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A new hybrid multi-start tabu search for finding hidden purchase decision strategies in WWW based on eye-movements

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ABSTRACT

It is known that the decision strategy performed by a subject is implicit in his/her external behaviors. Eye movement is one of the observable external behaviors when humans are performing decision activities. Due to the dramatic increase of e-commerce volume on WWW, it is beneficial for the companies to know where the customers focus their attention on the webpage in deciding to make a purchase. This study proposes a new hybrid multi-start tabu search (HMTS) algorithm for finding the hidden decision strategies by clustering the eye-movement data obtained during the decision activities. The HMTS uses adaptive memory and employs both multi-start and local search strategies. An empirical dataset containing 294 eye-fixation sequences and a synthetic dataset consisting of 360 sequences were experimented with. We conduct the Sign test and the result shows that the proposed HMTS method significantly outperforms its variants which implement just one strategy, and the HMTS algorithm shows an improvement over genetic algorithm, particle swarm optimization, and K-means, with a level of significance $\alpha = 0.01$. The scalability and robustness of the HMTS is validated through a series of statistical tests.

1. Introduction

The understanding of human decision-making processes has been an important issue in many fields, such as, marketing, decision support systems (DSSs), electronic commerce, retailing, economic, politics, etc. A main challenge for this line of research is to disclose implicit cognitive operations in the mind. In the past, based on different observable behavioral cues, such as verbal report, mouse trace, and eye movement, various tracing methods have been invented to infer the underlying processes [1]. More importantly, with regard to the development of DSSs, these methods also show us a potential direction to enhance the adaptivity mechanism of DSSs. Traditionally, DSSs' supportive functionalities are predetermined in advance based on the basis of generally adopted strategies [2,3]. Apparently, this approach would be weak in coping with users' occasional cognitive needs occurring in the empirical setting. In view of this limitation, DSSs with the adaptability, termed as adaptive decision support systems (ADSSs), have been of great interest to many researchers and practitioners [4,5]. As the adjective "adaptive" highlights, this kind of DSS is featured as being able to provide supports more immediately in response to decision makers' different cognitive needs. It is expected that the supports of ADSSs can become more flexible and individualized.

As the eye tracking technology has made a great progress in the automatic data collection and analysis during these years, it is becoming feasible to integrate this technology into ADSSs to upgrade ADSSs' adaptability. Previous research has found that eye movements are directly related to the underlying cognitive process, which is also known as the eye-mind assumption, stating that subjects' eyes often fixate on the external referents whose corresponding representations are being processed in forming the subjects' cognition [6]. In the past, a great body of research on tracking eye movements has also consistently found the relationship between eye movements and cognitive processes in a variety of contexts, such as reading, perception, and visual search [7–9]. In the research on decision-making, eye movements have also been applied to probe covert decision strategies which guide people's decision process to reach a final decision. For example, Russo [10] inferred how people solved a multi-attribute choice problem by analyzing their eye movements. Multi-attribute choice problems are widely encountered in daily life. This decision requires people to choose one brand out of a set of alternatives which are described by a common set of attributes. Decision strategy implicitly processes the information sequence the subject fixates. Several typical decision strategies have been identified, for example, the weighted additive rule (WADD), the equal weight heuristic (EQW), the major-

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ity of confirming dimensions (MCD), the satisficing heuristic (SAT), the elimination-by-aspects (EBA), and the lexicographic heuristic (LEX). Therefore, the eye fixation sequences collected from many people performing the decision-making process are highly likely to resort to main clusters, and each sequence cluster is related to a particular decision strategy. We believe that the eye-movement data can provide a source of fruitful information for ADSSs, which, if further exploited, can infer and diagnose decision makers' cognitive needs and thus make more suitable responses to decision makers.

The state-of-the-art eye-trackers can access real-time eye-movement data, and have a variety of appearances designed for different usage situations. For example, some eye-trackers are wearable for assisting real-life activities of particular users (such as automobile drivers and hand-disabled people), while others are embedded in screen devices, which is particularly suitable for monitoring eye movements on a variety of consumer electronics' screens (desktop PC, notebook, iPhone, and iPad). Based on the modern eye tracking technology, a variety of promising adaptivity mechanisms for information systems have been proposed and examined during these years. For example, Jacob and Karn [11] investigated how users interact with different computer interfaces and how the result can be used to change interface design. The attentive user interface suggested by Vertegaal [12] is capable of adjusting the resolutions of any region on the screen according to the subject's gazing point. Parmar [13] tracked the eye-region in the driver's face and provides warning signal if a drowsiness pattern is detected. Effective website advertising was proposed by Schiessl et al. [14] through eye-movement analysis that where the users focus their attention on the website. Bojko [15] presented an adaptive web design approach which applies eye tracking to realize the number of fixations before the target was firstly seen and the number of times the target was gazed at during the whole session. Affective computing, which was coined by Picard [16], uses eye-movement information to estimate the affective states of users and make adaptive responses.

Regarding to the development of the adaptivity mechanism for ADSSs based on the eye movement data, we have obtained two main findings in our previous studies. First, with respect to an operational decision strategy, the similarity between eye-movement data obtained by empirical fixation sequence and the ideal fixation sequence (derived by domain experts) is high [17]. This implies the eye-movement data can be used to identify the cognition process of the subject. Second, if the true relationships among all the empirical fixation sequences are known a priori and these sequences are grouped into a number of disjoint clusters, we found that only a few principal sequences are needed to represent each cluster without deteriorating the classification accuracy for future sequences [18]. This technique is important when the addressed application involves a great volume of empirical fixation data such as in the context of web usage. Along this line, this study intends to bridge the two findings. Specifically, when the ideal fixation sequences are not available, we have to disclose the hidden decision strategies in an unsupervised manner. By computing the similarity between empirical fixation sequences, we can produce tentative clusters such that the empirical fixation sequences contained in the same cluster have higher homogeneity than those arranged in different clusters. The principal sequences for each cluster can be identified and they are useful in decision strategy applications such as mining, classification, and prediction. Traditional clustering methods are applicable to numerical attribute values, which are in contrast to the string representation for the eye-movement data. This paper proposes a new hybrid multi-start tabu search (HMTS) algorithm which can deal with string data and has several distinguished features, mainly built on the foundation of adaptive memory programming [19].

The remainder of this paper is organized as follows. Section 2 presents the rationale for human's decision-making and introduces the existing technologies for clustering and tabu search. Section 3 articulates the proposed HMTS algorithm with its distinct features. Section 4 describes the experimental results and performance evaluation. Finally, conclusions and future research lines are given in Section 5.

2. Related works

2.1. Rational decision-making models

To design an ADSS, adopting an appropriate human decision-making model is a necessary step which describes the procedure the decision-maker performs to choose one target out of a number of decision alternatives described by a set of attributed data. The attribute values could be numerical, alphabetical, or compound of both. As previously noted, it is beneficial to develop ADSS applications by linking together the decision-making model with the subject's behaviors such that a better service can be provided to the customers.

There exist many decision-making models that people apply in engineering and business domains. These models can be broadly classified as *rational* or *intuitive* models. Rational decision-making models partition the logical process into several stages and each stage aims to accomplish a simpler and smaller task than the original one. Intuitive decision-making models choose the option that mostly satisfies the emotional reactions to the alternatives, however, intuitive decision-making models are not considered as the opposite of rational decision-making models. Some researchers even study the logic behind the decisions made intuitively. Our study focuses the discussions on rational decision-making models because they are more structured and better investigated than the intuitive decision-making models.

The most prevalent examples of rational models include decision matrix analysis [20], SWOT analysis [21], Pareto analysis [22], and decision trees [23]. The decision matrix analysis establishes a set of evaluation criteria (attributes) and then prioritizes alternative concepts (decisions). The decision-making process is decomposed into a set of elementary information processes (EIPs) according to these evaluation criteria and the EIPs are scored for final concept ranking. The SWOT analysis compares the pros and cons from internal aspects (in terms of strengths and weaknesses) and external aspects (in terms of opportunities and threats) in order to specify an appropriate goal. The Pareto analysis is used to identify the most important causes to improve the performance. The reasoning is based on the Pareto principle that by doing 20% of work, 80% of the advantage of doing the entire job can be obtained. It proceeds by creating a bar chart which arranges the causes in a decreasing order of importance and a curve representing the cumulative percentage of gains helps identify the most important causes. The decision tree analysis employs a tree structure to expand the options. Each option may result in other options or uncertain consequences with probability. The tree expansion is completed when as many outcomes have been reached as the decision maker could consider. Each outcome is assigned a benefit value by the decision maker and the expected value for each option is then calculated for ranking.

The decision matrix analysis is considered in this paper because it is the most probable model the users adopt for purchasing via the web-based business-to-customer (B2C) e-commerce. This is due to the fact that most B2C e-commerce websites display their web pages by listing the attributed information of competing products. For example, it is a common behavior for frequent travelers to arrange the itinerary by selecting airline tickets, hotels and car