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GENETIC ALGORITHMS AND ROBOTICS

A Heuristic Strategy for Optimization

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FOREWORD

This series of books and monographs sets out to capture the essence of the current state-of-the-art in Robotics and Automation. Dr Yuval Davidor's book represents an excellent example of this. His book explains, analyses and assesses a novel approach to robotic control which is not only important, but fascinating.

Control strategies for robotic devices based on classical optimization methods are known to be inadequate for important aspects of automated operations. Yet intelligent control is an essential building block of the complex systems constituting advanced robotic installations. Whether robots are used in factory locations for non-trivial tasks or in non-factory, but hazardous environments such as mining, tunnelling or fire fighting, the single major problem facing system designers lies in control engineering. There is a clear need for control strategies which are flexible, but sufficiently 'intelligent' to guide and monitor complex interactions of remotely controlled mechanisms.

Dr Davidor argues convincingly that genetic algorithms offer the scope to help achieve such flexibility in the face of complexity. His book explains the fundamentals underlying genetic algorithms in terminology readily understood by the scientist, engineer or mathematician. He develops his theme to show that existing applications can be extended by using genetic algorithms to generate robot trajectories. He goes on to develop a genetic algorithmic approach

which is capable of specifying near optimum trajectories.

Genetic algorithms as a topic of study is set to grow rapidly, and there is a rapidly expanding research community drawn from mathematicians, computer scientists, engineers and biologists around the world. The research community focussing on robotic control engineering is already large and growing fast. Dr Davidor's book has much to offer both communities. His novel and original analyses of a highly interdisciplinary field of investigation seems likely to establish a valuable foundation for new, strategic and effective methodologies.

Professor T. M. Husband
Imperial College
London

PREFACE

This book grew out of research activity I conducted at the Centre for Robotics and the Department of Computing at Imperial College, London, during the years 1986-89, for my doctoral dissertation. While working on process control problems in robotics, I stumbled on a problem which classical optimization techniques could not adequately solve – the optimization of redundant and under-specified systems. I seemed to be stuck. One evening, a phone call from a friend drew my attention to a television programme in which the person interviewed spoke about the type of problems I was trying to solve. I caught the second half of the BBC Horizon episode entitled: *The Blind Watchmaker*. The person interviewed was Professor John H. Holland of the University of Michigan. I obtained the address of Professor Holland from the BBC and wrote to him, only to discover later that he is the 'father' of what is called *genetic algorithms* – a model of adaptation in natural and artificial systems. A model of adaptation which not only offers a powerful optimizing leverage with which a diverse range of engineering problems can be processed, but also sheds new light on the intriguing mechanisms of evolution. Genetic algorithms have been applied to a diverse range of problems. Problems which range from real world applications such as flow control of a gas pipeline, design of airfoil profiles, robot trajectory planning and electronics, to more theoretical problems of combinatorics, game theory, economics and machine learning. For me, the

television programme has marked the beginning of an enchanting research odyssey into the secrets of natural adaptation and the mechanisms of evolution – a research odyssey which still continues.

The material covered in this book is interdisciplinary in nature. It combines topics from population genetics, control theory, manufacturing technology, and aspects of computer science. It does this by applying a genetic algorithm (GA), a heuristic probabilistic search procedure, to the domain of robotics. Rather than reproduce good work already available in the literature on the essentials of the above subjects, this book intends to give a detailed description of how to apply a GA to real world problems as it has not thus far received proper treatment. I have chosen as a model the generation of robot trajectories. The choice of the specific problem was motivated by the fact that trajectory generation applies to many process control issues in manufacturing. By applying a GA to a real world problem, such as the generation and optimization of robot trajectories, considerable insight is acquired into the workings of GAs and into the aspects of the human interface with complex domains. It is with this intention and in this spirit that this book is presented – to attempt to provide a clear introduction to the workings of GAs in the context of optimization of large, complex and redundant systems. It is only as a means of introducing and treating the aspects mentioned above that this book tries to provide the basic tools for acquiring an intuitive understanding as to what GAs are, how they work and when it might be rewarding to use them.

The book is divided into two parts. Part I describes GAs and constitutes an illustrative introduction to the art and practice of these special search procedures. It also attempts to provide an answer to that in genetic algorithms which brings computer procedures and nature so intimately together. Part II gives a detailed description of an application of a GA model in the generation and optimization domain of robot trajectories. There are three chapters at the end of Part II which are devoted to some general aspects of learning and adaptation. The subjects of these three chapters emerged from the GA model and the considerable similarity between the model and natural phenomena.

ACKNOWLEDGEMENTS

While enjoying myself with the research, I got to know people who not only helped me with my work, but who also impressed me with their personality. Some of them, as often happens, may not even be aware of the extent of influence they had on me, and the book. Their extensive contribution to the book, to my knowledge and understanding of the subject, is most appreciated. To them, and to their unstinted interest in research, I owe a sincere gratitude. I wish to thank the Centre for Robotics and Automated Systems, and the Department of Computing at Imperial College, where most of this work was carried out.

I particularly want to thank Antonia Jones, of the Department of Computing at Imperial College, who served as one of my dissertation supervisors, taught me scientific discipline, and tried to educate me in the art of coherent writing. I enjoyed her unconditional support and benefitted greatly from her patience and knowledge. I thank Tom Westerdale, of Birkbeck College, who was a well of unpublished history of GAs and a wall against which I could bounce ideas. I thank Tom Husband, the Head of the Department of Mechanical Engineering at Imperial College, whose support I enjoyed throughout and who enabled me to ride some tempestuous incidents during my stay at the Centre for Robotics and Automated Systems. I also want to thank David Goldberg, of the University of Alabama, for his ongoing support and advice

extended wholeheartedly over the last couple of years, and for comments which helped me improve the quality of my scientific work.

I want to express special thanks to Leon Zlajpah of Jozef Stefan Institute, Yugoslavia, for allowing me the free use of a robot dynamic simulation he developed, and for active support in tailoring the simulation to suit the special requirements set by this work.

Finally, I wish to thank Einat Delman who had to put up with my capriciousness while designing the cover for this book.

PART I

THE GENETIC ALGORITHMS PHILOSOPHY

CONTENTS

Chapter 1
YET ANOTHER SEARCH METHOD

Robot systems are an example of systems that are the result of the integration of a medley of subsystems and feedback loops where literally hundreds of variables may affect their operation. The core problem in robot process control, and also a frequent problem in many other systems, is that the optimal values of the system's control parameters are not known, and there is no straightforward algorithm to discover them. Traditional optimization techniques, such as self tuning and adaptive control, depend too greatly on a deterministic relationship between the control parameters and the resulting performance; an explicit effect of an input signal on the performance of the system. These techniques have improved, but are unable to optimize the performance of very complex systems.

Attempts have been made (in the manufacturing environment) to overcome the effect of this plethora of parameters influencing the performance by recording all the relevant data, and developing procedures to handle and interpret these data. These attempts have avoided the main issue as the programmer of these control procedures is still required to possess a thorough understanding of the system's basic concepts; an understanding which he often does not have, nor has the time to acquire. The success, which conventional procedures do achieve, is either in situations where the system can be modelled with sufficient accuracy, or when the number of plausible parameter values is