A Rigorous Analysis of the Harmony Search Algorithm - How the Research Community can be misled by a "novel" Methodology

Dennis Weyland
IDSIA, Istituto Dalle Molle di Studi sull'Intelligenza Artificiale
Galleria 2, 6928 Manno-Lugano, Switzerland
dennis@idsia.ch

slightly different version published in
International Journal of Applied Metaheuristic Computing, volume 1-2, April-June 2010, pages 50-60

Abstract

In recent years a lot of novel (mostly naturally inspired) search heuristics have been proposed. Among those approaches is *Harmony Search*. After its introduction in 2000, positive results and improvements over existing approaches have been reported in numerous publications.
In this paper we give a review about the developments of *Harmony Search* in the last decade. Additionally we perform a rigorous analysis of this approach. In particular we compare *Harmony Search* to the well known and established search heuristic called *Evolution Strategies*. It turns out that *Harmony Search* is a special case of *Evolution Strategies*. We give compelling evidence for the thesis that research in Harmony, although undoubtedly conducted with the best of intentions, is fundamentally misguided, marred by a preoccupation with retracing paths already well traveled, and we conclude that future research effort could better be devoted to more promising areas. The overarching question is how such a method could become inaccurately portrayed as a significant innovation without confronting a respectable challenge of its content or credentials. We examine possible answers to this question, and implications for evaluating other supposedly innovative procedures, by disclosing the way in which limitations of the method have been systematically overlooked.

1 Introduction

Recent years have witnessed the introduction of numerous search heuristics, many of them inspired by metaphors from nature, physics and life. One of these, *Harmony Search*, has attracted considerable attention through its reported success based on the metaphor of jazz music improvisation, where jazz musicians try to improve harmonies over time. Since its introduction in the year 2000, *Harmony Search* has been the subject of many publications. At the time this paper was written, Google Scholar (`http://scholar.google.com`) gave a total of 586 hits for *"Harmony Search"*, with 329 hits for publications since 2007 and even a book about this method has been published recently [Geem, 2010]. A lot of positive results and improvements over existing approaches have been reported, which suggest that *Harmony Search* could be a promising method with a lot of potential for future improvements. In this paper we take a closer look at *Harmony Search* and try to understand what is really behind the metaphor of jazz improvisation and this presumably novel search heuristic.

The remaining part of the paper is organized as follows. In the next section we give a formal introduction of *Harmony Search* together with an overview about the developments regarding this heuristic in the last decade. Section 3 is dedicated to the well known and established search heuristic *Evolution Strategies* and to a rigorous comparison between *Evolution Strategies* and *Harmony Search*. With the background knowledge obtained in that part, we discuss in section 4 some representative publications regarding *Harmony Search* more in detail. We finish the paper with an extensive discussion in section 5 as well as with conclusions and an outlook about possible further work in section 6.

2 Harmony Search

Harmony Search (HS) is a search heuristic based on the improvisation process of jazz musicians [Geem et al., 2001]. In jazz music the different musicians try to adjust their pitches, such that the overall harmonies are optimized due to aesthetic objectives. Starting with some harmonies, they attempt to achieve better harmonies by improvisation. This analogy can be used to derive search heuristics, which can be used to optimize a given objective function instead of harmonies. Here the musicians are identified with the decision variables and the harmonies correspond to solutions. Like jazz musicians create new harmonies by improvisation, the HS algorithm creates iteratively new solutions based on past solutions and on random modifications. While this framework leaves a lot of space for interpretation, the basic HS algorithm is always described in the literature in the following way.

The HS algorithm initializes the Harmony Memory (HM) with randomly generated solutions. The number of solutions stored in the HM is defined by the Harmony Memory Size (HMS). Then iteratively a new solution is created as follows. Each decision variable is generated either on memory consideration and a possible additional modification, or on random selection. The parameters that are used in the generation process of a new solution are called Harmony Memory Considering Rate (HMCR) and Pitch Adjusting Rate (PAR). Each decision variable is set to the value of the corresponding variable of one of the solutions in the HM with a probability of HMCR, and an additional modification of this value is performed with a probability of PAR. Otherwise (with a probability of $1 - \text{HMCR}$), the decision variable is set to a random value. After a new solution has been created, it is evaluated and compared to the worst solution in the HM. If its objective value is better than that of the worst solution, it replaces the worst solution in the HM. This process is repeated, until a termination criterion is fulfilled. More detailed descriptions of this algorithm can be found in [Geem et al., 2005c, Mahdavi et al., 2007, Geem, 2005a]. Algorithm 1 gives an overview about the HS algorithm using pseudo code.

Since its introduction in the year 2000, *Harmony Search* has been subject of many publications. It has been applied to pipe network design [Geem et al., 2000, Geem et al., 2002], the design of water distribution networks [Geem, 2000, Geem, 2006a, Geem, 2007b, Geem, 2008],

Algorithm 1 Harmony Search Algorithm

Initialize the HM with HMS randomly generated solutions
repeat
  Create a new solution in the following way
  for all decision variables **do**
    With probability HMCR use a value of one of the solutions in the harmony memory and additionally change this value slightly with probability PAR
    Otherwise (with probability $1 - \text{HMCR}$) use a random value for this decision variable
  end for
  if the new solution is better than the worst solution in the harmony memory **then**
    Replace the worst solution by the new one
  end if
until Termination criterion is fulfilled
return The best solution in the harmony memory

vehicle routing [Geem et al., 2005a, Geem, 2005b], the generalized orienteering problem [Geem et al., 2005c], the geometry design of geodesic domes [Saka, 2007], satellite heat pipe design [Geem and Hwangbo, 2006], the design of steel sway frames [Degertekin, 2008, Saka, 2009], the design of grillage systems [Erdal and Saka, 2006, Erdal and Saka, 2008], university course timetabling [Al-Betar et al., 2008], scheduling of a multiple dam system [Geem, 2007c], bandwidth-delay-constrained least-cost multicast routing [Forsati et al., 2008a], the minimal covering species problem [Geem and Williams, 2007], mooring cost optimization [Ryu et al., 2007], multi-pass face-milling [Zarei et al., 2009], web page clustering [Forsati et al., 2008b], solving sudoku [Geem, 2007a] and music composition [Geem and Choi, 2007]. Various extensions to the basic algorithm have been proposed, e.g. dynamic algorithm parameters [Mahdavi et al., 2007], more bias to the current best solution [Omran and Mahdavi, 2008], modeling dependencies between decision variables [Geem, 2006b], a multi-objective variant [Geem and Hwangbo, 2006] and a hybridization with sequential quadratic programming [Fesanghary et al., 2008]. Even some theoretical work has been published [Lee and Geem, 2005, Mukhopadhyay et al., 2008].

In almost all publications regarding *Harmony Search* positive results have been reported. Together with the increasing number of publications, it suggests that HS is an adequate and promising search heuristic with a lot of potential for further research work. We clarify this statement in the remaining part of this paper, starting with a rigorous analysis of the HS algorithm in the next section.

3 Comparison to Evolution Strategies

In this section we give a short description of the well known and established search heuristic *Evolution Strategies* (ES). We then perform a rigorous comparison between ES and the HS algorithm.

The history of *Evolution Strategies* dates back to the 60s. At the beginning these algorithms were used to automatically adjust variables for a series of consecutive experiments. When computers became available at universities in the early 70s, those methods were used for the optimization of parameters within simulation models. Since then *Evolution Strategies* have been successfully applied to numerous optimization problems and a lot of extensions and improvements of those methods have been proposed. For a detailed historical review the interested reader is referred to [Beyer and Schwefel, 2002].

In this paper we focus on the so called $(\mu + 1)$ *Evolution Strategy* [Rechenberg, 1973], a method introduced in the early 70s, almost 30 years before the first *Harmony Search* publication was released. This algorithm uses a population of μ randomly generated solutions. In each iteration a new solution is generated from the existing solutions by using recombination and mutation operators. If this solution is better than the worst solution in the current population, it replaces the worst solution. This iterative process continues, until a termination criterion is met. An overview about this method is given in algorithm 2.

Algorithm 2 $(\mu$+1$)$ Evolution Strategy

Initialize the population with μ randomly generated solutions
repeat
    Create a new solution using recombination and mutation operators
    if the new solution is better than the worst solution in the population **then**
        Replace the worst solution by the new one
    end if
until Termination criterion is fulfilled
return The best solution in the population

Of course this is a very generic model and we have to define more concretely how new solutions are generated. In the past a huge variety of different recombination and mutation operators have been proposed in the evolutionary computation community [Beyer and Schwefel, 2002, Bäck et al., 2000a, Bäck et al., 2000b]. One choice for the recombination operator could be the global discrete recombination [Bäck et al., 1991, Bäck et al., 1993, Bäck and Schwefel, 1993]. Here each decision variable of the new solution uses the value of the corresponding decision variable of an arbitrarily (e.g. uniformly) selected solution in the current population. As a subsequent mutation operator the following strategy could be used for each decision variable. With a probability of p_1 we perform a small modification of the decision variable. In a second step we set the value of the decision variable with a probability of p_2 to a random value. Those are both common choices for mutation operators [Rechenberg, 1973, Schwefel, 1981, Fogel and Atmar, 1990, Michalewicz Cezary et al., 1992, Bäck and Schwefel, 1993, Michalewicz, 1996].

Now let us compare both heuristics, *Harmony Search* and the $(\mu + 1)$ *Evolution Strategy*, step by step. Both algorithms use a population of a fixed size. In case of the ES, the population is of size μ, in case of the HS algorithm, the population is called Harmony Memory and is of size HMS. Both algorithms are working iteratively and create exactly one new solution in each iteration. If this solution is better than the worst solution in the current population, the worst solution is replaced by the new one. This process continues, until finally a termination criterion is fulfilled. In all these steps both algorithms are completely identical. The only thing, in which they could differ, is the way, in which the new solutions are created.

Both algorithms handle all decision variables independently, so it is sufficient to focus on one decision variable. The HS algorithm uses the so called memory consideration with a probability of HMCR. In this case it sets the value of the decision variable to the value of the corresponding decision variable of a uniformly selected solution in the HM, and performs a small modification of that value afterwards with a probability of PAR. Otherwise (with a probability of $1 - \text{HMCR}$), the value of the decision variable is set to a completely random value. The ES discussed here performs a population wide uniform crossover and therefore sets the value of each decision variable to the value of the corresponding decision variable of a uniformly selected solution in the current population. Then with probability p_1 a first mutation operator modifies the value of the decision variable slightly. After that a second mutation operator sets the value of the decision variable to a completely random value with probability p_2. It is easy to see that the methods used to create the new solutions in both algorithms are equivalent. Given parameters HMCR and PAR for the HS algorithm, we can set $p_1 = \text{PAR}$ and $p_2 = 1 - \text{HMCR}$ to obtain the same method of creating solutions for the ES. On the other hand, given parameters p_1 and p_2 for the ES, we can set $\text{HMCR} = 1 - p_2$ and $\text{PAR} = p_1$ and in this case we obtain the same method of creating solutions for the HS algorithm.

This means that *Harmony Search* is a special case of the $(\mu + 1)$ *Evolution Strategy*, and therefore the best ES is at least as good as the HS algorithm. In other words: The HS algorithm is not able to outperform the best ES. Although HS is derived from a completely different metaphor, it is in its basic variant not a novel approach. For the moment, this does not mean that the concept of HS is not useful at all. There are a lot of publications regarding HS reporting positive results, and there is the possibility that there are other properties of jazz music and improvisation, which could probably lead to new concepts or ideas for search heuristics and optimization. To resolve those issues, we take a closer look at some representative HS publications in the next section, and pose the question of whether the studies that proclaim the virtues of the method have been carried out in a prudent manner.

4 Representative Publications in Detail

In this section we give a detailed presentation of some publications regarding *Harmony Search* and discuss the results in-depth. For this purpose we have chosen publications which are available online via Google Scholar (`http://scholar.google.com`). We start with those publications that focus on the applications of HS, then we present those publications that use modifications of the HS algorithm and we finish this section with one publication about theoretical results regarding HS. We should emphasize that the authors involved in the studies cited have undoubtedly proceeded in good faith, apparently with no knowledge of the fact that the ground they were covering was already well-traveled. As we later discuss, this gives reason to take action that will help future authors avoid similar mistakes.

Applications of Harmony Search

We have seen that the *Harmony Search* algorithm is a special case of the $(\mu + 1)$ *Evolution Strategy*. In this section we want to clarify the question of how the numerous positive results in literature could be obtained. It is clear that the best ES is at least as good as HS. This means that there exists at least one well known method, which cannot be outperformed by HS. So it is even more surprising that literature is full of publications reporting positive results using the HS algorithm. Examples for such publications are [Degertekin, 2008, Erdal and Saka, 2008, Geem et al., 2005b, Geem et al., 2005c, Geem and Williams, 2007, Al-Betar et al., 2008, Geem and Choi, 2007, Ryu et al., 2007, Geem, 2005b, Geem et al., 2005a, Geem, 2007c, Geem et al., 2000, Geem, 2005a, Geem and Hwangbo, 2006], which are used in this section. In all those papers empirical experiments regarding HS and other methods are performed. In the remaining part of this section we analyze those experiments based on *Guidelines for designing and reporting on computational experiments with heuristic methods* [Barr et al., 2001].

When performing empirical experiments with heuristic methods, the goal is usually to show that a specific method performs better than other methods on a class of problem instances with respect to some predefined objective, which is usually computational time and/or solution quality. Instead of using a class of problem instances, or a randomly sampled subset, in all the publications experiments are performed only on a few instances [Geem et al., 2000, Geem and Choi, 2007, Al-Betar et al., 2008, Erdal and Saka, 2006, Degertekin, 2008], or even on a single instance [Geem and Hwangbo, 2006, Geem, 2005a, Geem, 2007c, Geem et al., 2005a, Geem, 2005b, Ryu et al., 2007, Geem and Williams, 2007, Geem et al., 2005c, Geem et al., 2005b]. The majority of experiments are performed on a single instance, all but one of the experiments are performed on at most 5 instances and only in one experiment 11 instances are used.

Another problem is the size of the (few) instances used in the experiments. Heuristics are mainly used in scenarios, where it is not possible to use approximation algorithms or exact approaches for some reason. This usually implies that the size of the problems, which are tackled by heuristics, are rather large. In almost all of the publications mentioned above, the instance sizes are relatively small, which means that less than 50 decision variables are used. The most extreme publications here are [Geem et al., 2005c] with 27, [Geem et al., 2000] with 12, [Geem, 2005b, Geem et al., 2005a] with 10, [Ryu et al., 2007] with 6 and [Geem and Hwangbo, 2006] with 5 decision variables.

The next issue deals with the comparison to other methods. The best way to show that a new method is really successful is to demonstrate that it outperforms state-of-the-art approaches. In all of the publications mentioned above it is not clear whether a state-of-the-art method has been used for the comparisons or not. Another way to show that the new method is at least competitive or interesting, could be to demonstrate that it outperforms some standard approaches. There are plenty of different established search heuristics, like *Local Search*, *Tabu Search*, *Simulated Annealing*, *Evolution Strategies*, *Genetic Algorithms*, *Ant Colony Optimization* and *Particle Swarm Optimization*. All of them could be used for such a comparison. Unfortunately in most of the publications the HS algorithm is only compared to a few other approaches. In [Geem and Hwangbo, 2006, Geem et al., 2000, Geem et al., 2005b, Degertekin, 2008] 2 other approaches are used for the comparison and in [Geem and Williams, 2007, Geem, 2007c, Geem et al., 2005c, Geem et al., 2005a, Geem, 2005b] the HS algorithm is only compared to a single other approach. Even more dramatic is the fact that in [Erdal and Saka, 2006, Geem and Choi, 2007, Ryu et al., 2007] no comparisons are performed at all. Each of these publications can at most be used to demonstrate that HS can be used to tackle the problem (or instance) under consideration.

There are some other issues, which we do not discuss in detail here. For example, the experimental conditions are not completely clear in most of the publications, sometimes best solutions are used for comparisons instead of average solutions and statistical tests are not performed in any of the publications.

All in all, it is not possible to support the conclusions presented in those publications, using the inadequate experimental setups, which were discussed in this section.

Improvements of Harmony Search

So far we have not clarified whether the basic metaphor of the HS algorithm, the improvisation process in jazz music, can lead to any new and promising concepts for the field of optimization. Therefore we focus in this section on publications that introduce modifications of the HS algorithm [Mahdavi et al., 2007, Omran and Mahdavi, 2008, Geem, 2006b, Fesanghary et al., 2008]. Here we want to clarify whether the modifications of the HS algorithm presented in those publications are new ideas or concepts. The question of whether we can expect any new and promising concepts for the future, or not, is postponed to section 5. Although most of the issues from the previous section also hold for the publications considered here, we only focus on the way in which the original HS algorithm is modified.

In [Mahdavi et al., 2007] the authors claim that the use of fixed parameters is a limitation to the HS algorithm. Instead of using fixed parameters, the parameters are changed in a predefined way. The dynamic adjustment of parameters is not a new concept and has been used successfully for many years [Bäck, 1992].

The journal article [Omran and Mahdavi, 2008] deals with another modification of HS. Here the authors modify the algorithm in a way that decision variables are set to the value of the corresponding variable in the best solution found so far with a higher probability than in the standard approach. This idea is not new, there are plenty of methods that use a stronger bias to the best solution found so far. An explicit example is given by the search process in *Particle Swarm Optimization* [Eberhart and Kennedy, 1995], an implicit example is given by different parent selection mechanisms in *Evolution Strategies* or *Genetic Algorithms* [Bäck et al., 2000a, Bäck et al., 2000b].

In [Geem, 2006b] the HS algorithm is extended in such a way that dependencies between pairs of decision variables are considered. The idea of modeling dependencies between decision variables exists since several years. For example, it is used implicitly by population based heuristics and explicitly in some Estimation of Distribution Algorithms [Pelikan and Mühlenbein, 1999, Mühlenbein and Mahnig, 1999].

The last publication in this subsection is [Fesanghary et al., 2008]. In this work the authors hybridize the HS algorithm with sequential quadratic programming. The concept of combining different problem solving methods on a more abstract (meta heuristic) level or in concrete hybrid approaches is also not new in the field of optimization [Davis, 1990, Berger et al., 1998].

All in all, there are no new ideas or concepts used in the modifications of the *Harmony Search* algorithm, which are presented in this section.

Theory about Harmony Search

Perhaps we can get new insights about *Harmony Search* from [Mukhopadhyay et al., 2008]. Here some theoretical results for the HS algorithm are presented. It is interesting to note that the results are based on similar analyses for *Evolution Strategies* [Beyer, 1998]. The authors want to illustrate the explorative power of the HS algorithm. For this purpose they modify the algorithm in the following way. Instead of creating one solution in each iteration, HMS many solutions are created. Those new solutions then completely replace the old population. It is obvious that this variant has nothing to do with the original HS algorithm, and it is hard to transfer any conclusions from this variant to the original HS algorithm. Additionally the results which are obtained in [Mukhopadhyay et al., 2008], cannot be valid. The authors *prove* that the sample variance between the solutions in the population grows exponentially, if some specific parameter values are used for the algorithm. Since they assume that the decision variables are bounded within an interval, the variance is bounded as well and cannot grow arbitrarily large. Therefore their results are simply incorrect.

In short, this work does not help us to identify any promising ideas or concepts, which are related to the metaphor used for the HS algorithm.

5 Discussion

In this section we discuss the results obtained in the previous section, together with their impacts. We begin with a short summary of the results. After that we explain which future development can be expected regarding the HS algorithm. We finish our discussion with some possible explanations for our results.

We started with a formal definition of the *Harmony Search* algorithm in section 2. In section 3 we compared this algorithm to a specific (not uncommon or exotic) *Evolution Strategy*. We showed that HS is completely equivalent to this well known and established ES. This result raises two questions. Why are there so many positive results about HS in the literature, if this is not really a new approach? And are there any other properties of jazz music and improvisation which could probably lead to new concepts or ideas for search heuristics and optimization in the future?

The first question can be answered easily. We analyzed different publications, which report positive results regarding *Harmony Search*. We showed that the experimental setups used in the experiments for those publications are inadequate. The few results that were obtained in those experiments cannot be used to support the conclusions presented in those publications.

It is a little bit more complicated to answer the second question. We examined four publications, which use modifications of the HS algorithm, and one publication, which deals with theoretical aspects of the HS algorithm. The modifications proposed in those publications are all well known and used for many years in the context of other search heuristics. It seems that only ideas and concepts, which have been applied successfully to other search heuristics, are used for HS. For example, there is a kind of parallel between the development of modifications for the HS algorithm and the development of modifications for *Evolutionary Algorithms* in the past. For both algorithms a bias towards better solutions in the population has been introduced and for both algorithms dynamic parameters have been used instead of fixed ones. It is only a matter of time until concepts like self adaptation for the HS algorithms will be proposed. But since the HS algorithm is itself an ES, the usefulness of such results will be limited. Also the theoretical paper could not help us to identify promising concepts of the HS algorithm. Of course, we cannot prove that there are no properties of jazz music and improvisation which might be usefully incorporated into search heuristics and for optimization. But in the last decade no new concept has been derived from this metaphor and the probability that this will ever happen appears on this basis to be rather low.

Before we finish the paper we want to discuss possible explanations for our findings. We do not state that they are in fact the true explanations, but in our opinion they are in general of high interest for the whole community and could also be relevant for this paper.

It is quite obvious that we, the whole research community, are operating in a completely antiquated and fallible framework. The scientific publication system as it is now has a lot of inherent defects, which handicap and slow down research. First of all there are a lot of financial concerns involved in the current system which leave a lot of space for misusage. Additionally the most widely used method to judge scientific publications, called peer reviewing, requires idealistic behavior on the part of the people participating in that process, and we can not rely on the assumption that such behavior will manifest itself gratuitously, especially if there are plenty of personal and career concerns involved. Furthermore the publication system has scarcely been affected by the rapid technological progress of the last decades. For example, we still have no comprehensive public access to scientific publications, although this would be easily realizable, and release durations are extremely long in some cases for no obvious reasons. We do not want to go into greater detail here and for people who are more interested in the defects of the scientific publication system, the article *Science's journal and conference system - a joke that got old* (`http://www.math.temple.edu/~wds/homepage/refereeing`) is strongly recommended.

Since not all people can be expected to behave in an idealistic way, it is not very surprising to find that a system which is not well-designed and carefully regulated can be subject to abuse. But the key issue is whether we should tolerate this situation, by continuing to operate within a system of scientific publication whose design and regulation is conspicuously deficient. In our opinion it is of the greatest importance to bend our efforts to correcting the defects of the current system.

6 Conclusions

In this paper we performed a rigorous analysis of the search heuristic *Harmony Search*. We showed that this heuristic is in fact a special case of an *Evolution Strategy* and we gave strong arguments for the theses that research in *Harmony Search* is fundamentally misguided and that future research effort could better be devoted to more promising areas.

There are some other purportedly novel approaches proposed in the literature, which could fall into the same category as *Harmony Search*. Admittedly, it is not entirely fair to single out HS as the sole representative of this category. Our goal is not to belabor the shortcomings of a single method, but to sensitize other researches to the existence of the situation in which such shortcomings can prevail, and to encourage a response that can lead to producing something better. We operate in an antiquated and fallible framework, and there is no remedy in sight as long as the number of an authors publications is considered more important than the quality of those publications, and as long as we use a reviewing system which is inherently inconsistent.

Acknowledgments

The author is grateful to the anonymous reviewers for their helpful comments and remarks. The author's research has been supported by the Swiss National Science Foundation, grant 200021-120039/1.

References

[Al-Betar et al., 2008] Al-Betar, M., Khader, A., and Gani, T. (2008). A harmony search algorithm for university course timetabling. In *7th International Conference on the Practice and Theory of Automated Timetabling (PATAT 2008), Montreal, Canada.*

[Bäck, 1992] Bäck, T. (1992). Self-adaptation in genetic algorithms. In *Toward a practice of autonomous systems: Proceedings of the First European Conference on Artificial Life*, pages 263–271.

[Bäck et al., 2000a] Bäck, T., Fogel, D., and Michalewicz, Z. (2000a). *Evolutionary computation 1.* Institute of Physics Publishing.

[Bäck et al., 2000b] Bäck, T., Fogel, D., and Michalewicz, Z. (2000b). *Evolutionary computation 2: Advanced algorithms and operators.* Institute of Physics Publishing, Ltd., The Public Ledger Building, Suite.

[Bäck et al., 1991] Bäck, T., Hoffmeister, F., and Schwefel, H. (1991). A survey of evolution strategies. In *Proceedings of the Fourth International Conference on Genetic Algorithms.*

[Bäck et al., 1993] Bäck, T., Rudolph, G., and Schwefel, H. (1993). Evolutionary programming and evolution strategies: Similarities and differences. In *Proceedings of the Second Annual Conference on Evolutionary Programming*, pages 11–22. Citeseer.

[Bäck and Schwefel, 1993] Bäck, T. and Schwefel, H. (1993). An overview of evolutionary algorithms for parameter optimization. *Evolutionary computation*, 1(1):1–23.

[Barr et al., 2001] Barr, R., Golden, B., Kelly, J., Steward, W., and Resende, M. (2001). Guidelines for designing and reporting on computational experiments with heuristic methods. In *Proceedings of International Conference on Metaheuristics for Optimization, Kluwer Publishing*, pages 1–17.

[Berger et al., 1998] Berger, J., Salois, M., and Begin, R. (1998). A hybrid genetic algorithm for the vehicle routing problem with time windows. *Lecture Notes in Computer Science*, 1418:114–127.

[Beyer, 1998] Beyer, H. (1998). On the "explorative power" of ES/EP-like algorithms. *Lecture notes in computer science*, pages 323–334.

[Beyer and Schwefel, 2002] Beyer, H. and Schwefel, H. (2002). Evolution strategies–A comprehensive introduction. *Natural Computing*, 1(1):3–52.

[Davis, 1990] Davis, L. (1990). Hybrid genetic algorithms for machine learning. In *IEE Colloquium on Machine Learning*, page 9.

[Degertekin, 2008] Degertekin, S. (2008). Optimum design of steel frames using harmony search algorithm. *Structural and Multidisciplinary Optimization*, 36(4):393–401.

[Eberhart and Kennedy, 1995] Eberhart, R. and Kennedy, J. (1995). A new optimizer using particle swarm theory. In *Proceedings Sixth Symposium on Micro Machine and Human Science*, pages 39–43.

[Erdal and Saka, 2006] Erdal, F. and Saka, M. (2006). Optimum design of grillage systems using harmony search algorithm. In *Proceedings of 8th International Conference on Computational Structures Technology (CST 2006), Las Palmas de Gran Canaria, Spain.*

[Erdal and Saka, 2008] Erdal, F. and Saka, M. (2008). Effect of beam spacing in the harmony search based optimum design of grillages. *Asian Journal of Civil Engineering (Building and Housing)*, 9(3):215–228.

[Fesanghary et al., 2008] Fesanghary, M., Mahdavi, M., Minary-Jolandan, M., and Alizadeh, Y. (2008). Hybridizing harmony search algorithm with sequential quadratic programming for engineering optimization problems. *Computer Methods in Applied Mechanics and Engineering*, 197(33-40):3080–3091.

[Fogel and Atmar, 1990] Fogel, D. and Atmar, J. (1990). Comparing genetic operators with Gaussian mutations in simulated evolutionary processes using linear systems. *Biological Cybernetics*, 63(2):111–114.

[Forsati et al., 2008a] Forsati, R., Haghighat, A., and Mahdavi, M. (2008a). Harmony search based algorithms for bandwidth-delay-constrained least-cost multicast routing. *Computer Communications.*

[Forsati et al., 2008b] Forsati, R., Mahdavi, M., Kangavari, M., and Safarkhani, B. (2008b). Web page clustering using harmony search optimization. In *Electrical and Computer Engineering, 2008. CCECE 2008. Canadian Conference on*, pages 001601–001604.

[Geem, 2000] Geem, Z. (2000). *Optimal design of water distribution networks using harmony search.* PhD thesis, Korea University.

[Geem, 2005a] Geem, Z. (2005a). Harmony search in water pump switching problem. *Lecture Notes in Computer Science*, 3612:751.

[Geem, 2005b] Geem, Z. (2005b). School bus routing using harmony search. In *Genetic and Evolutionary Computation Conference (GECCO 2005), Washington DC, USA*.

[Geem, 2006a] Geem, Z. (2006a). Comparison Harmony Search with Other Meta-Heuristics in Water Distribution Network Design. ASCE.

[Geem, 2006b] Geem, Z. (2006b). Improved harmony search from ensemble of music players. *Lecture Notes in Computer Science*, 4251:86.

[Geem, 2007a] Geem, Z. (2007a). Harmony search algorithm for solving sudoku. *Lecture Notes in Computer Science*, 4692:371.

[Geem, 2007b] Geem, Z. (2007b). Harmony search algorithm for the optimal design of large-scale water distribution network. In *Proceedings of the 7th International IWA Symposium on Systems Analysis and Integrated Assessment in Water Management (Watermatex 2007), IWA, Washington DC, USA (2007b)(CD-ROM)*.

[Geem, 2007c] Geem, Z. (2007c). Optimal scheduling of multiple dam system using harmony search algorithm. *Lecture Notes in Computer Science*, 4507:316.

[Geem, 2008] Geem, Z. (2008). Harmony search optimisation to the pump-included water distribution network design. *Civil Engineering and Environmental Systems*, 99999(1):1–1.

[Geem, 2010] Geem, Z. (2010). Recent advances in harmony search algorithm.

[Geem and Choi, 2007] Geem, Z. and Choi, J. (2007). Music composition using harmony search algorithm. *Lecture Notes in Computer Science*, 4448:593.

[Geem and Hwangbo, 2006] Geem, Z. and Hwangbo, H. (2006). Application of harmony search to multi-objective optimization for satellite heat pipe design. In *Proceedings of US-Korea Conference on Science, Technology, and Entrepreneurship (UKC 2006), Teaneck, NJ, USA,(CD-ROM)*. Citeseer.

[Geem et al., 2001] Geem, Z., Kim, J., et al. (2001). A new heuristic optimization algorithm: harmony search. *Simulation*, 76(2):60.

[Geem et al., 2002] Geem, Z., Kim, J., and Loganathan, G. (2002). Harmony search optimization: Application to pipe network design. *International Journal of Modelling & Simulation*, 22(2):125–133.

[Geem et al., 2000] Geem, Z., Kim, J., and Yoon, Y. (2000). Optimal layout of pipe networks using harmony search. In *Proceedings of 4th International Conference on Hydro-Science and Engineering, Seoul, South Korea*.

[Geem et al., 2005a] Geem, Z., Lee, K., and Park, Y. (2005a). Application of harmony search to vehicle routing. *American Journal of Applied Sciences*, 2(12):1552–1557.

[Geem et al., 2005b] Geem, Z., Lee, K., and Tseng, C. (2005b). Harmony search for structural design. In *Proceedings of the 2005 conference on Genetic and evolutionary computation*, pages 651–652. ACM New York, NY, USA.

[Geem et al., 2005c] Geem, Z., Tseng, C., and Park, Y. (2005c). Harmony search for generalized orienteering problem: best touring in China. *Lecture Notes in Computer Science*, 3612:741.

[Geem and Williams, 2007] Geem, Z. and Williams, J. (2007). Harmony search and ecological optimization. *International Journal of Energy and Environment*, 1:150–154.

[Lee and Geem, 2005] Lee, K. and Geem, Z. (2005). A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice. *Computer methods in applied mechanics and engineering*, 194(36-38):3902–3933.

[Mahdavi et al., 2007] Mahdavi, M., Fesanghary, M., and Damangir, E. (2007). An improved harmony search algorithm for solving optimization problems. *Applied Mathematics and Computation*, 188(2):1567–1579.

[Michalewicz, 1996] Michalewicz, Z. (1996). *Genetic algorithms+ data structures.* Springer.

[Michalewicz Cezary et al., 1992] Michalewicz Cezary, Z. et al. (1992). A modified genetic algorithm for optimal control problems. *Computers & Mathematics with Applications*, 23(12):83–94.

[Mühlenbein and Mahnig, 1999] Mühlenbein, H. and Mahnig, T. (1999). FDA-A scalable evolutionary algorithm for the optimization of additively decomposed functions. *Evolutionary computation*, 7(4):353–376.

[Mukhopadhyay et al., 2008] Mukhopadhyay, A., Roy, A., Das, S., Das, S., and Abraham, A. (2008). Population-variance and explorative power of harmony search: an analysis. In *Second National Conference on Mathematical Techniques: Emerging Paradigms for Electronics and IT Industries (MATEIT 2008), New Delhi, India.*

[Omran and Mahdavi, 2008] Omran, M. and Mahdavi, M. (2008). Global-best harmony search. *Applied Mathematics and Computation*, 198(2):643–656.

[Pelikan and Mühlenbein, 1999] Pelikan, M. and Mühlenbein, H. (1999). The bivariate marginal distribution algorithm. *Advances in Soft Computing-Engineering Design and Manufacturing*, pages 521–535.

[Rechenberg, 1973] Rechenberg, I. (1973). Evolutionsstrategie: Optimierung technischer Systeme nach Prinzipien der biologischen Evolution.

[Ryu et al., 2007] Ryu, S., Duggal, A., Heyl, C., and Geem, Z. (2007). Mooring cost optimization via harmony search. In *Proceedings of the 26th ASME International Conference on Offshore Mechanics and Arctic Engineering.*

[Saka, 2007] Saka, M. (2007). Optimum geometry design of geodesic domes using harmony search algorithm. *Advances in Structural Engineering*, 10(6):595–606.

[Saka, 2009] Saka, M. (2009). Optimum design of steel sway frames to BS5950 using harmony search algorithm. *Journal of Constructional Steel Research*, 65(1):36–43.

[Schwefel, 1981] Schwefel, H. (1981). *Numerical optimization of computer models.* John Wiley & Sons, Inc. New York, NY, USA.

[Zarei et al., 2009] Zarei, O., Fesanghary, M., Farshi, B., Saffar, R., and Razfar, M. (2009). Optimization of multi-pass face-milling via harmony search algorithm. *Journal of Materials Processing Tech.*, 209(5):2386–2392.