach is developed to update both the reputation rating and the trust rating that node  $i$  holds for node  $j$  based on evidence collected in the past. Evidence is weighted according to its order of being collected. To detect and avoid false reports, *RRSMAN* updates the reputation rating held by node  $i$  for node  $j$  according to the advice provided by node  $k$  only if node  $k$  is trustworthy or the advice is compatible with the reputation rating held by node  $i$ . The advice is considered as compatible if its difference with the reputation rating held by node  $i$  is less than a deviation threshold, which is a positive constant. Three problems exist in the *RRSMAN* approach. Evidence collected by a node is weighted only according to its order of being observed. Therefore, the weights of two pieces of evidence collected on one month ago and on one year ago have no much difference as long as they have been collected one after another. Another problem is that this approach determines the preference similarity between two nodes based on only their current reputation ratings to one other node, which is certainly insufficient. The third problem concerns its way of integrating advice. The *RRSMAN* approach updates the reputation rating of a node by considering other nodes' advice. Pieces of advice provided by other nodes are considered equally as long as these nodes are trustworthy or each piece of advice is compatible.

## 2.2 Capabilities

To compare the above approaches, we analyze the capabilities they have based on their summaries. We list the following four capabilities that an effective approach should have.

- **Preference:** Agents may have different preferences. When a buyer agent estimates the reputation of a seller agent from advice provided by advisor agents, advisor agents with different preferences may have different opinions about the seller agent's reputation. Therefore, an effective approach should be able to take into account preference similarity between buyer and advisor agents when it copes with unfair ratings. For example, the *Cluster Filtering* approach [3] uses collaborative filtering techniques to identify nearest neighbors

**Table 1: Capabilities of Approaches for Handling Unfair Ratings**

Approaches	Preference	High	Low	Varying
Iterated Filtering		✓	✓	✓
TRAVOS	✓	✓	✓	
Cluster Filtering	✓	✓		✓
GM-GC		✓	✓	
Bayesian Network	✓	✓	✓	
RRSMAN	≈ ✓	✓	✓	≈ ✓

**Table 2: Categorization of Approaches for Handling Unfair Ratings**

Categories	Public	Private
Global	GM-GC	TRAVOS, RRSMAN Bayesian Network
Local	Iterated Filtering, Cluster Filtering	

of a buyer agent;

- **High:** The approach should be able to handle unfairly high ratings;
- **Low:** The approach should be able to handle unfairly low ratings;
- **Varying:** The approach should be able to deal with changes of seller agents’ behavior. Because of changes of seller agents’ behavior, agents may provide different ratings for the same seller agent. Even though two ratings provided within different periods of time are different, it does not necessarily mean that one of them must be unfair. Different ways are proposed to deal with this situation. BRS [10] uses a forgetting factor to dampen ratings according to the time when they are provided. The older ratings are dampened more heavily than the more recent ones.

Table 1 lists capabilities of the approaches summarized in the previous section. In this table, the mark “✓” indicates that an approach has the capability. For example, the *Iterated Filtering* approach is capable of handling unfairly high and low ratings, and dealing with changes of agents’ behavior. The mark “≈ ✓” indicates that an approach has the capability, but in a limited manner. For example, the *RRSMAN* approach determines the similarity between a buyer agent and an advisor agent based on only their current opinions on one seller agent, which is certainly insufficient. In addition, it deals with changes of agents’ behavior by dampening advisor agents’ ratings according to only their orders of being provided.

### 2.3 Categories

We have summarized different approaches proposed to handle unfair ratings, including *Cluster Filtering*, *Iterated Filtering*, *TRAVOS*, *GM-GC*, *Bayesian Network*, and *RRSMAN*. These approaches can be categorized in terms of two dimensions, a “public-private” dimension and a “global-local” dimension.

**Public versus Private:** When a buyer agent lacks personal experience with a seller agent, it can estimate the reputation of the seller agent based on collected ratings of the seller agent provided by advisor agents. Ratings will be considered differently according to trustworthiness of advisor agents. Ratings provided by more trustworthy advisor

agents will be considered more heavily. An approach of handling unfair ratings is *private* if the buyer agent estimates the trustworthiness of an advisor agent based on only its personal experience with previous ratings provided by the advisor agent. The current rating provided by the advisor agent is likely to be fair if the advisor agent’s past ratings are also fair. For example, the *TRAVOS* model [8] estimates the accuracy of the advisor agent’s current rating based on the amount of fair and unfair previous ratings provided by it that are similar to its current rating. An approach of handling unfair ratings is *public* if the buyer agent estimates trustworthiness of the advisor agent based on all the ratings it has supplied for any of the seller agents in the system. A rating is likely to be reliable if it is the same as/similar to most of the other ratings to same seller agents. For example, the *Iterated Filtering* approach [10] filters out unfair ratings that are not majority amongst others.

**Global versus Local:** An approach is *local* if it filters out unfair ratings based on only the ratings for the current seller agent. The *Cluster Filtering* approach [3] applies a divisive clustering algorithm to separate the ratings to a seller agent into two clusters, the lower rating cluster and the higher rating cluster. The ratings in the higher rating cluster are then considered as unfair ratings. An approach of handling unfair ratings is considered as *global* if it estimates the trustworthiness of an advisor agent based on ratings for all the seller agents that the advisor agent has rated. The *GM-GC* proposed in [2] is a *global* approach.

The categorization of approaches for handling unfair ratings is summarized in Table 2. Note that there is no approach falling in the category of “private and local”. It is simply because that there is a conflict in this category. A buyer agent asks advice about a seller agent from an advisor agent only when it lacks personal experience with the seller agent. An approach belonging to the “private and local” category will evaluate the trustworthiness of the advisor agent based only on the buyer agent’s ratings and the advisor agent’s ratings for the seller agent currently being evaluated as a possible partner (referred to as the current seller agent). The buyer agent’s limited experience with the current seller agent is certainly not sufficient for determining the trustworthiness of the advisor agent.

### 2.4 Impact of Reputation System Architectures

Reputation system architectures have an impact on the

selection of approaches for handling unfair ratings. There are basically two types of reputation systems in terms of their different architectures, centralized reputation systems and distributed reputation systems [5].

In centralized reputation systems, central servers collect ratings for each seller agent from buyer agents after transactions between them have succeeded. Central servers do not record all of the ratings of each individual buyer agent. Therefore, approaches used in these systems cannot consider buyer agents' personal experience with advisor agents' advice. The approaches used in centralized reputation systems, such as *Iterated Filtering*, *Cluster Filtering* and *GM-GC*, are based on all ratings of seller agents and belong to the "public" category. Results from those approaches do not differ for different buyer agents.

In distributed reputation systems, there is no central location for submitting ratings or obtaining advisor agents' ratings. A buyer agent should simply request advice about a seller agent from advisor agents. Even though some of distributed reputation systems have distributed stores for collecting ratings, it is still costly to obtain all ratings for the seller agent. Therefore, approaches used in these systems cannot consider all agents' ratings for the seller agent. The approaches used in distributed reputation systems, such as *TRAVOS*, *Bayesian Network* and *RRSMAN*, handle unfair ratings by estimating the trustworthiness of an advisor agent based on each individual buyer agent's personal experience with the advisor agent's advice. These approaches belong to the "private" category.

### 3. A PERSONALIZED APPROACH

As discussed in Section 2.4, approaches for handling unfair ratings are limited by reputation system architectures. Specifically, the approaches used in centralized reputation systems, such as *Iterated Filtering*, *Cluster Filtering* and *GM-GC*, cannot consider buyer agents' personal experience with advice provided by advisor agents. However, buyer agents' personal experience with advisor agents' advice is very important for estimating trustworthiness of advisor agents because agents tend to trust their own experience more than others' opinions. Furthermore, the *Iterated Filtering* approach is only effective when the significant majority of ratings are fair, the *Cluster Filtering* approach cannot handle unfairly low ratings, and the *GM-GC* approach is computationally intractable.

Inspired by the approaches used in distributed reputation systems, we propose a personalized approach for an enhanced centralized reputation system. This system creates a profile for each buyer agent to record its ratings for each seller agent it has rated. The personalized approach essentially combines advantages of both approaches used in centralized and distributed reputation systems. It allows a buyer agent to estimate the reputation (referred to as private reputation) of an advisor agent based on their ratings for commonly rated seller agents.<sup>1</sup> In this case, agents' preferences are also taken into account. If an advisor agent is trustworthy and has similar preferences with the buyer agent, the buyer and advisor agents will likely have many

<sup>1</sup>We call this type of reputation private reputation because it is based on the buyer agent's own experience with the advisor agent's advice, and is not shared with the public. The private reputation value of the advisor agent may vary for different buyer agents.

ratings in common. When the buyer agent has limited private knowledge of the advisor agent, the reputation (referred to as public reputation) of the advisor agent will also be considered.<sup>2</sup> The public reputation is estimated based on all ratings for the seller agents ever rated by the advisor agent. Finally, the trustworthiness of the advisor agent will be modeled by combining the weighted private and public reputations. The weights of them are determined based on the estimated reliability of the private reputation.

#### 3.1 Private Reputation

Our approach allows a buyer agent  $B$  to evaluate the private reputation of an advisor agent  $A$  by comparing their ratings for commonly rated seller agents  $\{S_1, S_2, \dots, S_m\}$ . For one of the commonly rated sellers  $S_i$  ( $1 \leq i \leq m$  and  $m \geq 1$ ),  $A$  has the rating vector  $R_{A,S_i}$  and  $B$  has the rating vector  $R_{B,S_i}$ . A rating for  $S_i$  from  $B$  and  $A$  is binary ("1" or "0", for example), in which "1" means that  $S_i$  is reputable and "0" means that  $S_i$  is not reputable.<sup>3</sup> The ratings in  $R_{A,S_i}$  and  $R_{B,S_i}$  are ordered according to the time when they are provided. The ratings are then partitioned into different elemental time windows. The length of an elemental time window may be fixed (e.g. one day) or adapted by the frequency of the ratings to the seller  $S_i$ , similar to the way proposed in [3]. It should also be considerably small so that there is no need to worry about the changes of sellers' behavior within each elemental time window. We define a pair of ratings  $(r_{A,S_i}, r_{B,S_i})$ , such that  $r_{A,S_i}$  is one of the ratings of  $R_{A,S_i}$ ,  $r_{B,S_i}$  is one of the ratings of  $R_{B,S_i}$ , and  $r_{A,S_i}$  corresponds to  $r_{B,S_i}$ . The two ratings,  $r_{A,S_i}$  and  $r_{B,S_i}$ , are correspondent only if they are in the same elemental time window, the rating  $r_{B,S_i}$  is the most recent rating in its time window, and the rating  $r_{A,S_i}$  is the closest and prior to the rating  $r_{B,S_i}$ .<sup>4</sup> We then count the number of such pairs for  $S_i$ ,  $N_{S_i}$ . The total number of rating pairs for all commonly rated sellers,  $N_{all}$  will be calculated by summing up the number of rating pairs for each commonly rated seller agent as follows:

$$N_{all} = \sum_{i=1}^m N_{S_i} \quad (1)$$

The private reputation of the advisor agent is estimated by examining rating pairs for all commonly rated sellers. We define a rating pair  $(r_{A,S_i}, r_{B,S_i})$  as a positive pair if  $r_{A,S_i}$  is the same value as  $r_{B,S_i}$ . Otherwise, the pair is a negative pair. Suppose there are  $N_f$  number of positive pairs. The number of negative pairs will be  $N_{all} - N_f$ . The private reputation of the advisor  $A$  is estimated as the probability

<sup>2</sup>We call this type of reputation public reputation because it is based on the public's opinions about the advisor agent's advice, and it is shared by all of the public. The public reputation value of the advisor agent is the same for every buyer agent.

<sup>3</sup>For the purpose of simplicity, we assume ratings for sellers are binary. Possible ways of extending our approach to accept ratings in different ranges will be investigated as future work. Further discussion can be found in the future work section.

<sup>4</sup>We consider ratings provided by  $B$  after those by  $A$  in the same time window, in order to incorporate into  $B$ 's rating anything learned from  $A$  during that time window, before taking an action. According to the solution proposed by Zacharia et al. [11], by keeping only the most recent ratings, we can avoid the issue of advisors "flooding" the system.

that  $A$  will provide reliable ratings to  $B$ . Because there is only incomplete information about the advisor, the best way of estimating the probability is to use the expected value of the probability. The expected value of a continuous random variable is dependent on a probability density function, which is used to model the probability that a variable will have a certain value. The beta family of probability density functions is commonly used to represent probability distributions of binary events. Therefore, the private reputation of  $A$  can be calculated as follows:

$$\alpha = N_f + 1, \beta = N_{all} - N_f + 1$$

$$R_{pri}(A) = E(Pr(A)) = \frac{\alpha}{\alpha + \beta}, \quad (2)$$

where  $Pr(A)$  is the probability that  $A$  will provide fair ratings to  $B$ , and  $E(Pr(A))$  is the expected value of the probability.

### 3.2 Public Reputation

When there are not enough rating pairs (discussed in the next section), the buyer agent  $B$  will also consider the advisor agent  $A$ 's public reputation. The public reputation of  $A$  is estimated based on its ratings and other ratings for the sellers rated by  $A$ . Each time  $A$  provides a rating  $r_{A,S}$ , the rating will be judged centrally as a fair or unfair rating. We define a rating for a seller agent as a fair rating if it is consistent with the majority of ratings to the seller up to the moment when the rating is provided.<sup>5</sup> As before, we consider only the ratings within a time window prior to the moment when the rating  $r_{A,S}$  is provided, and we only consider the most recent rating from each advisor.

Suppose that the advisor agent  $A$  totally provides  $N'_{all}$  ratings. If there are  $N'_f$  number of fair ratings, the number of unfair ratings provided by  $A$  will be  $N'_{all} - N'_f$ . In the same way as estimating the private reputation, the public reputation of the advisor  $A$  is estimated as the probability that  $A$  will provide fair ratings. It can be calculated as follows:

$$\alpha' = N'_f + 1, \beta' = N'_{all} - N'_f + 1$$

$$R_{pub}(A) = \frac{\alpha'}{\alpha' + \beta'}, \quad (3)$$

which also indicates that the more the percentage of fair ratings advisor  $A$  provides, the more reputable it will be.

### 3.3 Trustworthiness of Advisors

To estimate the trustworthiness of advisor agent  $A$ , we combine the private reputation and public reputation values together. The private reputation and public reputation values are assigned different weights. The weights are determined by the reliability of the estimated private reputation value.

We first determine the minimum number of rating pairs needed for  $B$  to be confident about the private reputation value it has of  $A$ . Based on the Chernoff Bound theorem [7], the minimum number of rating pairs can be determined by an acceptable level of error and a confidence measurement as follows:

$$N_{min} = -\frac{1}{2\varepsilon^2} \ln \frac{1-\gamma}{2}, \quad (4)$$

<sup>5</sup>Determining consistency with the majority of ratings can be achieved in a variety of ways, for instance averaging all the ratings and seeing if that is close to the advisor's rating.

where  $\varepsilon$  is the maximal level of error that can be accepted by  $B$ , and  $\gamma$  is the confidence measure. If the total number of pairs  $N_{all}$  is larger than or equal to  $N_{min}$ , buyer  $B$  will be confident about the private reputation value estimated based on its ratings and the advisor  $A$ 's ratings for all commonly rated sellers. Otherwise, there are not enough rating pairs, the buyer agent will not be confident about the private reputation value, and it will then also consider public reputation. The reliability of the private reputation value can be measured as follows:

$$w = \begin{cases} \frac{N_{all}}{N_{min}} & \text{if } N_{all} < N_{min}; \\ 1 & \text{otherwise.} \end{cases} \quad (5)$$

The trust value of  $A$  will be calculated by combining the weighted private reputation and public reputation values as follows:

$$Tr(A) = wR_{pri}(A) + (1-w)R_{pub}(A) \quad (6)$$

It is obvious that the buyer will consider less the public reputation value when the private reputation value is more reliable. Note that when  $w = 1$ , the buyer relies only on private reputation.

## 4. EXAMPLES

To illustrate how our approach models trustworthiness of advisors, this section provides examples that go through each step of the approach. Examples are also provided to demonstrate how trust values different buyer agents have of same advisors may vary, and to show the effectiveness of our approach even when the majority of ratings are unfair.

In an electronic marketplace, a buyer agent  $B$  needs to make a decision on whether to interact with a seller agent  $S_0$ , which depends on how much  $B$  trusts  $S_0$ . To model the reputation of the seller  $S_0$  when the buyer has had no or only limited experience with  $S_0$ ,  $B$  seeks advice from three advisor agents  $A_x$ ,  $A_y$  and  $A_z$  who have had experience with  $S_0$ . The advice about  $S_0$  from  $A_x$ ,  $A_y$  and  $A_z$  are ratings representing the reputation of  $S_0$ . Before aggregating the ratings provided by  $A_x$ ,  $A_y$  and  $A_z$ , the buyer agent  $B$  needs to evaluate the reliability of those ratings, which depends on the trustworthiness of the advisors  $A_x$ ,  $A_y$  and  $A_z$ . Our approach effectively models the trustworthiness of advisors based on how reliable the previous ratings provided by them are.

Consider the case where the advisors  $A_x$ ,  $A_y$  and  $A_z$  each has rated only the five seller agents ( $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$ , and  $S_5$ ). In this case, we may assume  $S_0$  and  $S_5$  refer to the same seller agent. Table 3 lists the ratings provided by  $A_x$ ,  $A_y$  and  $A_z$  for the five sellers. The symbol "T" represents a sequence of time windows, in which  $T_1$  is the most recent time window. To simplify the demonstration, we assume that each advisor agent provides at most one rating within each time window. We also assume that those are the only ratings provided by them.

As can be seen from Table 4, the buyer agent  $B$  has also provided some ratings for the five sellers. The buyer agent  $B$  might have not provided any rating for some sellers within some time window. For example, it has provided only one rating for the seller  $S_5$ , which is in the time window  $T_1$ . We assume that the ratings provided by  $B$  are after those provided by  $A_x$ ,  $A_y$  and  $A_z$  if they are within the same time window.

**Table 3: Ratings of Sellers Provided by Advisors**

$A_j$	$A_x$					$A_y$					$A_z$				
	$T_1$	$T_2$	$T_3$	$T_4$	$T_5$	$T_1$	$T_2$	$T_3$	$T_4$	$T_5$	$T_1$	$T_2$	$T_3$	$T_4$	$T_5$
$S_1$	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$S_2$	1	1	1	1	1	0	1	0	1	1	0	0	0	0	0
$S_3$	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0
$S_4$	1	1	1	1	1	1	0	0	1	0	0	0	0	0	0
$S_5$	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0

**Table 4: Ratings Provided by the Buyer Agent  $B$**

$T$	$T_1$	$T_2$	$T_3$	$T_4$	$T_5$
$S_1$	1	1	1	1	1
$S_2$	1	1	1	1	-
$S_3$	1	1	1	-	-
$S_4$	1	1	-	-	-
$S_5$	1	-	-	-	-

**Table 5: Private and Public Reputations of Advisors**

$A_j$	$A_x$	$A_y$	$A_z$
$N_f(A_i)$	15	8	0
$\alpha$	16	9	1
$\beta$	1	8	16
$R_{pri}(A_j)$	0.94	0.53	0.06
$N'_f(A_j)$	25	12	0
$\alpha'$	26	13	1
$\beta'$	1	14	26
$R_{pub}(A_j)$	0.96	0.48	0.04

We compare the ratings provided by  $A_x$ ,  $A_y$  and  $A_z$  in Table 3 and ratings provided by  $B$  in Table 4. The buyer agent  $B$  has the same number of rating pairs with each advisor agent ( $N_{all}(A_j) = 15$  and  $j \in \{x, y, z\}$ ). However,  $B$  has different numbers of positive rating pairs with  $A_x$ ,  $A_y$  and  $A_z$ , which are listed in Table 5. Accordingly, as can be seen from Table 5, the private reputation values of  $A_x$ ,  $A_y$  and  $A_z$  are different, in which the private reputation value of  $A_x$  is the highest and that of  $A_z$  is the lowest. It indicates that the advisor agent  $A_x$  is most likely to provide fair ratings and have similar preferences with the buyer agent  $B$ , whereas  $A_z$  most likely will lie and have different preferences with  $B$ .

According to Table 3, the total number of ratings provided by each advisor agent is the same ( $N'_{all}(A_j) = 25$ ). We also count the number of fair ratings each advisor agent provides. A rating here is considered as a fair rating when it is consistent with the majority of ratings for the seller agent within a same time window. Consider the case where all of the five seller agents are reputable and the majority of ratings are fair. In this case, a rating of 1 provided by an advisor agent will be considered as a fair rating, whereas a rating of 0 will be considered as an unfair rating. From the advisor agents' ratings listed in Table 3, we can see that ratings provided by the advisor agent  $A_x$  are all fair, the advisor agent  $A_z$  always lies, and some of the ratings provided by the advisor agent  $A_y$  are unfair. Table 5 lists the number of fair ratings provided by each advisor agent and the corresponding public reputation value of it. From Table 5, it is clear that the advisor agent  $A_x$  is most likely to provide

fair ratings, and the advisor  $A_z$  most likely will lie.

**Table 6: Trustworthiness of Advisor Agents**

$\varepsilon$	0.1	0.15	0.2
$N_{min}$	115	51	29
$w$	0.13	0.29	0.52
$Tr(A_x)$	0.957	0.954	0.950
$Tr(A_y)$	0.487	0.495	0.506
$Tr(A_z)$	0.043	0.046	0.05

To combine private reputation and public reputation, the weight  $w$  should be determined. The value of  $w$  depends on the values of  $\varepsilon$  and  $\gamma$ , and the number of rating pairs  $N_{all}(A_j)$ , which is the same for every advisor agent in our example. Suppose we have a fixed value, 0.8 for  $\gamma$ , which means that the confidence value should be no less than 0.8 in order for the buyer agent to be confident with the private reputation values of advisor agents. In this case, the more errors it can accept, the more confident it is with the private reputation values of advisor agents, which also means that the more weight it will put on the private reputation values. Table 6 lists different acceptable levels of errors, their correspondent weights of private reputation values, and different results of trust values. It clearly indicates that  $A_x$  is the most trustworthy, and  $A_y$  is more trustworthy than  $A_z$ . As a result, the buyer agent  $B$  will place more trust in the advice provided by  $A_x$ . It will consider the advice provided by  $A_x$  more heavily when aggregating the advice provided by  $A_x$ ,  $A_y$  and  $A_z$  for modeling the reputation of the seller agent  $S_0$ . Discussion of possible aggregation functions is out of the scope of this paper. Our framework serves the purpose of representing the trustworthiness of advisors, so that this may be taken into account, when determining how heavily to rely on their advice.

**Table 7: Ratings Provided by the Buyer Agent  $B'$**

$T$	$T_1$	$T_2$	$T_3$	$T_4$	$T_5$
$S_1$	1	1	-	-	1
$S_2$	1	-	-	1	-
$S_3$	1	1	-	-	-
$S_4$	1	1	-	-	-
$S_5$	1	-	-	-	-

**Table 8: Trust Values  $B'$  Has of Advisors**

$A_j$	$A_x$	$A_y$	$A_z$
$R_{pri}(A_j)$	0.92	0.58	0.08
$R_{pub}(A_j)$	0.96	0.48	0.04
$Tr(A_j)$	0.947	0.514	0.054

To demonstrate how the trust values different buyer agents have of the same advisors may vary, we consider another buyer agent  $B'$ , that also needs to make a decision on whether to interact with a seller agent  $S'_0$  ( $S'_0$  may differ from  $S_0$ ). We may assume  $S'_0$  and  $S_4$  refer to the same seller agent. The ratings provided by  $B'$  for the five seller agents are listed in Table 7. By going through the same process as above, we can calculate the trust values the buyer agent  $B'$  has of  $A_x$ ,  $A_y$  and  $A_z$ , when  $\varepsilon = 0.2$  and  $\gamma = 0.8$ . The results are presented in Table 8. Comparing Table 8 with Tables 5 and 6, we can see that the private reputations the buyer agent  $B'$  has of advisors are different from those the buyer agent  $B$  has. Although the public reputations of advisors that the buyers have are the same, the trust values that the buyers have are still different.

**Table 9: Public Reputations of Advisors When Majority of Ratings are Unfair**

$A_j$	$A_x$	$A_y$	$A_z$
$N'_f(A_j)$	0	13	25
$\alpha'$	1	14	26
$\beta'$	26	13	1
$R_{pub}(A_j)$	0.04	0.52	0.96

**Table 10: Trustworthiness of Advisors When Majority of Ratings are Unfair**

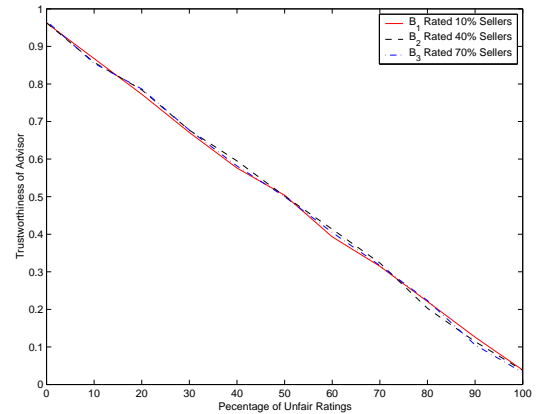
$\varepsilon$	0.1	0.2	0.25
$N_{min}$	115	29	19
$w$	0.13	0.52	0.79
$Tr(A_x)$	0.157	0.508	0.751
$Tr(A_y)$	0.521	0.525	0.528
$Tr(A_z)$	0.843	0.492	0.249

To show the robustness of our model, now consider a case where the majority of ratings provided by advisor agents are unfair. Adjusting our earlier example, a rating of 1 provided by an advisor agent for any seller agent will now be considered as an unfair rating, whereas a rating of 0 will be considered as a fair rating. As a result, the public reputations that the buyer  $B$  has of the advisor agents  $A_x$ ,  $A_y$  and  $A_z$  will be different, which can be seen from Table 9. We model the trust values the buyer agent  $B$  has of the advisors  $A_x$ ,  $A_y$  and  $A_z$ , when  $B$ 's acceptable levels of errors of private reputation values are different. Results are presented in Table 10. From this table, we can see that our approach can still correctly represent the trustworthiness of advisor agents by making adjustments to rely more heavily on the private reputations.

## 5. EXPERIMENTAL RESULTS

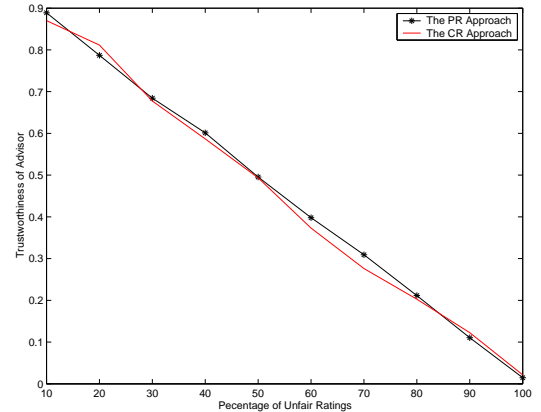
Our approach models the trustworthiness of advisors according to the reliability of the ratings provided by them. To demonstrate the effectiveness of the approach, we carry out experiments involving advisors that provide different percentages of unfair ratings. The expectation is that trustworthy advisors will be less likely to provide unfair ratings, and vice versa. We also examine how large numbers of dishonest advisors will affect the estimation of advisors' trustworthiness. Results indicate that our approach is still effective by

making adjustments to rely more heavily on private reputations of advisors, in this case.



**Figure 1: Trustworthiness of Advisor**

The first experiment involves 100 sellers, 3 buyers, and one advisor. The 3 buyers,  $B_1$ ,  $B_2$  and  $B_3$ , rate 10, 40 and 70 randomly selected sellers, respectively. The advisor totally rates 40 randomly selected sellers.<sup>6</sup> We examine how the trust values the buyers have of the advisor change when different percentages (from 0% to 100%) of its ratings are unfair. As illustrated in Figure 1, the trust values the buyers have of the advisor decrease when more percentages of the advisor's ratings are unfair. From this figure, we can also see that our approach is still effective when the buyer  $B_1$  does not have much experience with sellers, in the sense that  $B_1$  can still reduce the reputation of the advisor when it provides more unfair ratings.

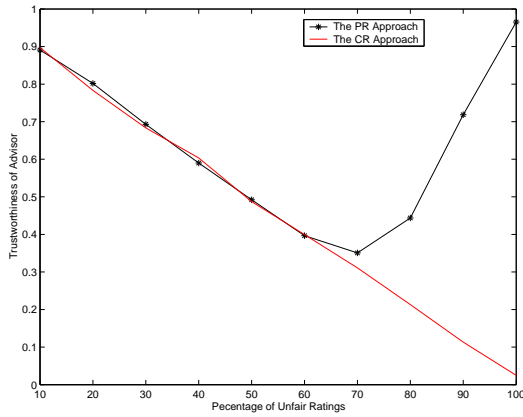


**Figure 2: Trustworthiness of A When Majority of Advisors are Honest**

The second experiment involves 100 sellers, 80 advisors, and one buyer. The buyer and each advisor rate 80 of the randomly selected sellers. We model the trust value the buyer has of one of the advisors,  $A$ . The trustworthiness of the advisor will be modeled as the combination of its private and public reputations (referred to as the CR approach)

<sup>6</sup>Note that we simplify the experiments by limiting each buyer or advisor to provide at most one rating for each seller.





**Figure 3: Comparison of the CR and PR Approaches**

and as only its public reputation (referred to as the PR approach), respectively. The advisor  $A$  will provide different percentages (from 10% to 100%) of unfair ratings. Figure 2 illustrates the trustworthiness of  $A$  when 24 (30% of all) advisors are dishonest. Those dishonest advisors provide the same percentage of unfair ratings as the advisor  $A$  does. Results indicate that the trustworthiness of  $A$  modeled by using the CR and PR approaches decreases when more percentages of ratings provided by  $A$  are unfair. Therefore, these two approaches are not affected when only a small number of advisors are dishonest. Figure 3 represents the trustworthiness of  $A$  when 48 (60% of all) advisors are dishonest. In this figure, the trustworthiness of  $A$  modeled by using the CR approach still decreases when more percentages of ratings provided by  $A$  are unfair, which indicates that our approach is still effective when the majority of advisors provide large numbers of unfair ratings. In contrast, the trustworthiness modeled by using the PR approach increases when more than 60% of ratings provided by the dishonest advisors are unfair, which indicates that the PR approach is only effective when the majority of ratings are fair.

## 6. CONCLUSIONS AND FUTURE WORK

In this paper, we first survey different approaches for handling unfair ratings, and their advantages and disadvantages. We list the capabilities that an approach should have. Approaches for handling unfair ratings should be able to take into account the preference similarity between buyer agents and advisor agents. They should be able to handle both unfairly high and low ratings. They should also be able to deal with changes of agents' behavior over time. We compare those existing approaches based on the four capabilities. We then categorize these approaches in terms of two dimensions, a "public-private" dimension and a "global-local" dimension. We also discuss the impact of reputation system architectures on the selection of approaches for handling unfair ratings. Approaches used in centralized reputation systems belong to the "public" category and cannot consider buyer agents' personal experience with advisor agents' advice (ratings), whereas approaches used in distributed reputation systems belong to the "private" category and cannot consider all ratings for seller agents. This categorization of the different approaches provides a valuable perspective on

the key challenges faced in designing an effective reputation system that makes use of advice from other agents, but takes care to consider the trustworthiness of those ratings.

Based on the study of these approaches, we propose a personalized approach for effectively handling unfair ratings in enhanced centralized reputation systems. The personalized approach has all four of the capabilities. It also has the advantages of both approaches used in centralized reputation systems and approaches used in distributed reputation systems. It allows a buyer agent to estimate the private reputation of an advisor agent based on their ratings for commonly rated seller agents. When the buyer agent is not confident with the private reputation value, it can also use the public reputation of the advisor agent. The public reputation of the advisor agent is evaluated based on all ratings for the seller agents rated by the advisor agent. Experimental results demonstrate the effectiveness of the personalized approach in terms of adjusting agents' trustworthiness based on the percentages of unfair ratings they provided. Trustworthiness of advisor agents will be decreased more/less if advisor agents provide more/fewer unfair ratings. Our approach can effectively model the trustworthiness of advisors even when buyer agents do not have much experience with seller agents. Furthermore, our approach is still effective when the majority of advisor agents provide large numbers of unfair ratings, by adjusting to rely more heavily on private reputations of advisor agents.

In future work, the personalized approach will be implemented and embedded in a simulated trust and reputation model. Experiments will be carried out to compare the performance of the personalized approach with the performance of other existing approaches, such as the *Iterated Filter* approach and the *TRAVOS* model. The performance could be evaluated, for instance, based on average estimation error, which is the average difference between seller agents' actual reputation values and estimated reputation values. In other words, our future work would explore in more detail how buyer agents can make effective decisions about seller agents in the marketplace, once they have carefully evaluated the trustworthiness of the advice they are receiving from advisors. This in turn provides for an attractive environment in which to conduct business: allowing agents to represent either consumers or businesses, as they operate with improved procedures for interpreting the information they receive about sellers from other buyer agents.

Another avenue for future work is to make adjustments to the current model, to broaden its applicability. For example, we could move beyond binary ratings for seller agents to accept ratings in different ranges. In this case, we could begin with a modest set of possible values, each with a qualitative interpretation (e.g. very reputable, neutral, not reputable, etc.) as in [2]. Another possible extension is to allow advisors and buyer agents to represent the reputation of a seller agent not as a single rating but as a rating of different dimensions of trustworthiness. We could, for example examine different aspects (e.g. delivery time, quality and prices) of sellers' products similar as used by Wang and Vassileva [9], but take into account relationships among those aspects by using for example, a quality of service ontology used by Maximilien and Singh [6].

Another potential future work is to distinguish ratings for the current seller agent from ratings for other seller agents. As stated earlier in the related work section, there is no ap-

proach belonging to the “private and local” category because buyer agents’ limited experience with the current seller agent is insufficient to estimate trustworthiness of advisor agents. However, we believe that ratings for the current seller agent should influence buyer agents’ decisions more heavily, and therefore should gain more weight when estimating trustworthiness of advisor agents.

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