The Foundations of Cybernetics

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The Foundations of Cybernetics

Preface

In this book I have tried to summarise the principal features of cybernetics as I see them. As far as detail is concerned, I have tried to concentrate on examples which seem to illustrate the points made in each branch of the subject. There has of course been, as is inevitable, a time gap between the completion of the text and of the writing of this preface and a further gap which must occur prior to publication. This matters less in a book of this kind, which is concerned with examining and describing *basic principles* which are slow-changing and illustrating them with selected detail, than it would in a description of a new theory or a detailed analysis which aims to be wholly contemporary. The reader must still though make allowance for such time delays.

My own view of cybernetics is of a discipline with its "pure" and "applied" side. This book is mainly concerned with the "pure" side, and this means it is to a great extent concerned with what is called artificial intelligence (sometimes called machine intelligence). But the overlap with psychology, physiology and education are clearcut, and we have, in the text, discussed these overlapping fields in some measure. The overlap of cybernetics with sociology, business and economics on the other hand – which is perhaps one stage further removed into the applied field – we have not discussed at all. These do seem to merit separate texts.

One report that has appeared in recent years – the so-called Lighthill report – sheds some light on our subject, and we should at least mention it. It divides the field of artificial intelligence into two main branches which are essentially neurobiological (including behavioural studies) and automation (mainly special purpose automatic control systems). It accepts progress in these fields, but views it as disappointing, and regards the bridge between the two as virtually non-existent. It is this bridge category (in the terminology of the Lighthill report) that this book is largely concerned with.

The Lighthill report contributes positively in drawing attention to:

1) The difficulties encountered in a very complicated field, and reminds us in effect that all sciences go through periods where the extent of things-still-to-be-done weighs heavily – or appears to – against what has already been achieved.

2) The viewpoint adopted to what has been written in cybernetics, comes from an outside authority – an established scientist in his own fairly closely allied field, and such a view is of value to us who are perhaps too close to the subject to see it critically enough.

But against this, the report is inevitably superficial, and in particular:

1) It fails to appreciate the importance of heuristics. They are not of course second best in any sense, but represent the best possible methods used for many high level processes such as occur in thinking, planning and problem solving.

2) It talks in terms of the "combinatorial explosion" relative to the control systems needed for artificially intelligence purposes. If this, admittedly complicated, problem were insuperable then human beings themselves would not exist.

3) It fails altogether to appreciate the breadth and depth of the subject, principally because of a lack of familiarity with the literature. Such reports however – especially coming as this did from outside the subject – are of value to us within the subject if only because they allow us to analyse and evaluate the the development of cybernetics.

I have omitted to mention in this book much work of considerable cybernetic merit", such as that published by the Edinburgh group in their series of excellent books entitled "Machine Intelligence", and many articles that have appeared in the journal "Artificial Intelligence". Other work of special interest includes that of Dr. Feigenbaum on "Heuristic Dendril", and the work of Dr. Winograd in his book "Natural Language Programming" (Edinburgh University Press, 1972), a very exciting book by Russell Ackoff and M. E. Emery "On Purposefulness Systems" (Tavistock Publications, 1961) and Stafford Beer's "Platform for Change" (Wiley, 1975), and we could list many more which are not though referred to in the text.

These references have been omitted either because the work came too late to be assimilated by me or it seemed either too advanced or insufficiently central to my theme to illustrate the basic principles of the subject as I see them. The interested reader should follow up the above clues if they are interested in the broadening and deepening of their knowledge of the subject.

Finally let it be said that I hope this book will be found to be useful to many students of cybernetics at all levels, but rather especially it should give an adequate and broad account of its development as of this time to undergraduates and post-graduates in this or allied subjects.

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CHAPTER 1

The fundamentals of cybernetics

Argument

In this first chapter we discuss the fundamentals of cybernetics. We also discuss where this book fits into the cybernetic literature – especially its relation to the author's own previous books on the subject.

Cybernetics is a study of control and communication systems, both in hardware and theory. It studies its occurrence both in animals and men. In one sense, the basic question has been "could machines be made to think?" but in another sense this does not matter; what matters is that machines can be made to do many complicated things for us. The point being that we might on one hand want to know whether we can design a machine more intelligent than ourselves, or we might want merely to take advantage of whatever help is available in the field of automatic control systems.

1.1 OVERVIEW

In this first chapter, it is intended to give an overview of the whole book. To allow the reader to pick his way carefully among the points of contact of various so-called disciplines and see where they have a common overlap within cybernetics.

The choice of the word "cybernetics" as a name for the subject was Norbert Wiener's (1948), and it goes without saying that there are many different ways of regarding cybernetics. We might have thought of it as information science, or information technology or even automata theory; indeed there are a large number of possible titles which more or less suitably depict this new science.

The choice of titles still leaves doubts as to the viewpoint to be adopted. We shall be thinking primarily of mathematics, logic, automata and computing as methods, and the simulation and synthesis of organismic "mainly human" behaviour as the principal aims.

The author has previously written a number of books and papers on cybernetics and allied topics, and there is therefore some need to distinguish this book from the previous ones and also to try to give some justification for the fact that this book has been written. The first book "Automation, Cybernetics and Society" (1959) was written as a semi-popular introduction to the subject from a somewhat "applied" point of view. "The Brain as a Computer" (1961 Edition II, 1973) was intended to be a detailed research orientated approach to

the biological and behavioural applications of cybernetics. "Cybernetics and Biology" (1965) was an outline account of biological applications of cybernetics intended for biologists only. Finally, "Models of Thinking", which was published early in 1970, is a research monograph for postgraduates and research workers in the field of cognition. None of these books provides an introduction to cybernetics from an "all-round" viewpoint aimed primarily at the undergraduate. This book aims to provide just such an introductory text.

Cybernetics has background roots in mathematics, philosophy, psychology, physiology, philosophy of science and logic, at the very least. These subjects are themselves interrelated in a fairly complicated manner. We cannot, for example, discuss in *detail* the mathematical side of the subject; some of the subject matter of set theory, recursive functions, mathematical logic, meta-mathematics, etc. must though be mentioned. All we can hope to do is to supply an outline account of the relation of these fields to automata and automata theory, and clarify the reason for studying automata within cybernetics.

We can make up for the above omission by giving a fairly lengthy list of references for each such related set of topics. With this set of references we can and shall indicate the manner in which these closely allied topics might be followed up in depth. It is rather as if our treatise is on "ball games" and we cannot sensibly give a detailed account of baseball or cricket, but we can summarize them and their development, and provide detailed references, with notes, to allow for the follow-up for those who are interested in the detail.

With this agreement as to how we are going to treat the relation of cybernetics to its forebears, we may proceed to our main purpose. Before each chapter we shall state the theme with which the chapter is concerned, and after each chapter we shall try and summarize the actual findings. The theme is intended to be abstract and the findings are intended to be relatively concrete.

For the person to whom cybernetics is peripheral, to read the abstract of each chapter, and the summary, will give him a fair idea as to the nature of the subject. We shall also in each chapter try to bring the reader up to date, with a brief summary of current progress in that aspect of cybernetics.

1.2 THE VIEWPOINT

The word "cybernetics" itself was, as we have already mentioned, first suggested by Norbert Wiener (1948) as the name for the new science of control and communication both in animals and man and indeed, of course, machines. He felt that there was a need to separate out, and study in their own right, the problems common to control and communication, which had their original background in physics, electrical engineering, computer engineering, philosophy, mathematics, physiology, psychology, psychiatry, sociology, and other sciences.

In spite of their varied origins, these subjects were all thought by Norbert Wiener to have some common features and it is these which we refer to collectively as cybernetics, and therefore the associated problems we shall call cybernetic problems.

Cybernetics therefore has a subject matter of great breadth – although the subject is primarily concerned with certain specific features of control and communication, especially those that synthesise (copy in terms of ends rather than means) or simulate (copy in terms of both ends *and* means) organismic behaviour. The first and most important point about cybernetics is that for many purposes it intentionally overlooks the distinction that is usually made between "living" and "non-living" systems. It is felt that scientific methods, especially mathematics, can be applied as effectively to biological and social systems as to inanimate systems; these are mainly physical and chemical systems. Secondly, cybernetics includes the concept of *negative feedback* and also feed-forward as central themes. It is from these concepts that the notions of adaptive systems and selectively reinforced systems arise; these are systems that modify their behaviour in the light of a changing environment and it is from these features that our simulation of organismic behaviour is derived.

Behaviour which is modified as a result of experience we call "adaptive". This includes simple adaptation from negative feedback and more complete adaptation through learning. Learning itself, in the more advanced sense, depends directly on what we call "selective reinforcement". This is the process of positively reinforcing satisfying and successful acts and negatively reinforcing unsatisfying or unsuccessful acts; more simply, it is a matter of having knowledge for future use. If we are right in an action, we must know we are right, and if we are wrong, we must know we are wrong; and in each case it is preferable to know *why* we were right or wrong.

Cybernetics is, in another sense, the search for precision. Precision may be achieved in part by introducing mathematics or logic into a subject. In cybernetics this has been done, but it is not always a mathematical model that we seek; we seek sometimes to have hardware models and sometimes verbal models which may still carry the required precision. In any case, the model must be *effective* and we shall be returning frequently to this question of effectiveness since this, perhaps more than any other single feature, is the key to cybernetics and to cybernetic thinking.

The philosophical problem of artificial intelligence is something that should also be considered, since some people feel there are basic philosophical problems concerned with our search to simulate human behaviour.

The question which is sometimes asked is: "Can (or could) machines be made to think?". This question has practical importance, since there still exists a body of opinion which regards *machines* as fundamentally different from *organisms.* Initially, we must notice that our question of machines thinking is difficult to