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INFORMATION FLOW

The Logic of Distributed Systems

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In the same way, the world is not the sum of all the things that are in it. It is the infinitely complex network of connections among them. As in the meanings of words, things take on meaning only in relationship to each other.

The Invention of Solitude Paul Auster

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Preface

Information and talk of information is everywhere nowadays. Computers are thought of as information technology. Each living thing has a structure determined by information encoded in its DNA. Governments and companies spend vast fortunes to acquire information. People go to prison for the illicit use of information. In spite of all this, there is no accepted science of information. What *is* information? How is it possible for one thing to carry information about another? This book proposes answers to these questions.

But why does information matter, why is it so important? An obvious answer motivates the direction our theory takes. Living creatures rely on the regularity of their environment for almost everything they do. Successful perception, locomotion, reasoning, and planning all depend on the existence of a stable relationship between the agents and the world around them, near and far. The importance of regularity underlies the view of agents as information processors. The ability to gather information about parts of the world, often remote in time and space, and to use that information to plan and act successfully, depends on the existence of regularities. If the world were a completely chaotic, unpredictable affair, there would be no information to process.

Still, the place of information in the natural world of biological and physical systems is far from clear. A major problem is the lack of a general theory of regularity. In determining which aspects of the behavior of a system are regular, we typically defer to the scientific discipline suited to the task. For regularities in the movements of birds across large distances, we consult experts in ornithology; but if the movements are of bright lights in the night sky, we'd be better off with an astronomer. Each specialist provides an explanation using a theory or model suited to the specialty.

To whom can we turn for questions about information itself? Can there be a science of information? We think so and propose to lay its foundations in this book. Out of the wide variety of models, theories, and less formal modes of explanation used by specialists, we aim to extract what is essential to understanding the flow of information.

How to Read This Book

This book has several intended audiences, some interested in the big picture but not too concerned about the mathematical details, the other of the opposite sort. Here is a brief outline of the book, followed by indications of which parts various readers will want to read, and in what order.

Introduction to the Theory. The book has three parts. Part I contains a discussion of the motivations for a model of this kind and surveys some related work on information. An overview of our information-channel model is presented, and a simple but detailed example is worked out.

Development of the Theory. The heart of the book is in Part II and consists of a detailed elaboration of the mathematical model described in Part I. Although the basic picture presented in Part I is reasonably simple, there is a lot of mathematical spadework to be done to fill in the details. The mathematical part of the book culminates in a theory of inference and error using "local logics" in Lectures 12–16.

Applications of the Theory. The lectures in Part III explore some ideas for an assortment of applications, namely, applications to speech acts, vagueness, commonsense reasoning (focusing on monoticity and on the frame problem), representation, and quantum logic. Although there is some truth to the old saw that to a person with a hammer, everything looks like a nail, a wise person with a new tool tests it to see what its strengths and weaknesses are. It is in this spirit that we offer the "explorations" of Part III. We are interested in pounding nails but are equally interested in exploring our new hammer.

We have written the book so that philosophers and others less patient with mathematical detail can read Part I and then have a look through Part III for topics of interest. Mathematicians, logicians, and computer scientists less patient with philosophical issues might prefer to start with Lecture 2, and then turn to Part II, followed perhaps by poking around in Part III. Researchers in artificial intelligence would probably also want to start with Lecture 2 and some of the chapters in Part III, followed by a perusal of Parts I and II.

An index of definitions used in Part II, and a glossary of special notation used in Part II, can be found at the end of the book.

Mathematical Prerequisites. Although some familiarity with modern logic would be helpful in understanding the motivations for some of the topics we cover, the book really only requires familiarity with basic set theory of the sort used in most undergraduate mathematics courses. We review here some more or less standard notational conventions we follow.

If $a = \langle x, y \rangle$ is an ordered pair, then we write $1^{st}(a) = x$ and $2^{nd}(a) = y$. Given a function $f: X \to Y$, we write $f[X_0] = \{f(x) \mid x \in X_0\}$ (for $X_0 \subseteq X$) and $f^{-1}[Y_0] = \{x \in X \mid f(x) \in Y_0\}$ (for $Y_0 \subseteq Y$). By the range of f we mean $f[X]$. Given functions $f: X \to Y$ and $g: Y \to Z$, gf is the function that results from composing them to get the function $gf: X \to Z$ defined by $gf(x) = g(f(x))$. For any set A, pow A is its power set, that is, the set of all its subsets. If $\mathcal{X}$ is a set of subsets of A, then

$$\bigcup \mathcal{X} = \{x \in A \mid x \in X \text{ for some } X \in \mathcal{X}\}$$

and

$$\bigcap \mathcal{X} = \{x \in A \mid x \in X \text{ for all } X \in \mathcal{X}\}.$$

If $\mathcal{X}$ is empty, then so is $\bigcup \mathcal{X}$ but $\bigcap \mathcal{X} = A$.

The appearance of many diagrams may suggest that the book uses category theory. This suggestion is both correct and misleading. Category theory arose from the realization that the same kinds of diagrams appear in many branches of mathematics, so it is not surprising that some of these diagrams appear here. We must confess that we have found the basic perspective of category theory to be quite helpful as a guide in developing the theory. And, as it turned out, some of the category-theoretic notions (coproducts and, more generally, colimits) have an important information-theoretic interpretation. In writing this book we have tried to make clear the debt we owe to ideas from category theory, but, at the same time, not presuppose any familiarity with category theory, except in those exercises marked by a (†).

In mathematics it is typical practice to call the hard results "theorems" and the easier results "propositions." Because none of our results are very hard, we use "theorem" to designate the results that are most important to the overall theory we are developing. As a result, some of our theorems are simpler than some of our propositions.

World Wide Web Site. We have set up a home page for this book, to facilitate the distribution of developments based on the ideas presented here, as well as for any corrections that may need to be made. Its URL is

`http://www.phil.indiana.edu/~barwise/ifpage.html.`

You can also send us e-mail from this page.

Acknowledgments

This book has been in the making for well over a decade. Barwise's attempts at trying to understand information flow date back at least to his book written with John Perry, *Situations and Attitudes*, which appeared in 1983, and include the following papers: Barwise (1986), Barwise (1983), Barwise (1989), Barwise (1991), Barwise and Etchemendy (1990), Barwise, Gabbay, and Hartonas (1996), Barwise (1993), and Barwise and Seligman (1994). Seligman has been working on the same topic since starting his dissertation, which was completed in 1991; see Seligman (1990), Seligman (1991b), Seligman (1991a), and Barwise and Seligman (1994). The theory developed in this book is the product of an intense collaboration between the authors over the past four years. We started working together on the topic during 1992–93, when Seligman was at Indiana University on a postdoctoral fellowship. Two drafts of Parts I and II were written during the academic year 1994–95, when Seligman returned to Indiana University for a year's visit. The explorations in Part III were undertaken by Barwise in 1995–96. During that year, Parts I and II were revised by the two of us, exploiting regularities of the internet to facilitate massive amounts of information flow.

Both authors have previously contributed to the development of situation theory, a programmatic theory of information whose roots go back to *Situations and Attitudes*, discussed at length in Barwise (1989) and further developed in Devlin (1991). Though not presupposing familiarity with situation theory, the present book can be seen as a contribution to that subject by considering those tokens that are situations or events, classified using "infons" as types. Indeed, we consider the notion of a constraint to be the most important notion of situation theory and have tried, in this book, to make this notion less problematic. The task of reconciling the development of the ideas presented here with other details of situation theory remains to be undertaken.

We express our gratitude to Robin Cooper for providing the initial connection between the two of us, to Faber and Faber for permission to use the quotation from Paul Auster's *The Invention of Solitude*, to Indiana University (I.U.) for support of many kinds, to the I.U. Computer Science and Philosophy class

that worked through an earlier and much more opaque version during the fall of 1994, to the Situation Theory and Situation Semantics seminar at the Center for the Study of Language and Information (CSLI) for their interest in these topics over the years, to Imperial College for hospitality and support while Barwise wrote a draft of the first two lectures during July of 1995, to the members of the I.U. Program in Pure and Applied Logic for their support over the years, to Michael Dickson and Kenneth Kunen for helpful comments on the quantum logic chapter, to various readers, including Gerry Allwein, Kata Bimbo, Tony Chemero, Diarmuid Crowley, Steve Crowley, Albert Chapman-Leyland, Keith Devlin, Yuko Murakami, and an anonymous referee for helpful comments that have helped us improve the book, to Mary Jane Wilcox for assistance with proofreading, to Lauren Cowles of Cambridge University Press for her help of many kinds, to our families for putting up with us as we wrestled with the ideas that led to the theory, and to the members of the audiences at many talks we have given on this material over the past few years for their interest and questions. Finally, we thank you, the reader, for your attention to our book.

JON BARWISE
August 1996 JERRY SELIGMAN