

Preface to the First Edition

The present volume is intended as a contribution to the theory of those systems which contain internal predictive models of themselves and/or of their environment, and which utilize the predictions of their models to control their present behavior.

Systems of this type have a variety of properties which are unique to them, just as “closed-loop” systems have properties which make them different from “open-loop” systems. It is most important to understand these properties, for many reasons. We shall argue that much, if not most, biological behavior is model-based in this sense. This is true at every level, from the molecular to the cellular to the physiological to the behavioral. Moreover, model-based behavior is the essence of social and political activity. An understanding of the characteristics of model-based behavior is thus central to any technology we wish to develop to control such systems, or to modify their model-based behavior in new ways.

The essential novelty in our approach is that we consider such systems as single entities, and relate their overall properties to the character of the models they contain. There have, of course, been many approaches to planning, forecasting, and decision-making, but these tend to concentrate on tactical aspects of model synthesis and model deployment in specific circumstances; they do not deal with the behavioral correlates arising throughout a system simply from the fact that present behavior is generated in terms of a predicted future situation. For this reason, we shall not at all be concerned with tactical aspects of this type; we do not consider, for instance, the various procedures of extrapolation and correlation which dominate much of the literature concerned with decision-making in an uncertain or incompletely defined environment. We are concerned rather with global properties of model-based behavior, irrespective of how the model is generated, or indeed of whether it is a “good” model or not.

From the very outset, we shall find that the study of such global aspects of model-based behavior raises new questions of a basic epistemological character. Indeed, we shall see that the utilization of predictive models for purposes of present control confront us with problems relating to causality. It has long been axiomatic that system behavior in the present must never depend upon future states or future inputs; systems which violate this basic axiom are collectively called *anticipatory*, and are

routinely excluded from science. On the other hand, the presence of a predictive model serves precisely to pull the future into the present; a system with a “good” model thus behaves in many ways like a true anticipatory system. We must thus reconsider what is meant by an anticipatory system; the suggestion arising from the present work is that model-based behavior requires an entirely new paradigm, which we call an “anticipatory paradigm”, to accommodate it. This paradigm extends (but does not replace) the “reactive paradigm” which has hitherto dominated the study of natural systems, and allows us a glimpse of new and important aspects of system behavior.

The main theoretical questions with which we deal in the present work are the following: (a) What is a model? (b) What is a *predictive* model? (c) How does a system which contains a predictive model differ in its behavior from one which does not? In the process of exploring these questions, starting from first principles, we are led to a re-examination of many basic concepts: time, measurement, language, complexity. Since the modeling relation plays a central role in the discussion, we provide numerous illustrations of it, starting from models arising entirely within symbolic systems (mathematics) through physics, chemistry and biology. Only when the modeling relation is thoroughly clarified can we begin to formulate the basic problems of model-based behavior, and develop some of the properties of systems of the kind with which we are concerned.

It is a pleasure to acknowledge the assistance of many friends and colleagues who have aided me in developing the circle of ideas to be expounded below. A primary debt is owed to my teacher, Nicolas Rashevsky, who above all set an example of fearlessness in entering territory which others thought forbidden. An equally important debt is owed to Robert Hutchins, and to the Center which he created; it was there that I was first forced to confront the nature of anticipatory behavior. A third debt is to my colleagues at the Center for Theoretical Biology: James F. Danielli, Howard Pattee, Narendra Goel, and Martynas Ycas, for their intellectual stimulation and support over the years. Gratitude must also be expressed to Dalhousie University, where thought and the leisure to think are still valued, and especially to my colleague I.W. Richardson.

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Anticipatory Systems

Philosophical, Mathematical, and Methodological
Foundations

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2012, LX, 472 p., Hardcover

ISBN: 978-1-4614-1268-7