EC Techniques in the Structural Concrete Field

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INTRODUCTION

Throughout the last decades, one of society's concerns has been the development of new tools to optimize every aspect of daily life. One of the mechanisms that can be applied to this effect is what is nowadays called Artificial Intelligence (AI). This branch of science enables the design of intelligent systems, meaning that they display features that can be associated to human intelligence, search methods being one of the most remarkable. Amongst these, Evolutionary Computation (EC) stands out. This technique is based on the modelling of certain traits of nature, especially the capacity shown by living beings to adapt to their environment, using as a starting point Darwin's Theory of Evolution following the principle of natural selection (Darwin, 1859). These models search for solutions in an automatized way. As a result, a series of search techniques which solve problems in an automatized and parallel way has arisen. The most successful amongst these are Genetic Algorithms (GA) and, more recently, Genetic Programming (GP). The main difference between them is rooted on the way solutions are coded, which implies certain changes in their processing, even though the operation in both systems is similar.

Like most disciplines, the field of Civil Engineering is no stranger to optimization methods, which are applied especially to construction, maintenance or rehabilitation processes (Arciszewski and De Jong, 2001) (Shaw, Miles and Gray, 2003) (Kicinger, Arciszewski and De Jong, 2005). For instance, in Structural Engineering in general and in Structural Concrete in particular, there are a number of problems which are solved simultaneously through theoretical studies, based on physical models, and experimental benchmarks which sanction and adjust the former, where a large amount of factors intervene. In these cases, techniques based on Evolutionary Computation are capable of optimizing constructive processes while accounting for structural safety levels. In this way, for each particular case, the type of materials, their amount, their usage, etc. can be determined, leading to an optimal development of the structure and thus minimizing manufacturing costs (Rabuñal , Varela, Dorado, González and Martínez, 2005).

GENETIC ALGORITHMS

At the origin of what is now known as Genetic Algorithms are the works of John Holland at the end of the 1960's. He initially named them "Reproductive Genetic Planning", and it wasn't until the 70's that they received the name under which they are known today (Holland, 1975).

GA is a search algorithm inspired on the biological functioning of living beings. It is based upon reproductive processes and the principle which determines that better environmetally adapted individuals have more chances of surviving (Goldberg, 1989).

Like living beings, GAs use the basic heritage unit, the gene, to obtain a solution to a problem. The full set of genes (parameters characterizing the problem) is chromosome, and the expression of the chromosome is an individual in particular.

In Computer Science terms, the representation of each individual is a chain, usually binary, assigning a certain number of bits to each parameter. For each variable represented a conversion to discrete valued has to be performed. Obviously, not all parameters have to be coded with the same number of bits. Each one of the bits in a gene is usually called allele. Once the individuals' genotype (the structure for the creation of an individual in particular) is defined, we are ready to carry out the evolutionary process that will reach the solution to the problem posed.

We start with a random set of individuals, called a population. Each of these individuals is a potential solution to the problem. This would be the initial population or zero generation, and successive generations will be created from it until the solution is reached. The mechanisms used in the individuals' evolution are analogous to the functioning of living beings:

- **Selection** of individuals for reproduction. All selection algorithms are based on the choice of individuals by giving higher survival probabilities to those which offer a better solution to the problem, but allowing worse individuals to be also selected so genetic diversity will not be lost. Unselected individuals will be copied through to the following generation.
- Once the individuals have been selected, **crossover** is performed. Typically, two individuals (parents) are crossed to produce two new ones. A position is established before which the bits will correspond to one parent, with the rest belonging to the other. This crossover is named single point crossover, but a number of points could be used, where bit subchains separated by points would belong alternatively to one or the other parent.
- Once the new individuals have been obtained, small variations in a low percentage of them are performed. This is called **mutation**, and its goal is to carry out an exploration in the state space.

Once the process is over, the new individuals will be inserted in the new population, constituting the next generation.

New generations will be produced until the population has created a sufficiently adequate solution, the maximum number of generations has been reached, or the population has converged and all individuals are equal.

GENETIC PROGRAMMING

Genetic Programming (GP), like GAs, is a search mechanism inspired on the functioning of living beings. The greater difference between both methods consists in the way solutions are coded. In this case, it is carried out as a tree structure (Koza, 1990) (Koza, 1992). The main goal of GP is to produce solutions to problems through program and algorithm induction.

The general functioning is similar to that of the GAs. Nevertheless, due to the difference in solution coding, great variations exist in the genetic operations of initial solution generation, crossover and mutation. The rest of operations, selection and replacement algorithms, remain the same, as do the metrics used to evaluate individuals (fitness).

We will now describe two cases where both techniques have been applied. They refer to questions related to Structural Concrete, approached to as both a material and a structure.

EXAMPLE 1: Procedure to determine optimal mixture proportion in High Performance Concrete.

High Performance Concrete (HPC) is a type of concrete designed to attain greater durability together with high resistance and good properties in its fresh state to allow ease of mixing, placing and curing (Forster, 1994) (Neville and Aitcin, 1998) . Its basic components are the same of ordinary concrete, with the intervention in diverse quantities of additions (fly ash or silica fume, byproducts of other industries that display pozzolanic resistance capacities) plus air-entraining and/or fluidifying admixtures. Indeed, an adequate proportion of these components with quality cement, water and aggregates produces concrete with excellent behavior, generally after an experimental process to adjust the optimal content in each material. When very high resistance is not a requirement, the addition introduced is fly ash (FA) ; air-entraining admixtures (AE) are used to improve behavior in frost/defrost situations. When high resistance is needed, FA is substituted by a silica fume (SF) addition, eliminating AE altogether. In every case high cement contents and low water/binder (W/B) ratios are used (both cement and pozzolanic additions are considered binders).

A number of mixture proportioning methods exist, based on experimental approaches and developed by different authors. The product of such mixtures can