Interactive Evolutionary Computation

— Cooperation of computational intelligence and human *KANSEI* —

Hideyuki TAKAGI

Kyushu Institute of Design, Dept. of Acoustic Design

4-9-1, Shiobaru, Minami-ku, Fukuoka 815-8540, Japan

Phone&FAX: +81-92-553-4555, E-mail: takagi@kyushu-id.ac.jp

Keywords: interactive evolutionary computation, artistic applications, engineering applications, educational applications, human-computer interface.

***Abstract*— In this paper, we overview Interactive EC (evolutionary computation) research, showing the status quo and its remaining problems. The interactive EC technique optimizes systems from human interaction with computers. Recently, interest in this approach has increased in many application fields that we categorize into the artistic, engineering, and educational fields. We then overview the research within each field. Finally, we show several trials to address the problem of human fatigue.**

1 Introduction

1.1 Computational Intelligence in the Past Decade

One of the most significant keywords in computational intelligence research in the past decade is the cooperative technology of fuzzy systems (FS), neural networks (NN), and evolutionary computation (EC). Since the cooperative technology was proposed, it has become a practical technology widely used in the real world.

Auto-designing FS using NN, which started from NN-driven Fuzzy Reasoning [1, 2] in 1988, have been widely used for consumer products and industrial equipment since 1991.

FS is also used for NN; for example, the NARA system is a structured NN based on a fuzzy IF-THEN structure. Generally, a priori knowledge is frequently described by fuzzy IF-THEN rules. The NARA system is a structured NN designed according to the IF-THEN rule structure. The load of NARA is lower than that of a conventional NN, because a priori knowledge of the given task is embedded into the NN structure. Also, analyzing the structured NN and increasing its performance becomes easier [3].

[0]This paper appeared in the Proceeding of 5th Int'l Conf. on Soft Computing and Information / Intelligent Systems (IIZUKA'98), pp.41-50, Iizuka, Fukuoka, Japan, World Scientific (October 16-20, 1998).

Much research of auto-designing FS using GA has been proposed since Karr's paper in 1989 [4]. Nowadays, all membership functions in antecedent parts, consequent parameters, and the number of fuzzy rules can be auto-designed simultaneously by GA [5]. Korean companies use FSs and neuro-fuzzy systems in their consumer products. Some of their FSs and neuro-fuzzy systems were designed by GA since 1994 [6, 7].

On the contrary, FS is used to dynamically tune GA parameters. GA performance deeply depends on GA parameters, such as population size, crossover rate, and mutation rate. Their optimal values change according to the searching situation. The problem is that there is no deterministic method to optimize the values. However, we have qualitative knowledge of the relationship or tendency between GA performance and GA parameters. Dynamic Parametric GA is a GA whose parameters are controlled by fuzzy rules describing the qualitative knowledge aiming to optimize the GA parameters in each generation [8].

Cooperative technology of NN and GA was proposed in 1990s, also. Korean air conditioners of LG Electronics are controlled by an RCE type of NN. The configuration and learning of the NN are conducted by GA, which realizes a user trainable function [7].

It is generally difficult to apply GA to an on-line process control. Suppose that a control value is applied to the on-line process to select the best control value. Once the control value is applied to the real process, the process situation changes until the best one is selected. One solution is to make an NN learn the input-output characteristics of the process and embed the trained NN into a fitness function as a process simulator. The best individual is obtained by the process simulation using the NN, and only the best one is actually applied to the on-line process. This approach was applied to hydroponics system [9].

1.2 Humanized Technology

NN and EC are biologically inspired technologies. Knowledge processing dealt in AI or fuzzy reasoning is a model of a human function. This analytical approach, i.e. modeling of human functions, has been the major part of computational intelligence research, so far.

Although there is no doubt that this analytical approach plays important role in future computational intelligence research as well as prior research, we do not believe that this approach is the only one in the computational intelligence research. When developed techniques are applied to application tasks, maximizing the performance of the system is the final goal in most cases. In this case, the performance of systems embedding human function itself is frequently expected to be better than that embedding the model of human function.

We think that the cooperation system between human and computational intelligence becomes one approach in computational intelligence research. This is a concrete solution to humanized technologies. Interactive EC is one such technology.

This paper mainly provides an overview of interactive EC applications, pointing out the possibilities and remaining problems, and comments on its future research direction.

2 Interactive EC

The interactive EC is a technology that optimizes systems based on human subjective evaluation. Simply stated, the EC fitness function is replaced by a human.

Humans have two aspects: knowledge and *KANSEI*. Conventional AI has mainly focused on the former. *KANSEI* is the total concept of intuition, preference, subjectivity, sensation, perception, cognition, and other psychological processing functions. The interactive EC is a technology that embeds the *KANSEI* into system optimization.

For example, suppose we wish to tune a music synthesizer to create a timber between a violin and clarinet or we wish to create graphic art that matches the emotion of our living room. Since these tasks can be seen as the optimization parameter of the music synthesizer and computer graphics (CG), we can apply numerical optimization techniques to the tasks.

For these cases, there is no measure for the evaluation of the optimization techniques except the measure in the human mind. The interactive EC is the optimization technique based on the subjective scale. Humans evaluate the distance between the goal and a system output in psychological space. On the other hand, EC searches in a parameter space. The interactive EC is a system that humans and EC cooperatively optimize a target system based on the mapping relationship between the two spaces.

3 Applications of Interactive EC

Main objective of this paper is to provide an overview of the research on the interactive EC. We categorize its application fields into three categories and introduce each research, although this paper cannot introduce every paper.

3.1 Artistic Applications

3.1.1 Graphic Art

Image creation was the major application in the initial stage of the Interactive EC research. The first application was conducted by Dawkins, [10, 11] who created a stir in evolutionary theory with the concept of the selfish gene. Following his work, research on image creation based on the interactive EC was presented in art and artificial life; interactive EC-based drawing lines, such as morphological lines of insects [12], plant lines based on the L-system [13], and face drawing [14, 15, 16]: interactive EC-based CG, such as for creating [17, 18, 19, 21, 22, 23, 24], 3-D CG rendering of artificial life art [25], and animal and plants CG [26]. 3-D CG design and music allocation in the CAVE system use the interactive GP (genetic programming) [27, 28, 29], though their main objective is not art itself but to research the virtual environment. Sections 3.1.2 and 3.1.3 are included in this category, also.

Sims created CG art by using interactive GP. They iteratively evolved dynamic equations by subjectively evaluating graphics created by the equations and obtained what they expected [17, 18, 19].

Figure 1 is an example of an image obtained by interactive GP and its tree expression of the equation created by Unemi. Unemi's SBART system displays 20 images, and a human operator chooses the best images as parents. Another 20 images are generated from these parent images. The human operator then gives a two-value evaluation which corresponds to artificial mating. This type of interactive EC is called simulated breeding [20].

The interactive EC is used to generate animated motion. Ventrella applied the interactive EC to generate entertaining motion of a deformed body consisting of only lines with the interaction with animator [30, 31].

There are several ways to create new offsprings. One of interesting methods is to predict CG position using auto-regression model which is frequently used for time sequential analysis. Graf et al. applied this technique to modify the shape of CG model [32].

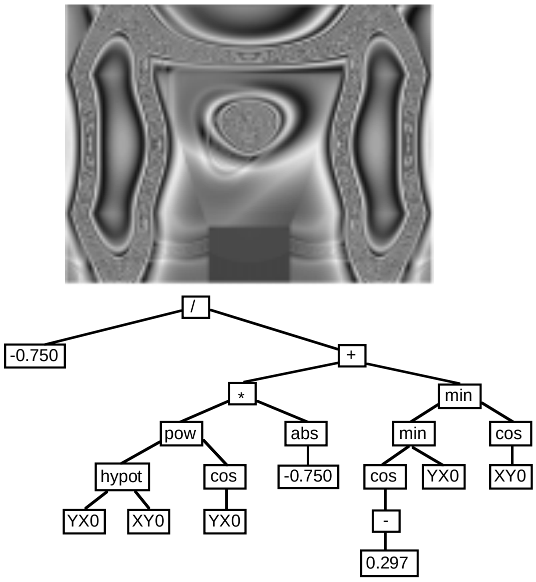

Figure 1: SBART: Simulated breeding based art. Genetic programming evolves the tree expression of the equations that creates graphc art. SBART is obtained at URL:http://www.intlab.soka.ac.jp/˜unemi.

3.1.2 3-D CG Lighting

3-D CG is a simulation of a photograph. Lighting conditions such as the position and type of light sources, luminous intensity, and color cause completely different CG impressions just as in photography. Unlike professional photographers, we can only subjectively evaluate the quality of CG art since we do not have the lighting knowledge and technique to obtain a desired impression. Since the experience level of CG users range from professional to business to hobby nowadays, the role of a CG lighting support system which influences CG quality becomes important. We applied the interactive GA to the lighting support [33, 34].

The 3-D CG in our first experiment used 3 lights with 2 type of an infinite and omnidirectional lights, 16 levels of intensity, on/off, and coordinates in a 3-D space. They are coded in 90-bit chromosomes in the first experiment. The second experiment uses 113-bit GA coding by adding a color condition, which becomes more difficult to search. The tasks of two experiments are to optimize the lighting parameters and match the lighting CG impression to the given design concept.

The Sheffé's paired comparison method, one of subjective test methods, was conducted to evaluate which a lighting approach created a well-matched CG image to the given design concept.

The test result shows that the interactive GA is not significantly useful for experienced CG designers but for CG designers with little or no experience. Experienced designers' explicit intentions shortens their manual lighting times, while amateurs' designs, often accomplished by trial and error, takes more time than that of the interactive GA.

The originality of this work is to provide a method to quantitatively evaluate the effect of the interactive GA by using subjective and statistical tests, while prior works just applied the interactive EC to several tasks or showed its capability to create images or sound. We believe that it shows one important approach to the research supporting human creativity where quantitative evaluation seems to be difficult.

3.1.3 Industrial Design

Since most industrial designs are a product of CAD systems, it is easy to imagine that the industrial design is created from design parameters, such as length, angle, coordinates, color number and so on. The interactive EC is used to optimize these CAD parameters.

Some applications include the shape design of a concrete arch dam [35], suspension bridges [36], cars [37, 38], and one-piece dresses [39, 40]. Interactive EC based layout design [41, 42, 43] which can be applied to several fields such as hypercards layout on a display, GUI display design, or office layout, would be categorized in this section.

Another practical image application is composing montage picture [44], though this is neither graphic art nor industrial design.

3.1.4 Music

The interactive EC was applied to the music field such as melody production [45] and rhythm production for percussion section [46].

Figure 2 is the GenJam system developed by Biles et al., and it inputs rhythm section parts and chord progressions and outputs jazz melody. A human mentor hears the melody and pushes the appropriate button when he/she feels that the melody part is either good or bad. If one evaluation is given when the entire melody is played, it takes too much time for total interactive EC process and fatigues the human mentor. Their approach allows the human mentor to evaluate the created melody part by part and evolves a melody phrase rather than the entire melody, which shortens the evaluation time. It provides the interactive EC applications to time sequential signals with useful evaluation information.

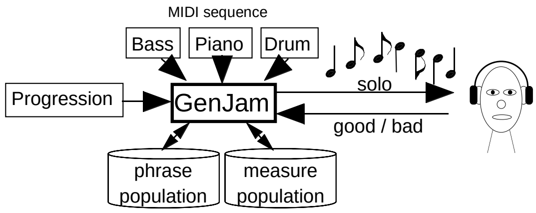

Figure 2: GenJam system: interactive jazz solo generator.

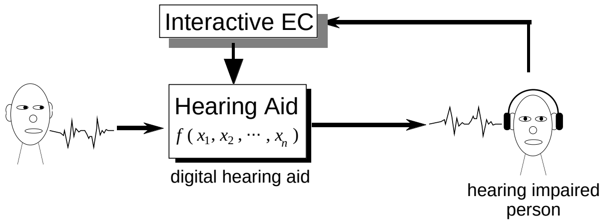

Figure 3: Auto-adjusting a digital hearing aid. The interactive EC optimizes the parameters of signal processing based on how a hearing impaired person hears.

3.2 Engineering Applications

While earlier applications of the interactive EC were biased toward the artistic fields, other application fields, such as engineering, have been developed and expanded recently [47].

3.2.1 Speech Processing

Our motivation was to evaluate the applicability of the interactive EC to tasks which sequentially display system outputs to a human operator because earlier works dealt with images which are easier to compare spatially.

Our task is to design an FIR filter that audibly reduces speech distortion and a GA optimizes the eight filter parameters based on a human operator's hearing evaluation. The input distorted signal to the experimental system is made by an IIR filter that suppresses the power of normal speech in the low frequency range where voice formants exist.

The recovered speech that the FIR filter designed by the interactive GA is evaluated through subjective tests. The result of the subjective tests shows that the quality of the recovered speech is significantly better than original distorted speech not only for the interactive GA operators but also for other subjects as well. It means that the filter was not designed for the operators' self-satisfaction and that the interactive GA is a useful technique to recover the distorted speech [48, 49].

The interactive EC can be also used for speech synthesis. Speech has two aspects: phonetic and prosodic aspects. A voice impression is expressed by the prosodic parameters such as pitch, amplitude, duration, and speed. Sato applied the interactive EC to modify the prosodic parameters to change voice impressions to reflect peace, anger, joy, etc. [50].

3.2.2 Hearing Aid

The wide use of hearing aids encourages older people to enjoy their lives in an aging society. Although the psychological hesitation of its use still remains, hindering its wide and natural use, an essential problem has not yet been solved: natural sound quality and fitting. Recently, digital hearing aids using digital signal processing technology have been developed to address the technical problem.

Although the digital hearing aids have greater potential than conventional analog ones, its fitting technique to maximize its performance to a wide variety of users has not yet been developed. The essential reason is that only the user can evaluate the hearing quality. TEnen the most qualified doctor in the world cannot perceive and evaluate a fitted hearing aid for a hearing impaired person as the person himself. Unfortunately, generally speaking, hearing impaired persons cannot tune signal processing parameters of hearing aids.

Here, we are developing the technique that automatically tunes the parameters of the signal processing according to the user's hearing perception based on the interactive EC [51] (See Figure 3.)

This approach has a unique feature that conventional hearing aid systems do not have. So far, medical doctors or engineers measure the hearing characteristics of hearing impaired people, such as with an audiogram, and then the hearing impaired people get their hearing aids fitted. When the fitting is incomplete, they return to their doctors or specialists for a fine adjustment. This approach has two problems: the measured hearing characteristics represent very few parts of human auditory system, and the measurement takes time. On the contrary, our new auto-fitting method tunes the hearing aid parameters based on the how the hearing impaired persons hear, which is the comprehensive characteristics from auditory peripheral to central nerves, without measured their hearing characteristics, basically.

3.2.3 Virtual Reality

The interactive EC may solve the problem of determining which factor gives us VR (virtual reality). Imagine the VR control of an arm wrestling robot (see Fig-

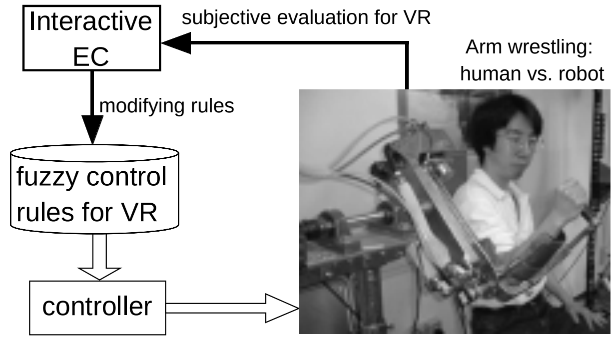

Figure 4: Virtual reality of arm wrestling. Fuzzy logic controller evolves based on human perception of virtual reality.

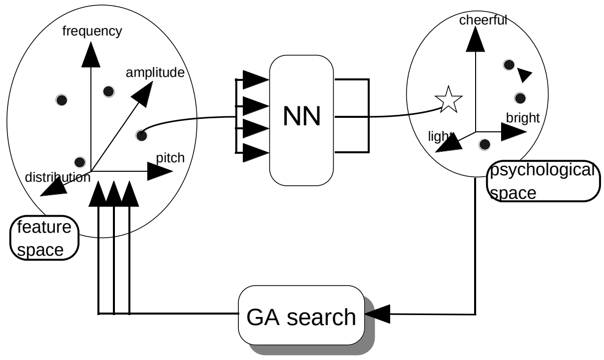

Figure 5: Media database can be retrieved by reverse-mapping from the psychological space of a user to the physical space of the media in the database after obtaining the opposite mapping relation.

ure 4.) Whether a human player feels VR in the arm wrestling robot depends on the control rules.

To analyze the factor of force perception, we obtained the control rules to win using a classifier system in the first stage. When the arm wrestling robot pushes a human player forward, the control rule of the classifier system is awarded. During the fighting, the rules evolve using GA operations at each 1,000th step, and finally 20,000 rules were obtained. The second step is to compile the 20,000 rules into several fuzzy rules to help our analysis, and we finally obtained 8 fuzzy rules using fuzzy knowledge acquisition techniques based on GA [52].

The final stage is that the interactive EC modifies the fuzzy control rules for winning and obtains those for VR. Since only a human player can evaluate how he or she feels as if the opponent is a human, we can use the interactive EC to modify the parameters of the fuzzy control rules. It is expected that the VR factors of the force perception may be explicated by analyzing the difference between fuzzy control rules for winning and those for VR.

3.2.4 Database Retrieval

Suppose we wish to retrieve an image or music from a huge database or the internet. In most cases, the images or music that we want to retrieve is not a specific one but one that is suitable for a certain purpose or that is preferable. Keyword retrieval can rarely be used for this purpose, and we often do not know what images or music are in the huge database or on the internet.

A technology which determines a more suitable or preferable image or music according the evaluation of retrieved ones is required for this type of media retrieval. The interactive EC can be applied to this task.

The EC searches images or music on their feature space, while human evaluates them on a psychological space. A mapping method from the psychological space to the feature one is needed to find the best matched images or music to the target point on the psychological space. Generally speaking, the dimension number of the psychological space is so far less than that of the feature space that it is difficult to map in this direction. On the other hand, the mapping in the opposite direction is easier.

NN is suitable to map from an m dimensional space to an n dimensional space where ($m \leq n$). We may be able to use the learned NN for the inverse mapping from the psychological space to the feature space. Here, GA is used for the inverse mapping (Figure 5). Of course, there are several points that correspond to one point on the psychological space due to one versus multiple mapping. This means that multiple images or music which give us same impression can be retrieved, which is desirable for media retrieval.

When the retrieved medium does not match the searching impression, we have two choices: pretrial and retrieval with the different coordinate on the psychological space. Usually, both are combined and used. The interactive EC is used for the latter [53, 54].

3.2.5 Knowledge Acquisition

When a new product is planned for development, the marketing concept of the product is first decided. Then, several product attributes are adjusted to match to the product concept. The problem is adjusting the attributes to the concept. Their relationship may be obtain from marketing questionnaires. But, noise in the questionnaire data is inevitable.

Terano et al. applied the interactive EC technique for knowledge acquisition from questionnaire data of consumer products [55, 56, 57, 58]. They used 2,300 questionnaire data sets on oral care products such as toothpaste, and each data set had 16 attributes such as "good taste and flavor," "good for family use," "liquid type," "reliable manufacturer," etc. Their objective was to acquire reliable rules with fewer number of attributes that characterize each oral care product. Human interaction was conducted to choose better and more reliable rules that EC generates, and the chosen rules were used to generate new offspring rules. They reported that both the number of attributes in the obtained rules and the size of rule trees dramatically decreased and that they could obtain certain marketing strategy.

Venturini et al. applied the interactive EC for data mining, too [59].

To speed up the interactive EC, Tabuchi et al. did not allow human interaction in every generation but in every 100th generation [60]. They use 8 types of damage data of stainless steel, and each data set is described using 17 measured parameters. Their task was to obtain clustering rules that input these 17 parameters and output the type of the damage using GP techniques. They reported that rules generated by GP were dramatically changed after a human operator interacted to the obtained rules at 100th and 200th generation and showed the robustness to the noisy data.

3.2.6 Image enhancement

Image enhancement for medical images is helpful and necessary for medical doctors to detect diseased parts easily and correctly. Although the performance of the image filters for medical image enhancement is evaluated by only humans, especially medical doctors, the filters are poorly designed and not yet optimized. The best enhanced image might depend on doctors' preference. This is a good task for the interactive EC.

Poli et al. applied the interactive GP to design image filters that enhances MRI (magnetic resonance image) and echo-cardiographic images [61]. The GP creates math equations that describes the image filters according to the human's visual distinguishability.

Another approach is to determine the sequence of image filtering. Due to the wide spread of digital cameras, image scanners, PCs, and internet, the possibility that amateurs work with images has increased. Most amateurs use retouching software that prepares several image filters. Generally speaking, different orders of image filtering results in differently retouched images, i.e. an image filtered by A, B, and C is different from an image filtered by C, B, and A. Although it may be difficult for amateurs to decide on a filtering sequence, it is not difficult for them to evaluate which image is better or preferable.

Mutoh el al. applied simulated breeding, which corresponds to the interactive EC with 1 bit evaluation, to auto-generate the sequence of image filtering [62].

3.3 Education, Edutainment, and Therapy

Recently, the interactive EC has widely applied to several fields. One of such new application field is an educational field.

3.3.1 Writing Support System

Since the interactive EC displays several individuals, sometimes they inspire a human operator; it implies that the interactive EC is useful to stimulate human creativity. This inspired creativity obtained during the interactive EC iteration is more important for education than EC outputs.

Kuriyama et al. use this characteristic of the interactive EC for writing support system for children [63]. Composing a story is more important and difficult than writing sentences, and children in the lower classes are frequently puzzled.

Their system displays 24 pictures and lets a child choose two sets of a four-picture sequence; this sequence is the writing story. Their system then creates several four-picture sequences using the selected parents' four-picture sequences and GA operations. The child chooses two better four-picture sequences in the next generation. This iteration is repeated until a satisfactory story is written.

3.3.2 Games

Similar to educational applications, edutainment or games are a good application field of the interactive EC, because it is much easier for children to select better ones than give detail instruction or write program. This selection corresponds to an award of reinforcement learning, and the interactive EC can train the control rules or mechanism of a target system similar to reinforcement learning.

Development of moving robots for children is a type of this interactive EC application. For example, Lund et al. developed an NN based robot, and the connections of the NN that inputs robot sensor information and outputs movement control values are evolved according to the selection of better movement robots by children [64, 65].

Pagliarini et al. developed several games. The previously mentioned robot is one of them. Other games include an artificial life survival game, painting graphics based on NN evolution, and drawing faces [64].

Their drawing face software is used for not only edutainment but also mental therapy. Italian therapists joined them and started a project to apply the software to encourage mental diseased children to understand face expression [64].

4 Remaining Problems

The biggest remaining problem is reducing human fatigue. Since a human operator cooperates with tireless computer and evaluates individuals of EC, the interactive EC process cannot be continued for many generations. This is the biggest problem prohibiting the practical use of interactive EC.

The secondary problem derived from the fatigue problem is that the interactive EC searches the goal with a smaller population size and generates fewer number of searching generations than a normal EC search.

The good news is that many interactive EC tasks do not require a large number of generations to achieve satisfactory results. Due to the good initial convergence of EC, unlike gradient methods, the human fatigue problem may be fewer than gradient searches. Task characteristics of subjective searches and numerical/combinational optimizations are quite different, and the former does not have the exact optimum point. This is why it is sufficient for the human evaluated task to reach to an optimum 'area' rather than one point, which searches out a satisfactory solution with fewer searching generations.

Nevertheless, we must solve the fatigue problem to make the interactive EC fit for practical use. There are three approaches to solve this problem: improving the input interface, improving the display interface, and quickening EC convergence [66].

4.1 Improving the Input Interface

Psychological fatigue is deeply influenced by the ease of evaluating the outputs of the interactive EC and feeding back the evaluation values to the EC. For example, as we cannot exactly distinguish the difference between 62 and 63 points in 100 levels rating, to determine 62 or 63 points of our subjective evaluation to individuals causes psychological fatigue.

It is expected that human operators can daringly evaluate the EC individuals and therefore reduce their psychological fatigue when five or seven levels rating is used instead of high order level rating. Such psychological *discrete* input method that distinguishes from 100 or 200 levels rating is proposed [67, 68, 69]. Since the rougher level rating results higher level of quantization noise, the EC convergence may become worse. We evaluated the total performance of the proposed method by taking into account both the advantages and disadvantages.

The subjective test and statistical test have shown that the proposed method significantly reduces human fatigue. A simulation experiment has shown that the worse convergence becomes significant when the EC search reaches several 10s or 100s of generations. It has shown that the poorer convergence in practical interactive EC generations, such as less than the first 10 or 20 generations, is not problem. This simulation result supports the result of the subjective test [67, 68, 69].

An interesting input method for time sequential display was proposed. When music or sound is displayed as interactive EC individuals, it must be displayed to a human operator sequentially. Therefore, its evaluation time per generation becomes longer than that of image individuals which can be spatially evaluated. To shorten the evaluation time, GenJam allows the user to perform evaluations during created jazz melody rather than after the entire melody is played [45]; the human mentor pushes 'good' or 'bad' key during the melody, and EC evolves a melody phrases after one melody is played, i.e. one generation uses only one melody.

4.2 Improving the Display Interface

If the display order of the interactive EC is taken into consideration, it is expected to become easier for human to evaluate individuals rather than from random displays. For example, if EC displays individuals roughly in the order of human evaluation, human operators can evaluate them by comparing neighbor individuals, which is expected to reduce human fatigue. Or, when similar evaluated individuals are grouped and displayed, it is expected to roughly evaluate individuals.

To realize such a display, a system needs to learn the evaluation characteristics of the human operator. Methods to predict the human evaluation characteristics using NN [70, 71, 66, 72] and using Euclidean distance [66, 72] were proposed. Their simulation test showed the higher predictive capability of the two methods, but a subjective test was not significantly effective in reducing human fatigue [72]. Further research is needed.

4.3 Quickening EC Convergence

Quickening EC search significantly reduces human fatigue. Although any fast EC search methods are applicable, methods whose convergence in early generations that are especially fast are useful for the interactive EC. As previously mentioned, the practical evaluation generation of the interactive EC is less than first 10 or 20 generations. Quickening methods that work later, such as second order convergence of gradient methods near global minimum, are not suitable.

A new elitist method by approximating the searching surface using convex curve was proposed and applied to the interactive EC. A simulation shows the significance of a fast convergence, but subjective tests shows the effect of a fast convergence did not significantly reduce human fatigue [66].

Another research theme on the interactive EC is to develop an EC technology which searches and converges with a small population. Due to human fatigue, the display size for spatially displayed images, and the capacity of human memory for sequentially displayed individuals, small numbers of individuals have to be used for EC search. An EC that works well with smaller population sizes has not been developed yet.

5 CONCLUSION

FS, NN, and EC became popular technologies in 1980s, and their cooperative technologies became popular since late 1980s. These technologies have become practical and been used for several products in the real world.

We believe that humanized technology follows these Soft Computing technologies. As we also believe that the interactive EC will become an important technology, we have given an overview of the status quo of this research and have shown a wide variety of its applicability and capability.

The biggest problem of the interactive EC is human fatigue which still hinders the practical use of the technology. As researcher begin addressing this problem, we hope that it is solved and that interactive EC is widely used in the real world.

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