Chapter XXXI
How Genetic Algorithms Handle Pareto-Optimality in Design and Manufacturing

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ABSTRACT

An informal analysis is provided for the basic concepts associated with multi-objective optimization and the notion of Pareto-optimality, particularly in the context of genetic algorithms. A number of evolutionary algorithms developed for this purpose are also briefly introduced, and finally, a number of paradigm examples are presented from the materials and manufacturing sectors, where multi-objective genetic algorithms have been successfully utilized in the recent past.

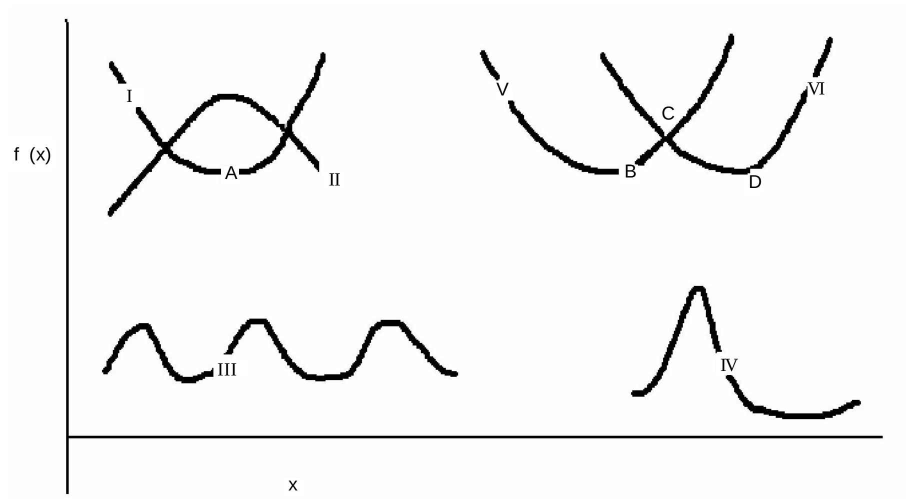
INTRODUCTION

Why Pareto-Optimality and What it is

Making decisions based upon a single criterion is increasingly becoming a difficult task in the complex scenario of design and manufacturing, as we encounter it today. More than one condition routinely affects the complex industrial processes, both at the design and the manufacturing stage. Several criteria that need to be satisfied simultaneously often become conflicting, rendering the search for an absolute and unique optimum in many cases as nearly impossible. I will further elaborate this point using the schematic diagram shown in Figure 1, where a total of six functions (I to VI) are shown schematically and vertical lines drawn through the points A to D would determine some unique combinations, either in the function pairs I and II or V and VI. Now suppose that using these functions we want to accomplish any of the following sets of tasks:

a. Minimize I and at the same time Maximize II
b. Minimize (or Maximize) III and at the same time Minimize (or Maximize) IV
c. Minimize V and at the same time Minimize VI

Figure 1. Elaborating the concept of Pareto-optimality



The point 'A' marked in Figure 1 is perhaps an appropriate choice for the task 'a',[1] and the task 'b' cannot be performed meaningfully, as the functions III and IV exist in the different regimes of the variable space. A close inspection of the functions V and VI will however reveal that an obvious and unique choice is not possible in case of task 'c'. The three points in B, C, and D marked onto functions V and VI lead to the scenario shown in Table 1.

If we use the information provided in Table 1 for a simple comparison between the points B, C, and D, we immediately realize the fact that if any one of them is *better* than another in terms of one objective, either V or VI, then it is invariably *worse* in terms of the other. Such solutions therefore represent a compromise between various objectives and are termed as *non-dominated* solutions. The other possibility would be one solution *dominating* the other. For that to happen the dominating solution should *at least* be as good as the other in terms of *all* the objective functions, and must fare better in terms of *at least* one. This we specifically call a *weak dominance,* since one can, and some people do, implement a *strong dominance* condition which necessitates that the dominating solutions be better in terms of *all* the objective functions.[2]

Table 1. The non-dominated points

	How good in terms of V?	How good in terms of VI?
B	Better than C, Better than D	Worse than C, Worse than D
C	Worse than B, Better than D	Better than B, Worse than D
D	Worse than B, Worse than C	Better than B, Better than C

To put it simply, Pareto-optimality, the elegant concept proposed by Italian mathematician Vilfredo Pareto (1848-1923), amounts to a quest for the best possible non-dominated solutions. The *Pareto-front*[3] is a representation of the Pareto-optimal points in the functional space and represents the best possible compromises or trade-offs between the objectives. Beyond the original concepts of Pareto (1906), an enormous amount of mathematical analyses have already gone into this subject, of which a comprehensive treatise is provided by Miettinen (1999); readers are referred to it.

In the arena of design and manufacturing, the introduction of Pareto-optimality represents