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User-system cooperative evolutionary computation for both quantitative and qualitative objective optimization in image processing filter design

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A B S T R A C T

This study proposes a cooperative evolutionary optimization method between a user and system (CEUS) for problems involving quantitative and qualitative optimization criteria. In a general interactive evolutionary computation (IEC) model, both the system and user have their own role in the evolution, such as individual reproduction or evaluation. In contrast, the proposed CEUS allows the user to dynamically change the allocation of search roles between the system and user, resulting in simultaneous optimization of qualitative and quantitative objective functions without increasing user fatigue. This is achieved by a combination of user evaluation prediction and the integration of interactive and non-interactive EC. For instance, the system performs a global search at the beginning, the user then intensifies the search area, and finally the system conducts a local search in the intensified search area. This study applies CEUS to an image processing filter design problem that involves both quantitative (filter output accuracy) and qualitative (filter behavior) criteria. Experiments have shown that the proposed CEUS can design image filters in accordance with user preferences, and CEUS interacting with a non-naive user enhanced the initial global search so that it converged and found a reasonable solution more than four times faster than a non-interactive search.

1. Introduction

Designing a good fitness function is crucial for finding good solutions to real-world problems with evolutionary computation (EC) algorithms. A function based on the ideal model may not be sufficient to solve such real-world problems, and ambiguous complemental subfunctions may be necessary to obtain practical quasi-optimal solutions. Such additional criteria are not always apparent in advance, and it is intractable to redesign the fitness function during the search.

Interactive EC (IEC) provides a way to solve problems that require implicit human preferences and emotions to evaluate solutions [29]. In IEC, solutions are evaluated by a human, and explicit fitness functions are not used in general IEC models. Various IEC applications have been proposed, such as computer graphics [8,10,30] and musical composition [2,5,31].

Most of real-world problems essentially require optimization based on both explicit and implicit criteria. Although some studies on IEC have been conducted to estimate user preferences and reduce user fatigue in evaluating solutions [18,20,1], only a few attempts have been made so far at optimization based on both explicit and implicit criteria.

In addition, for EC-based problem-solving systems, there is a strong demand for allowing users to control the search more flexibly and effectively incorporate human heuristics into the search. For instance, a user may want to let the system conduct a global search at the beginning, manually select a few promising solutions during the search, and then let the system conduct a local search of the area near the selected solutions. Alternatively, a user may want to manually construct a solution at the beginning of the search and then let the system search for better modified solutions. Originally, EC allows the user to modify the search result manually and then reuse the modified result as an initial population. Such operations are conducted implicitly and naturally outside EC systems. Most EC applications allow users to choose a solution from those solutions obtained by the optimization only after the search. This study considers such temporal user operations in EC and IEC as *dynamic search role changes*. Usually, a system and its user have fixed roles, such as in general IEC models, the system reproduces solutions and the user evaluates them in every generation. However, a combination of temporal, dynamic search role changes, and learning based on user operations should allow non-interactive EC (Non-IEC) to

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incorporate user preferences and implicit heuristics into the search and IEC to reduce the user's solution estimation workload.

This study proposes a cooperative EC method between a user and system (CEUS[1]) for problems involving explicit and implicit optimization criteria. The proposed CEUS allows the user to dynamically change the allocation of search roles between the system and user, resulting in simultaneous optimization of qualitative and quantitative objective functions without increasing user fatigue. For instance, CEUS allows the user to evaluate solutions or perform a genetic operation at any time. It also allows the user to carefully redesign solutions or evaluate them in every generation.

These advantages of CEUS are achieved by a combination of user evaluations predictions and integration of IEC and Non-IEC. CEUS estimates user preferences with Case-Based Reasoning (CBR) [21,23]. Although some methods have already been proposed for using predictions to alleviate user fatigue, these methods require a certain amount of training data and cannot handle changes in user preferences and intuitive conditions. CBR allows predicting user preferences only from a few user operations that are acquired as cases, and it manages changes in user preferences by forgetting old cases when conflicts between cases would occur.

This study focuses on image filter generation, where the problem is to approximate an unknown image filter from a combination of known primitive filters. In previous studies [3,16,24], an image filter was automatically designed without user interactions. However, for professional users, automatic design is not always useful because it requires significant processing time and does not accept user operations or requests during the search. In addition, automatically designed filters may not be amenable to user changes in their structure or parameters; revising just a small part of such a filter can damage its function or performance. Therefore, user operations should be accepted during rather than after the search. However, general IEC requires the user to evaluate solutions in every generation. Since many generations are necessary to find a good solution in image filter design, using IEC for image filter design is not realistic.

This study proposes an image filter design method IFD_{CEUS} that uses both explicit and implicit criteria corresponding to filter quality and behavior, respectively, and is based on CEUS. IFD_{CEUS} allows users to switch search roles between the system and user, which incorporates user preferences and implicit knowledge into the search while avoiding an increase in user fatigue. For instance, users familiar with image processing can directly edit the solution structure, while other users can choose appropriate solutions by examining the output images.

Our experiments show that IFD_{CEUS} can respond to various user demands for cooperative search. In particular, IFD_{CEUS} allows the user familiar with computer graphics to design a filter of reasonable quality on the basis of the user's preferences or heuristics more than four times faster than Non-IEC.

The rest of this paper is organized as follows. Section 2 presents a survey of IEC and the image filter design problem. An image filter design method based on user-system cooperative evolution is proposed in Section 3. Section 4 provides experimental results and discussions. Finally, Section 5 presents our conclusions.

2. Related work

2.1. Interactive evolutionary computation

To alleviate the problem of human fatigue, which is a difficult technological hurdle in IEC, the following approaches have been investigated: user interface improvements, EC search performance improvements to reduce the total search cost, and user evaluation predictions.

Predicting of users' subjective evaluations is a promising approach to alleviate user fatigue in solution evaluation. For example, Nishio proposed a fuzzy-based method to predict user preferences [18]. Johanson and Poli presented Interactive Genetic Programming with a Neural Network (NN) based automatic fitness rater [9] for music generation. In addition, Biles et al. employed NN based fitness estimator for improvising jazz solos [4].

Osaki proposed methods for estimating user preferences on the basis of Euclidean distance and NN [20]. Gong et al. presented Interactive GA (IGA) with radial basis function network for fitness estimation [6]. Amamiya et al. proposed a method to divide a design variable space into preferred and non-preferred areas with Support Vector Machine (SVM) [1]. Llora et al. presented a support vector machine for modeling user fitness [12]. Sun et al. proposed surrogate model to approximate user's fuzzy fitness evaluation by a support vector classification machine and a support vector regression machine [27]. Furthermore, Sun et al. proposed semi-supervised learning assisted IGA to reduce the evaluation burden of a user [26].

Combining IEC and Non-IEC search is also an effective approach to reduce the user's evaluation work. Kitamoto proposed a pipeline-type Genetic Algorithm (GA) that does not use a concept of generation alternation [11]. In this method, the user evaluates some solutions, while genetic operations are applied to others. Two pipelines connect the two main processes and enable the processes to be performed in parallel. Tabuchi proposed a model combining IEC and Non-IEC search in which the user evaluates solutions after every 100 generations of a Non-IEC search [28].

2.2. Image filter generation

Image processing is one of today's most rapidly evolving areas of information technology, with a growing number of applications in various areas of science and engineering. Although many advanced technologies and research studies in image processing have reached the point where they are practical, trial and error are still necessary to design an image processing program even for professionals.

Various methods have been proposed for improving and automating image processing filter design algorithms. Nagao proposed EC-based methods that approximate an unknown image filter with a combination of known primitive filters connected in a list, tree or graph [3,16,24,17]. The filter structure is obtained by EC algorithms such as GA and Genetic Programming. The methods do not require the help and interactions of human experts and are applicable to various image processing filter generation problems.

Nagao's methods produce multiple filters with almost the same fitness value and different image processing characteristics in problems where it is hard to generate an optimal filter. For instance, in a traffic sign extraction problem [14,15], it is quite difficult to generate an ideal filter that extracts traffic signs even in environments with backlighting or occlusion and prevents miss detection of background areas with colors similar to the signs. Therefore, Nagao's methods generate various semi-optimal filters that have similar fitness values and different image processing behavior; some filters avoid noise but do not always find the signs, while other filters that do not miss the signs produce noisy outputs. For practical use, a user must choose the most appropriate semi-optimal filter; however the method may not produce a filter that is adequate for the user's purpose. Although users' requirements should be incorporated into a fitness function for these methods, it is difficult to predict the output filters' behavior in advance on the basis of the method and properties of the problem. Some mechanisms are necessary to dynamically incorporate ambiguous user demands into the search.

[1] CEUS is an acronym for Cooperative Evolution between a User and System.