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Genetic algorithms for modelling and optimisation

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Abstract

Genetic algorithms (GAs) are a heuristic search and optimisation technique inspired by natural evolution. They have been successfully applied to a wide range of real-world problems of significant complexity. This paper is intended as an introduction to GAs aimed at immunologists and mathematicians interested in immunology. We describe how to construct a GA and the main strands of GA theory before speculatively identifying possible applications of GAs to the study of immunology. An illustrative example of using a GA for a medical optimal control problem is provided. The paper also includes a brief account of the related area of artificial immune systems.

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Keywords: Genetic algorithms; Immunology; Optimisation; Evolution

1. Introduction

The purpose of this paper is to provide immunologists and mathematicians interested in immunology with an introduction to genetic algorithms (GAs), as a computational technique with potential applications in mathematical immunology. We begin, in Section 2, with some background on the emergence of GAs as a research discipline, inspired by abstraction from natural evolution. The detailed structure of a GA with simple examples of its component parts is presented in Section 3. In Section 4, we explore the key advances that have been made in the theoretical understanding of how GAs operate, though it is a subject where successful application far outstrips the theory. Potential applications of GAs to the study of immunology are introduced in Section 5, which also includes an illustrative account of an application

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of GAs to modelling and optimisation in chemotherapy. Section 5 also contains a brief account of the related area of artificial immune systems. The main conclusions of the paper are presented in Section 6.

2. Background

GAs are a heuristic solution-search or optimisation technique, originally motivated by the Darwinian principle of evolution through (genetic) selection. A GA uses a highly abstract version of evolutionary processes to evolve solutions to given problems. Each GA operates on a population of artificial *chromosomes*. These are strings in a finite alphabet (usually binary). Each chromosome represents a solution to a problem and has a *fitness*, a real number which is a measure of how good a solution it is to the particular problem.

Starting with a randomly generated population of chromosomes, a GA carries out a process of fitness-based selection and recombination to produce a successor population, the next generation. During recombination, parent chromosomes are selected and their genetic material is recombined to produce child chromosomes. These then pass into the successor population. As this process is iterated, a sequence of successive generations evolves and the average fitness of the chromosomes tends to increase until some stopping criterion is reached. In this way, a GA "evolves" a best solution to a given problem.

GAs were first proposed by John Holland [17] as a means to find good solutions to problems that were otherwise computationally intractable. Holland's Schema Theorem [17], and the related building block hypothesis [15], provided a theoretical and conceptual basis for the design of efficient GAs. It also proved straightforward to implement GAs due to their highly modular nature. As a consequence, the field grew quickly and the technique was successfully applied to a wide range of practical problems in science, engineering and industry. GA theory is an active and growing area, with a range of approaches being used to describe and explain phenomena not anticipated by earlier theory [22]. In tandem with this, more sophisticated approaches to directing the evolution of a GA population are aimed at improving performance on classes of problem known to be difficult for GAs [25,16,26]. The development and success of GAs have greatly contributed to a wider interest in computational approaches based on natural phenomena and it is now a major strand of the wider field of Computational Intelligence, which encompasses techniques such as Neural Networks, Ant Colony Optimisation, Particle Swarm Optimisation and Artificial Immunology [13].

Evolution strategies (ESs) developed independently of GAs and began at approximately the same time, in the late 1960s. In common with GA, ESs use a string representation of solutions to some problem and attempt to evolve a good solution through a series of fitness-based evolutionary steps. Unlike GA, an ES will typically not use a population of solutions but instead will make a sequence of mutations of an individual solution, using fitness as a guide [2]. Although of independent origin, the two fields have grown together and evolutionary computation is sometimes now used as an umbrella term for the whole area.

3. The structure of a genetic algorithm

A GA is constructed from a number of distinct components. This is a particular strength because it means that standard components can be re-used, with trivial adaptation in many different GAs, thus easing implementation. The main components are the chromosome encoding, the fitness function, selection, recombination and the evolution scheme.