SINVLIO: Using semantics and fuzzy logic to provide individual investment portfolio recommendations

Ángel García-Crespo[1], José Luis López-Cuadrado[2], Israel González-Carrasco[2], Ricardo Colomo-Palacios *, Belén Ruiz-Mezcua[3]

Computer Science Department, Universidad Carlos III de Madrid, Av. Universidad 30, Leganés 28911, Madrid, Spain

A B S T R A C T

Portfolio selection addresses the problem of how to diversify investments in the most efficient and profitable way possible. Portfolio selection is a field of study that has been broached from several perspectives, including, among others, recommender systems. This paper presents SINVLIO (Semantic INVestment portfoLIO), a tool based on semantic technologies and fuzzy logic techniques that recommends investments grounded in both psychological aspects of the investor and traditional financial parameters of the investments. The results are very encouraging and reveal that SINVLIO makes good recommendations, according to the high degree of agreement between SINVLIO and expert recommendations.

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1. Introduction

Portfolio selection discusses the problem of how to allocate one's capital to a large number of securities so that the investment brings the most profitable return [63]. The concept behind investment portfolios is to combine several different investment targets and so avoid concentrating too much risk in any one target, thus dispersing overall investment risk [9]. Selecting securities and investments is not a simple process, as it requires not only optimizing returns, but more importantly, minimizing potential risks [41]. However, with the vast amount of securities in today's market, it is becoming more and more difficult for investors to scrutinize each and every stock on the market [64]. According to Shyng et al. [70], the process of selecting an appropriate investment portfolio can be divided into two stages. The first step starts with observation and experience and ends with beliefs regarding the future performance of available securities. The second stage starts with relevant beliefs about the future performance of various investment products and ends with the choice of a portfolio.

Individual investors, and sometimes even professional fund managers, often allow their emotions to get in the way of rational investment decision-making [4]. In many cases, this may lead to them making mistakes in investment [9]. From a decision-making point of view, the stock portfolio problem can be divided into two questions [40]:

1. Which stock do you choose?
2. Which investment ratio do you use to allocate your capital to this stock?

The grandfather of portfolio theory and Nobel Prize-winner Harry Markowitz stated, not without reason, that 'portfolio selection' uses stocks' historical mean and variance together with the efficient frontier paradigm to construct the optimal portfolio [54]. The aim of this paper is to extend his traditional model by including the psychological preferences and the biases of the investor and, as a consequence of this, improve the categorization of the investor. Based on the studies conducted by Watson [78] and Skinner [72], several recent and important works have examined investor psychology and its influence in investment decision making (e.g. [13,16,21,44,45,38,39]). This paper takes previous works into account and proposes a method which uses ontologies to classify, define and match investors and investments of the application of fuzzy and semantic technologies.

Another special issue of this paper is recommender systems. Recommender systems are commonly defined as applications that e-commerce sites exploit to suggest products and provide

* Corresponding author. Tel.: +34 91 624 5958; fax: +34 91 624 9129.
  E-mail addresses: angel.garcia@uc3m.es (Á. García-Crespo), joseluis.lopez.cuadrado@uc3m.es (J.L. López-Cuadrado), israel.gonzalez@uc3m.es (I. González-Carrasco), ricardo.colomo@uc3m.es (R. Colomo-Palacios), belen.ruiz@uc3m.es (B. Ruiz-Mezcua).
[1] Tel.: +34 91 624 9417; fax: +34 91 624 9129.
[2] Tel.: +34 91 624 9117; fax: +34 91 624 9129.
[3] Tel.: +34 91 624 9968; fax: +34 91 624 9129.

consumers with information to facilitate their decision-making processes [58]. A recommender system can provide a set of solutions that best fit the user, depending on different factors concerning the user, the objective or the context it is applied in. Such systems can reduce search efforts [49] and provide valuable information to assist consumers' decision-making process [65] in order to solve the problem of information overload [46]. According to Porcel and Herrera-Viedma [62], a recommender system could be seen as a decision support system (DSS). Adomavicius and Tuzhilin [2] provide a survey of recommender systems and describe various limitations of current recommendation methods, as well as discussing possible extensions to improve recommendation capabilities and make recommender systems applicable to an even broader range of applications. Financial and investment applications for recommender systems are widely covered in the literature (e.g. [5,20,56]).

The remainder of the paper is structured in four sections. Section 2 reviews relevant works on risk tolerance, fuzzy logic and portfolio selection. Section 3 provides the theoretical foundations of SINVLIO (Semantic INVestment portfoLIO), as well as its architecture and implementation. Section 4 describes the evaluation process carried out. Finally, Section 5 summarizes the main conclusions of this research and outlines the future research.

2. Background

The use of intelligent expert systems in the field of investments has been studied from different perspectives. Valentine presents the advantages of the use of expert systems for finances, and states that the behavior of such systems is controlled by the rules provided [77]: if the rules provided by the expert have an economic orientation, then the expert system will have an economic orientation. In this paper, the aim is to provide a behavioral orientation to portfolio recommendations by means of fuzzy logic and semantic technologies. Other approaches build financial models to forecast stock prices which are based on a combination of methods and techniques [11].

Investor risk tolerance has likewise been studied from a broad number of perspectives. Aspects such as wealth [12], gender [50] or even lunar cycles [19] have been studied for their role in determining risk aversion or risk tolerance. Indeed, the study of the influence of the person's perception on financial behavior has become more important over the last two decades [28].

Personal or professional judgment, heuristics, objective single item question, risk scales or mixed measures are commonly used methods in measuring risk tolerance [28]. Based on previous studies on investor characteristics, Statman [73] affirms that while normal investors are affected by emotions and biases, rational investors are not.

Psychological and biological aspects are influential in the formation of economic preferences [35]. Behavioral finance studies how biases and cognitive errors influence both investors and decision making processes [55]. Indeed, aspects of investor psychology have been widely studied in the literature. Muhammad remarks that psychological biases affect investor behavior and prices [55]. Other authors note that these psychological biases can also lead to systematic errors [3]. Following similar considerations regarding the influence of the psychological aspects on the finance, De Bondt et al. propose a new class of asset pricing model by adding behavioral elements [18].

In certain cases, personal investment decisions depend on investor intuition and, as mentioned, biases in judgment may influence the decision-making process. Kahneman and Riepe determine a set of questions and recommendations for investment advisors to take into account the psychological biases of the investor (such as

overconfidence, optimism or hindsight) in their recommendations [43]. Grable and Lytton categorize investors according to their responses to a questionnaire [28–31]. Sudebar et al. [75] also worked on investor categorization through the application of a set of questionnaires. Shefrin and Statman present a complete review of portfolio theories based on behavioral aspects, and propose a positive portfolio theory [68]. Other research lines explore the classification of the investor from a different point of view. Thus, Roscoe and Howorth interpret charts in order to categorize investors. They distinguish between trend-seekers and pattern-seekers, and whether they trade as a system or an art [66]. From a knowledge management perspective, Cheng et al. implement a financial knowledge management system but they do not take into account the above-mentioned personal aspects [10].

Muhammad [55] suggests implementing regulatory policies to minimize the impact of mistakes deriving from psychological factors. According to this author, on the one hand, it is necessary to take into account the psychological aspects in order to avoid the mistakes deriving from the biases and cognitive errors, and, on the other hand, the risk tolerance and the psycho-social aspects of the investor must be considered in order to provide a portfolio in which investors feel good.

In the area of portfolio generation, the use of genetic algorithms has been studied and applied, as reported in [8]. Abiyev and Menekay [1] combine fuzzy logic in order to represent aspects related to the risk and return of each investment, using genetic algorithms to create portfolios [1]. Genetic algorithms have also been applied to stock prediction [6]. Shipley also works with a model using fuzzy logic in order to represent the relationship between risk and return of the investment [69]. The use of neural networks is a classical approach in portfolio selection [36] and risk assessment [82], even when combined with fuzzy-logic [79]. However, the use of the psycho-social aspects of the investor combined with these techniques has not been reported in the literature.

Furthermore, there are fuzzy logic approaches that have been developed for portfolio selection. While Yan provides a bifuzzy approach for selecting portfolios with a given degree of risk tolerance [81], Gupta et al. present a hybrid approach for simultaneously considering optimal asset allocation and suitability issues [32]. Ghazinoorya et al. recommend portfolio products based on the concept of portfolio matrices combined with fuzzy logic [26], although this approach does not explicitly consider the psycho-social aspects of the investor. Chen and Hung propose a fuzzy approach based on fuzzy linguistic variables in order to represent expert knowledge of portfolio selection [7]. These authors use the investor's risk preferences to determine the investment ratio for each stock in the proposed portfolio. Despite taking into account the risk profile of an investor, this interesting proposal does not determine it.

The decision rules regarding investment selection must be based on a shared vocabulary in order to categorize products from different sources. Ontologies are "a formal and explicit specification of a shared conceptualization" [74]. Ontologies and semantic technologies have been widely used over the last years in many intelligent applications that combine ontologies with reasoners (e.g. [23,22]). Financial ontologies like FEF ontology [42] or the ontology of the SONAR project [25] have been applied to categorize and recommend financial products. However, ontologies regarding the psycho-social aspects of investors have not been found in the research work carried out so far. The aim of the system proposed in this paper is to combine the semantic approach with fuzzy logic techniques in order to:

- Categorize investors according to their risk tolerance by using an ontology.
- Categorize the investments based on a financial ontology.