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2 authors:

Amiram Moshaiov
Tel Aviv University

Gideon Avigad
GTT Informed Construction Decisions

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Amiram Moshaiov
Tel-Aviv University
School of Mechanical Engineering
Tel-Aviv, Israel
972-3-6407098
moshaiov@eng.tau.ac.il

Gideon Avigad
Tel-Aviv University
School of Mechanical Engineering
Tel-Aviv, Israel
972-4-9833124
gideon@eng.tau.ac.il

ABSTRACT
Recent studies on the support of engineers during conceptual design resulted in a non-traditional type of Multi-Objective Problems (MOPs), namely concept-based ones. In concept-based MOPs the focus is on conceptual solutions that are represented by sets of particular solutions. This means that a concept has a one-to-many relation with the objective space. Such a set-based concept representation is most suitable for human-computer interaction. In concept-based MOPs concept-related preferences could be easily incorporated with or without range-related preferences. This paper provides an overview of studies on concept-based problems, which have been conducted at Tel-Aviv University, and suggests some future research directions.

Categories and Subject Descriptors
I.2.8 [Artificial Intelligence]: Problem Solving - Heuristic methods

J.6.1 [Computer-aided Engineering]: Computer-aided Design

General Terms
Algorithms, Design.

Keywords
MOEA, EMO, conceptual design, engineering design, interactivity, robustness.

1. INTRODUCTION
The general motivation for our work on the concept-based approach, which is overviewed here, is to develop a novel interactive framework to support engineering design.

Engineering design is one of the most human-related activities featuring intellectualism, creativity and ingenuity [1]. From the entire design process, the conceptual design stage is usually viewed as a phase with the most human intensive creativity, whereas the following stages could be viewed as more suitable for mechanization. Our focus is on the development of interactive methods, using a non-traditional concept-based approach, to link conceptual with preliminary and detailed design stages. The concept-based approach is not restricted to Multi-Objective Problems (MOPs). Yet, we have concentrated our efforts on MOPs due to the nature of engineering design, which commonly involves trade-offs among contradicting objectives (e.g., accuracy vs. cost).

Traditionally search and optimization techniques have been used with conceptual solutions (or in short, concepts) that have each a one-to-one relationship with a point in the objective space. This is not a surprise when considering human tendency to (at best) provide a concept with just a one-to-one relationship with the objective space. It usually reflects the designers' mental models based on their experience and understanding of the concept and its overall performance. The concept-based approach deviates from this tradition. It is based on the understanding that in general a conceptual solution should be viewed as a category of solutions. In contrast to the traditional approach, in the concept-based approach a conceptual solution is represented by a set of particular solutions, allowing performance variability among the particular solutions, which are associated with a conceptual solution (e.g., [2-5]). In this non-traditional approach to concept search and selection there is an underlining assumption that the set-based representation of a concept can be supplemented with evaluations of the particular solutions of the set. The set-based concept representation provides a stage for a synergistic human-computer interaction. The approach involves a mixture of computable models with mental models. In the concept-based search, as introduced by us, computers are utilized to extensively search the decision space at the level of particular solutions, whereas humans articulate their preferences at the level of conceptual solutions. In addition to such inherent concept-based preferences, concept-based MOPs may involve range-related

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preferences. Both types of preferences could be implemented either a-priori, or interactively during the search.

The above describes a convenient split of efforts between computers and humans. Yet, one may wonder why defining concept-based problems and providing new algorithms for their solution is significant at all. The major motivation for the development of the concept-based approach is rooted in the significance of conceptual design. In modern engineering the proper evaluation and selection of concepts might make the difference between a flourishing company and a disappearing one. The need for a concept-based search and optimization becomes apparent when considering ideas from modern concurrent design such as families of designs and delaying decisions. The advantage of the latter idea is perhaps not an obvious one, and the reader is therefore referred to a comprehensive discussion in [6] on delaying decisions during product development, and the issue of uncertainty of the market demands. Such concurrent engineering methodologies suggest that designers should pay careful considerations not only to the selected detailed design but also to its selected concept, (and its influence on the company survivability). This justifies the development of the concept-based approach with both concept optimality and robustness considerations.

Naturally, conceptual design involves lack of details and the associated uncertainties. Humans have the ability to evaluate concepts, regardless of the lack of a clear model, with a risk of making a substantial mistake. The concept-based approach may serve as a base to develop tools for rational computer-supported concept search and selection, and to help the decision-making under the inherent uncertainties. As outlined in this paper the concept-based approach has been studied with respect to many relevant issues, using EC implementation. The accumulated evidence is promising; the approach appears generically powerful in exploiting computers, while leaving humans in the decision loop of concept search and selection with multiple objectives.

2. BACKGROUND

The cognitive ways, by which humans treat problems by and large, employ no formal mathematical definition, but rather conceptualize solutions. When trying to develop a synergy between humans and computers, and in particular with respect to design, it should be noted that humans are able to evaluate solutions even without a clear model. This is well reflected in artistic design, and the interactive EC approach [7]. It is quite often that humans are satisfied with a particular solution which is not necessarily an optimal solution. This is probably not just a result of the frequent lack of models to evaluate the solutions, but it is also related to humans' inability to mentally handle the entire search space. Computers provide a mean to better search the problem space, but they fail to generate conceptual solutions to most non-trivial problems.

Humans, and in particular engineers, are usually aware of trade-offs as related to the selection of concepts. For example, the significance of trade-offs to creative design has been highlighted in the TRIZ method, which resulted from a comprehensive study of patents by Altshuller [8]. Many Multi-Criteria Decision Making (MCDM) methods exists to handle trade-offs in making a decision on a concept (see for example [9]), yet such methods are not the focus of our discussion, which concentrates on computer-based search. Traditionally, when it comes to search for optimization, MOPs have been treated using methods such as the weighted sum of the objectives or the goal attainment approach. Such techniques have a major deficiency involving the need to have a-priori knowledge about the problem, and in particular a-priori narrowing of the objective space by way of some preferences. Modern processing technologies provide a means to consider parallel search methods which are suitable for range-independent MOP solving. In particular EC tools are known to be suitable for supporting engineering design (e.g., [10-11]). Their attractiveness for engineering design has been strengthened by the recent developments of reliable and generic MOEAs, such as NSGA-II and SPEA2, and by the introduction and adoption of special EC methods for engineering design such as COGA (See recent reviews in [12] and [13] by Coello, and Parmee respectively). Pareto-based search has been implemented for engineering design and other applications by non EC methods (e.g., [3]). Yet, it appears that in recent years Evolutionary Multi-Objective Optimization (EMOO) techniques are becoming the most popular methods to solve MOPs.

The majority of MOP-related studies employ a traditional approach rather than a Concept-based MOP (C-MOP) approach [4]. One may define a C-MOP in deferent ways, which reflect different approaches to MOPs, including both range-dependent and range-independent ones (e.g., [5] and [2] respectively). C-MOPs are not restricted to engineering design and should be viewed to be generic problems as demonstrated by an implementation to a path planning problem (e.g., [14]). The following section provides an overview of research on C-MOPs and their solution by EC techniques, which has been conducted at Tel-Aviv University.

3. C-MOPs AND THEIR SOLUTION BY EC

Any C-MOP involves the notion of conceptual solution, which is represented by a set of particular solutions. In contrast to the traditional approach, a C-MOP involves a one-to-many relationship between a conceptual solution and the objective space. This means that a C-MOP allows performance variability among the particular solutions, which are associated with a conceptual solution. Inherently, the concept-based approach provides understanding of the relations not only between concepts but also among their particular solutions.

The first Pareto-based C-MOP definition has only recently been formalized by Mattson and Messac in [3]. They have chosen the term s-Pareto to designate that the problem is set-based. It should be noted that the s-Pareto has been renamed as concept-based Pareto, or in short C-Pareto, (e.g., [15]), to clarify that the set represents conceptual solutions. Variants of the C-MOP have been treated elsewhere without a formal definition. For example, Anderson, [2], has also searched for the C-Pareto using a sequential EC approach, without formalizing the problem as in [3]. Moshaiov, in [15], has indicated the equivalence of the problems of [2] and [3], which are independent from the order of search. Avigad and Moshaiov, in [4], have formalized the comparison and investigated the numerical aspects of the simultaneous and the sequential approach in finding the C-Pareto using EC.

In contrast to the work of Mattson and Messac that uses a non-evolutionary solution approach, we have concentrated, in all our studies, on the development of EC methods for the solution of C-MOPs. In particular, for the simultaneous search of the C-Pareto we have developed novel algorithms, which are based-on the NSGA-II algorithm, [16]. Due to their inherent parallel processing, EC techniques are a natural choice for C-MOPs, which involve the simultaneous handling of sets of solutions.

Due to the uncertainties that are involved in concept search and optimization, the Pareto-based C-MOP definition of Mattson and Messac is attractive only to some degree. A formal extension has been suggested by Moshaiov in [15], which allows a flexible definition for Pareto-optimal concepts. This has been further discussed and demonstrated in our recent studies concerning the use of such an approximated C-Pareto-front for multi-objective path planning in robotics [17-18].

C-MOPs are not restricted to Pareto-based optimization. For example, in [19] we have suggested a concept-based goal attainment approach. It is based on a structured EC that employs sub-concepts. In [5], we have developed and demonstrated an interactive version of our concept-based goal attainment approach, in which the interaction contains both user preferences of sub-concepts and concepts, as well as the ability to dynamically change the goal. In other words, it involves both concept-based and range-based preferences. In both studies, [5] and [19], we have concentrated on examples from mechatronics to demonstrate the applicability of both interactive and non-interactive C-MOPs to multi-disciplinary design.

Interactivity concerning user preferences of concepts and sub-concepts has been also studied by us with respect to Pareto-based C-MOPs. We have developed a Pareto-directed C-MOP approach. It constitutes a modification of a Pareto-based C-MOP to include concept-based preferences (see [15] and [20]). In these studies a novel idea of an objective-subjective front has been suggested. In [15] the Pareto-directed C-MOP approach has been demonstrated on a multi-objective interactive path planning problem. In [20], we have developed an approach to handle the amalgamation of sub-concept preferences in Pareto-directed C-MOPs within a hierarchy of abstractive spaces. This approach utilizes the apparent advantages of the simultaneous evolution to share and save computational resources of available individuals, thus directing the search towards optimal solutions, which belong to preferred concepts/sub-concepts.

Another important class of C-MOPs, which we have suggested and explored with an EC solution approach, involves problems that concern robustness, which is inherent to conceptual design. We have concentrated on three different types of robustness including: a. robustness to human preference uncertainty, [21]; b. robustness to delayed decision, [22]; c. robustness to variability and uncertainty of market's demands, [23]. Similarly to the optimality-based C-MOPs, the robustness-based C-MOPs may involve concept-related preferences as well as range-related preferences, which could be implemented interactively. The solution of the above robustness related MOPs, has been achieved by introducing some novel algorithms (e.g., the worst case EC-based optimization in [22]).

All the described investigations of C-MOPs and their solution by EC methods are promising. Yet, as described below, there is a need to further study several issues before practical concept-based tools could be developed.

4. FUTURE RESEARCH DIRECTIONS

The development of the concept-based approach has involved novel ideas, most of which require further studies and elaborations from both computational and engineering design view points. For example, there is a need to develop test suites for the evaluation of algorithms for C-MOPs, and to carry the related studies. Of a particular interest is the exploration versus exploitation dilemma, as related to the concept-based approach. Also, there is a need to examine our methods and algorithms with problems of more than two objectives and with real coding.

In engineering design the selected solution might not necessarily be from the Pareto-optimal set, (e.g., the COGA approach, the interactive concept-based approach). Our studies on C-MOPs have highlighted the need to distinguish between concept robustness and optimality, and to develop measures for these concept selection aspects using the set-based representation of the concepts. Such measures could be used to influence the fitness evaluation and in the development of new variants of C-MOPs. Furthermore, there is a potential in linking our approaches and measures with those of MCDM. Another significant avenue of research is to link concept-based search with concept generation techniques. With this respect it should be noted that the structured approach to C-MOPs as used in [5], and [20], could be a starting point.

We have demonstrated the generic nature of the concept-based approach, yet the significance of our work to other application areas should be studied. For example, the approach can be applied to business and to planning problems. It should also be noted that the concept-based approach might also be attempted with experimental-based evaluations as done in evolutionary robotics. As suggested in [15], and [24], viewing design concepts as sets resembles that of species and may be studied in a cybernetic approach. It can also be applied in A-life studies as indicated in [18].

Further studies on the concept-based approach might lead to the establishment of a practical interactive concept-based EC framework and tools, which will be used to actually support DMs in taking conceptual decisions. As a part of such studies, a comparison of the evolutionary approach with the solution approach taken by Mattson and Messac, and other potential solution approaches, should be done. It is noted that regardless of the attractiveness of using bio-inspired methods, what really counts in computer-supported engineering work is the applicability and optimality of the chosen method. Since that many engineering problems involve time consuming evaluations of solutions, optimizing the computational efforts with respect to available hardware should be a major concern when comparing such methods.

5. SUMMARY

This paper provides an outline of developments on concept-based MOPs and their solution by EC. Our reported studies concern both optimality and robustness of concepts, and the related evolutionary algorithms. We have demonstrated the search and selection of concepts both by the use of only computable models, and by the use of a mixture of computable models with mental models, in an interactive fashion. The overview on the concept-based approach is accompanied by a discussion on possible directions for future research. It suggests that the described approach opens up many new avenues for exploration.

6. REFERENCES

[1] Horvath, I. A Contemporary Survey of Scientific Research into Engineering Design. *Proceedings of the International Conference on Engineering Design, ICED 01 Glasgow, (200*1).

[2] Anderson, J. *Multiobjective Optimisation in Engineering Design Applications to Fluid Power Systems.* Ph.D. Thesis, Linkoping University, Sweden, (2001).

[3] Mattson, C. A., and Messac, A. Pareto Frontier Based Concept Selection under Uncertainty with Visualization. *Optimization and Engineering, 6; (2005) 85–115*.

[4] Avigad, G., Moshaiov, A. Simultaneous Concept-based EMO. A technical report, available from www.eng.tau.ac.il/~moshaiov, also submitted to IEEE Trans on EC (2006).

[5] Avigad, G., Moshaiov, A., and Brauner, N. Concept-based Interactive Brainstorming in Engineering Design. *Journal of Advanced Computational Intelligence and Intelligent Informatics, 8; 5; (2004) 454-459.*

[6] Sobek, D.K., and Ward, A.C. Principles from TOYOTA'S Set-based Concurrent Engineering Process. *Proceedings of the 1996 ASME Design Engineering Technical Conferences and Computers in Engineering Conference, August 18-22, Irvine, California (1996).*

[7] Takagi, H. Interactive Evolutionary Computation: Fusion of the Capacities of EC Optimization and Human Evaluation. *Proc. of the IEEE, 89(9), (2001) 1275-1296.*

[8] Savransky, S.D. *Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving.* CRC Press (2000).

[9] Triantaphyllou, E. *Mulit-Criteria Decision Making Methods: A Comparative Study*. Kluwer Academic Publishers (2000).

[10] Bentley, P.J. (Ed.) *Evolutionary Design by Computers.* Morgan Kaufmann, San Francisco, California, (1999).

[11] Kicinger R., Arciszewski T., and De Jong K. Evolutionary Computation and Structural Design: a Survey of the State of the Art. *Computers and Structures, 83; 23-42; (2005) 1943-1978.*

[12] Coello, C.A.C. Recent Trends in Evolutionary Multiobjective Optimization. in A., Abraham, L. Jain and R. Goldberg (eds.), *Evolutionary Multiobjective Optimization Theoretical Advances And Applications,* Springer-Verlag, London, (2005) 7-32.

[13] Parmee, I.C. Human Centric Intelligent Systems for Design Exploration and Knowledge Discovery. *Proc. of ASCE 2005 Int. Conf. on Computing in Civil Eng. Cancun, Mexico (2005).*

[14] Moshaiov, A., and Avigad, G. Multi-objective Path Planning by the Concept-based IEC Method. P*roceedings of the 2004 IEEE Int. Conference on Computational Cybernetics, ICCC 2004. Vienna, Austria, (2004).*

[15] Moshaiov, A., Multi-objective cybernetics and the concept-based approach: will they ever meet?, Presented at the PPSN 2006 workshop on Multiobjective Problem Solving from Nature, (PPSN 2006), available at: http://dbkgroup.org/knowles/MPSN3/Moshaiov-MO-cybernetics.pdf , 2006.

[16] Srinivas, N., and Deb, K. Multi-objective Function Optimization Using non-dominated Sorting Genetic Algorithms. *Evolutionary Computation, 2, 3 (1995) 221-248.*

[17] Moshaiov, A., and Avigad, G. The Extended Concept-based Multi-objective Path Planning, *Proceedings of MOR workshop*, IROS, China, 2006.

[18] Moshaiov, A., and Avigad, G. The Extended Concept-based Multi-objective Path Planning and its A-life implications. *The proceedings the 1st IEEE Symposium on A-life, in* 2007 IEEE Symposium Series on Computational Intelligence, April 1-5, 2007 Honolulu, Hawaii, USA *(to appear).*

[19] Avigad, G., Moshaiov, A., and Brauner, N. Towards a general tool for mechatronic design. *Proceedings of the 2003 IEEE CSS Conference on Control Applications*, CCA 2003, June 23-25, Istanbul, Turkey, 2003.

[20] Avigad G., Moshaiov A., and Brauner N. Interactive Concept-based Search using MOEA: The Hierarchical Preferences Case. *Int. J. of Computational Intelligence*, 2; 3; (2005) 182-191.

[21] Moshaiov A., and Avigad, G. Concept-based IEC for Multi-objective Search with Robustness to Human Preference Uncertainty. *Proceedings of the IEEE Congress on Evolutionary Computations, (CEC 2006),* pp: 1893-1900, Vancouver, Canada, 2006.

[22] Avigad, G., Moshaiov, A., and Brauner, N. MOEA-based approach to delayed decisions for robust conceptual design. in *Applications of evolutionary computation, Lecture Notes in Computer Science,* LCNS 3449, pp: 584-589, Springer, 2005.

[23] Avigad, G., Moshaiov, A., and Brauner, N. MOEA for concept robustness to variability and uncertainty of market's demands. *In the proceedings of the first EC workshop within the 9-th AI*IA conference on AI.*, September 20-23, 2005 Milan Italy.

[24] Moshaiov, A., Multi-objective design in nature and in the artificial, (Invited keynote paper), in *Proceedings of the 5th International Conference on Mechanics and Materials in Design*, (Eds S.A. Meguid and J.F. S. Gomes), July, 2006.