Improved harmony search from ensemble of music players

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Knowledge-Based Intelligent Information and Engineering Systems

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Abstract. A music phenomenon-inspired algorithm, harmony search was further developed by considering ensemble among music players. The harmony search algorithm conceptualizes a group of musicians together trying to find better state of harmony, where each player produces a sound based on one of three operations (random selection, memory consideration, and pitch adjustment). In this study, one more operation (ensemble consideration) was added to the original algorithm structure. The new operation considers relationship among decision variables, and the value of each decision variable can be determined from the strong relationship with other variables. The improved harmony search algorithm was applied to the design of water distribution network. Results showed that the improved algorithm found better solution than those of genetic algorithm, simulated annealing, and original HS algorithm.

1 Introduction

Human beings have developed new technology by imitating natural or behavioral phenomena on the earth. Likewise, optimization researchers in various fields have developed better algorithms by analogizing solution-searching processes to biological and behavioral phenomena [1-4]. Genetic algorithm (GA), which is one of the most popular phenomenon-inspired algorithms, has performed good job in various optimization problems, sometimes finding better solutions than those of mathematics-based algorithms although it does not completely mimics every mechanism and structure of DNA or RNA [5].

Recently, another phenomenon-based algorithm, harmony search (HS), which mimics music improvisation process has been proposed [6]. The HS algorithm has been successfully applied to various real-world optimization problems such as structural design [7-8], water network design [9-11], traffic routing [12-13], fluid leakage detection [14], and model parameter calibration [15-16]. HS even found better solution within much less time for water pump switching problem than branch and bound method originally coded in IBM subroutine or Microsoft Excel Solver [17].

While the original HS algorithm uses three mechanisms (random selection, memory consideration, and pitch adjustment) as each musician's performing behavior, there is still a possibility to include more mechanisms by imitating real music performance. In this study, one more mechanism, named ensemble consideration, is devised to consider the relationship among musicians. Just like certain musician has

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stronger relationship with specific musician in a group, this mechanism enables the algorithm to combine closely related variables together.

2 Harmony Search Algorithm

HS algorithm conceptualized a behavioral phenomenon of music players in improvisation process, where each player continues to polish its tune in order to produce better harmony.

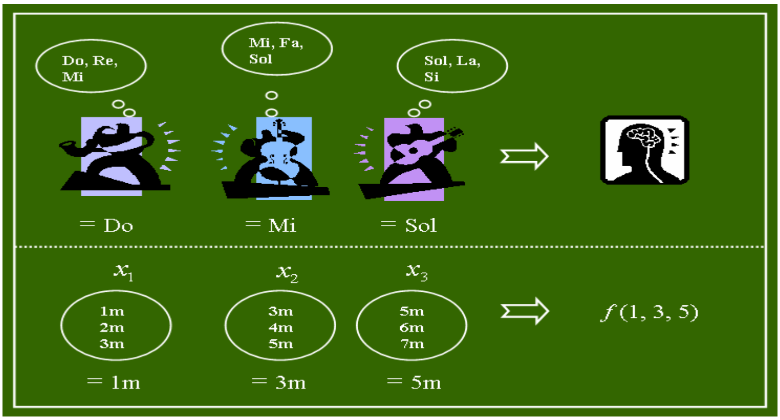

Fig. 1. Analogy between Improvisation and Optimization

Figure 1 illustrates the analogy between improvisation and optimization. Each music player (saxophonist, double bassist, and guitarist) in the figure can be matched with each decision variable (x_1, x_2, and x_3), and the candidate range of each music instrument (saxophone = {Do, Re, Mi}; double bass = {Mi, Fa, Sol}; and guitar = {Sol, La, Si}) can be matched with the candidate range of each variable value (x_1 = {1, 2, 3}; x_2 = {3, 4, 5}; and x_3 = {5, 6, 7}). If the saxophonist sounds the note Do, the double bassist sounds Mi, and the guitarist sounds Sol, these notes together becomes a new harmony (Do, Mi, Sol). If this new harmony has good quality, it is kept in each musician's memory. Likewise, if a new solution vector (1m, 3m, 5m) is generated in optimization process and it has good fitness in terms of objective function, it is kept in computer memory. This activity is repeated until (near-) optimal solution is reached. The HS algorithm is explained in detail in the following steps.

2.1 Problem Initialization

At first, the problem is formulated as the following optimization form:

$$\text{Optimize } f(\boldsymbol{x}) \tag{1}$$

$$\text{Subject to } x_i \in \mathbf{X}_i, i = 1,2,\ldots, N . \tag{2}$$

where $f(\cdot)$ is an objective (or fitness) function (= aesthetic standard); $\boldsymbol{x}$ is a solution vector (= harmony) composed of each decision variable x_i (= each music instrument); $\mathbf{X}_i$ is the set of candidate values (= set of candidate pitches) for each decision variable x_i, which becomes $\mathbf{X}_i = \{x_i(1), x_i(2), \ldots, x_i(K)\}$ ($x_i(1) < x_i(2) < \ldots < x_i(K)$) for discrete decision variables; N is the number of decision variables (= number of music instruments); and K is the number of candidate values for the discrete decision variables (= number of candidate pitches for each instrument).

The HS algorithm's parameters are also specified in this step: HMS (harmony memory size) is the number of solution vectors simultaneously existed in harmony memory; HMCR (harmony memory considering rate; 0 ≤ HMCR ≤ 1) is the rate of memory consideration; PAR (pitch adjusting rate; 0 ≤ PAR ≤ 1) is the rate of pitch adjustment; and MaxImp (maximum number of improvisations) is the maximum number of objective function evaluations.

2.2 Harmony Memory Initialization

Harmony Memory (HM), a matrix shown in Equation 3, is initially filled with as many randomly generated solution vectors as HMS. Corresponding function value of each random vector is also stored in HM.

$$\left[\begin{array}{cccc|c} x_1^1 & x_2^1 & \cdots & x_N^1 & f(\boldsymbol{x}^1) \\ x_1^2 & x_2^2 & \cdots & x_N^2 & f(\boldsymbol{x}^2) \\ \vdots & \cdots & \cdots & \cdots & \vdots \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_N^{HMS} & f(\boldsymbol{x}^{HMS}) \end{array}\right] \tag{3}$$

2.3 New Harmony Improvisation

Next, a new harmony, $\boldsymbol{x}' = (x_1', x_2', \ldots, x_N')$ is improvised by the following three mechanisms: random selection, memory consideration, and pitch adjustment.

Random Selection. For the value of each decision variable x_i' in the new harmony vector, as a musician plays any possible pitch within the candidate range of musical instrument (for example, {Do, Re, Mi, Fa, Sol, La, Si, Do+} in Figure 2), the value can be randomly chosen within the value range $\mathbf{X}_i$ with a probability of (1-HMCR).

$$x_i' \leftarrow x_i' \in \boldsymbol{X}_i = \{x_i(1), x_i(2), \ldots, x_i(K)\} \quad \text{w.p.} \quad (1 - HMCR) \tag{4}$$

Fig. 2. Playable Range of Musical Instrument

Memory Consideration. Instead of the above-mentioned random selection, as a musician plays any pitch out of the preferred pitches stored in his/her memory (for example, {Do, Mi, Do, Sol, Do} in Figure 3), the value of decision variable x_i' can be chosen from any pitches stored in HM with a probability of HMCR.

$$x_i' \leftarrow x_i' \in \{x_i^1, x_i^2, ..., x_i^{HMS}\} \quad \text{w.p.} \quad HMCR \tag{5}$$

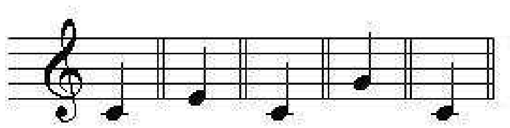

Fig. 3. Preferred Pitches Stored in Harmony Memory

Pitch Adjustment. Once one pitch is obtained in memory consideration as described in the above section, a musician can further adjust the pitch to neighboring pitches (for example, the note Sol can be adjusted to Fa or La as shown in Figure 4) with a probability of HMCR × PAR while the original pitch obtained in memory consideration is just kept with a probability of HMCR × (1-PAR).

$$x_i' \leftarrow \begin{cases} x_i(k+m) & \text{w.p.} \quad HMCR \times PAR \times 0.5 \\ x_i(k-m) & \text{w.p.} \quad HMCR \times PAR \times 0.5 \\ x_i(k) & \text{w.p.} \quad HMCR \times (1-PAR) \end{cases} \tag{6}$$

where $x_i(k)$ (the k$^{\text{th}}$ element in $\mathbf{X}_i$) in right hand side is identical to x_i' which is originally obtained in memory consideration; m is a neighboring index for discrete decision variables ($m \in \{1, 2, ...\}$; m usually has a value of 1).

Fig. 4. Pitch Adjustment

Ensemble Consideration. After the new harmony $\boldsymbol{x}' = (x_1', x_2', ..., x_N')$ is obtained using the above-mentioned three rules, one more operation can be considered from the relationship among decision variables. Just as a player has even stronger relationship with specific player in a music group (for example, the first and second players have stronger relationship in Figure 5), the new operation, ensemble consideration, enables the algorithm to combine closely related variables together.

Fig. 5. Relationship between Music Players

The value of decision variable x'_i can be chosen based on the value of other variable x'_j when x_i and x_j have strongest relationship among decision variables:

$$x'_i \leftarrow fn(x'_j) \quad \text{where} \quad \max_{i \neq j}\left\{\left[Corr(\boldsymbol{x_i}, \boldsymbol{x_j})\right]^2\right\} \tag{7}$$

where $Corr(\cdot)$ is statistical correlation function between $\boldsymbol{x_i} = (x_i^1, x_i^2, ..., x_i^{HMS})$ and $\boldsymbol{x_j} = (x_j^1, x_j^2, ..., x_j^{HMS})$, producing r (correlation coefficient); max(·) is maximum function which finds the strongest correlated variable x_j for the variable x_i based on r^2 (determination coefficient); and $fn(\cdot)$ is relationship function which produces the value of x'_i based on the value of x'_j. The relationship function $fn(\cdot)$ finds the most frequent value of x_i from the pairs of x_i and x_j in HM where x_j is equal to x'_j.

In order to operate the ensemble consideration with certain amount of chance, a new parameter ECR (ensemble consideration rate; $0 \le \text{ECR} \le 1$) is introduced. While GA preserves highly fitted structure (building blocks) implicitly [1], HS can explicitly preserve highly fitted structure using this ensemble consideration.

Violated Harmony Consideration. Once the new harmony $\boldsymbol{x'} = (x'_1, x'_2, ..., x'_N)$ is obtained using the above-mentioned four rules, it is then checked whether it violates problem constraints. Although the new harmony violates the constraints, it has still chance to be included in HM, just as rule-violated harmony (for example, parallel fifth violation as shown in Figure 6) was still used by musicians such as famous composer Ludwig van Beethoven.

Violated harmony can be considered by taxing a penalty. The penalty technique has been already used for considering constraints in many mathematical or phenomenon-inspired optimization techniques.

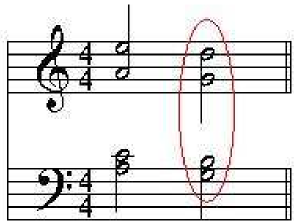

Fig. 6. Harmony Violating Parallel Fifth

2.4 Harmony Memory Update

If the new harmony vector $\boldsymbol{x}'$ is better than the worst harmony in the HM in terms of objective function, the new harmony is included in the HM and the existing worst harmony is excluded from the HM. If the termination criterion (MaxImp) is reached, computation is ended. Otherwise, section 2.3 and 2.4 are repeated.

In order to prevent premature HM where identical harmony vectors are predominant, the number of identical vectors in HM can be limited (Normally, up to two identical vectors).

3 Application to the Water Network Design

The improved HS algorithm including new operation of ensemble consideration is applied to the design of water distribution network, which is a combinatorial optimization problem to find minimal pipe diameters while satisfying water demand and pressure at each node. The real world network is Hanoi network as shown in Figure 7.

The following parameter values were used for the optimization: number of decision variables = 34; number of candidate values (=diameters) for the decision variables = 6; HMS = {30, 50, 100}; HMCR = {0.7, 0.9, 0.95}; PAR = {0.05, 0.1}; ECR = {0.0, 0.005, 0.01}; and MaxImp = 10,000. All solutions are hydraulically verified using a standard simulator, EPANET 2.0 [18].

The improved HS algorithm could find less costs ($6,197,960 for ECR = 0.005; and $6,116,506 for ECR = 0.01) than original HS algorithm ($6,221,158 for ECR = 0.0), where each ECR case performed 18 runs with different algorithm parameters (3 HMS's × 2 HMCR's × 3 PAR's). Each run took 9 seconds on Intel 1.8GHz CPU, evaluating the objective function 10,000 times, which is 3.5×10^{-21}% (= 10^4 / 6^{34}) of total solution space! The cost ranges of the proposed HS are [6.198E6, 7.689E6] (ECR = 0.005) and [6.117E6, 7.659E6] (ECR = 0.01) while that of the original HS is [6.221E6, 7.466E6]. From these cost ranges, it appears that the solutions of the ensemble HS fluctuates more dynamically than those of the original HS.

When further compared with other nature-inspired algorithms for this problem, improved HS (ECR = 0.01) could find better solution ($6,081,087) after 30,000 evaluations while GA found $6,187,320 after 1,000,000 evaluations [19] and simulated annealing (SA) found $6,093,469 after 53,000 evaluations [20].

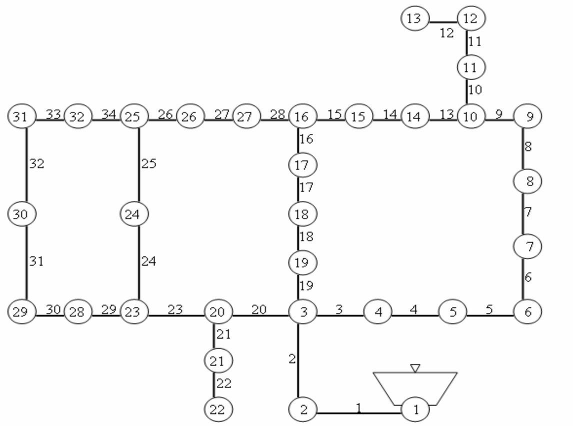

Fig. 7. Hanoi Water Network

4 Conclusions

A music phenomenon-based HS algorithm was further developed by mimicking musicians' interdependence. The value of one variable can be chosen from the value of another variable when they are strongly correlated in terms of statistical coefficient. The improved HS algorithm was then applied to a water network design. The ensemble-considered HS algorithm could find less-cost design than the original HS and other nature-inspired algorithms such as GA and SA.

Although GA keeps short-length good structures (building blocks) implicitly, this mechanism works well only when adjacent variables in a chromosome are strongly correlated. However, in real world problems (e.g., Hanoi network in Figure 7), this assumption does not seem always true; for example, pipe 28 and pipe 29 do not appear to have strong relationship because they are not located in neighboring place. Nevertheless, in a vector (or chromosome) in GA, these two variables have more chance not to be separated just because they are neighboring variables each other. That is the reason why this study developed the new operation, ensemble consideration, which can explicitly combine closely-related variables together, regardless of how far the two variables are separated in a solution vector.

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