Gray Coding in Evolutionary Multicriteria Optimization: Application in Frame Structural Optimum Design

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Abstract. A comparative study of the use of Gray coding in multicriteria evolutionary optimisation is performed using the SPEA2 and NSGAII algorithms and applied to a frame structural optimisation problem. A double minimization is handled: constrained mass and number of different cross-section types. Influence of various mutation rates is considered. The comparative statistical results of the test case cover a convergence study during evolution by means of certain metrics that measure front amplitude and distance to the optimal front. Results in a 55 bar-sized frame test case show that the use of the Standard Binary Reflected Gray code compared versus Binary code allows to obtain fast and more accurate solutions, more coverage of non-dominated fronts; both with improved robustness in frame structural multiobjective optimum design.

1 Introduction

Recently, interest in analysis and design of representations and operators for evolutionary computation has been liven up (e.g. a special Issue about this topic of the journal IEEE Transactions on Evolutionary Computation is coming). The motivation of this work is to analyse the influence of an adequate coding in multicriteria optimization, particularly we compare here the use of Gray coding versus binary coding. In multiobjective optimization the search has to deal with multiple requirements: the approximation to the optimum non-dominated front, the achievement of a smooth distribution along the front and also the completion of its maximum coverage [6][8]. So, the codification influence in the search towards the set of optimum solutions should be focused in such a plural way. The choice of the proper coding can have a drastic repercussion in the final results. The smoothness in the correspondence between the phenotypic and the genotypic space is the main claimed advantage of the Gray Code [29][30]. Guarantying this smoothness could be especially critical when the genotypic unit (represented with 0s and 1s) has its phenotypic correspondence in an ordered database, where each gene has a set of associated values, whose magnitudes can vary considerably even in consecutive genes. This is a frequent case when using discrete representation of the chromosome via 0s and 1s, for example in scheduling optimisation problems [10].

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Here a discrete frame structural multicriteria optimization problem belonging to that archetype is handled. The first application of evolutionary algorithms to structural optimization is dated twenty-five years ago [13]: A ten-bar truss is optimized for the minimum constrained mass problem, with continuous variables for the section area of the bars. A pioneer article for frame structures optimization using evolutionary algorithms is [18], where a genetic algorithm is used for the optimal design of skeletal building structures considering discrete sizing, geometrical and topological variables in two design examples. A recent state of the art of structural optimization with special emphasis in evolutionary optimization is [1], where the recent developments in the field, for the period 1980 to 2000, are documented by the ASCE (American Society of Civil Engineering) Technical Committee on Optimal Structural Design of the Technical Administrative Committee on Analysis and Computation. Interesting reviews about multicriteria optimization in structural engineering are [4][5][23], and a set of applications of multicriteria evolutionary optimization in structural and civil engineering are summarized in [6].

The organization of this paper is described as follows: First, the multiobjective frame structural problem is described. Section 3 disserts about the evolutionary approach and the use of Gray Code in multiobjective frame optimization. Section 4 exposes the 55 bar-sized test case. After that, the experimental results are shown in section 5, ending with the conclusions section.

2 Frame Structural Optimum Design

2.1 Definition of the Problem

The frame structural design problem considered has two conflicting objectives: the minimization of the constrained mass and the minimization of the number of different cross-section types considered in the final design. This design problem was introduced in [11], being solved using a combination of weights. It has been solved with elitist multiobjective evolutionary algorithms in [14][15]. Both objectives are explained as follows.

The first objective, the *minimization of the constrained mass* is taken into account to minimize the raw material cost of the designed structure. The constraints consider those conditions that allow the designed frame to carry out its task without collapsing or deforming excessively. The constraints are the following, taking into account the Spanish design code (EA-95) guidelines:

a) Stresses of the bars: where the limit stress depends on the frame material and the comparing stress takes into account the axial and shearing stresses by means of the shear effort, and also the bending effort (a common value for steel is of 260 MPa - S275JR steel -), for each bar:

$$\sigma_{co} - \sigma_{\lim} \leq 0 \tag{1}$$

b) Compressive slenderness limit: where the $\lambda_{\lim}$ value is 200 (to include the buckling effect the evaluation of the β factor, is based on Julian and Lawrence criteria). For each bar: