# Foreword

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Human beings have been curious since ancient times about how they draw inferences that extend their information beyond what they already know. Aristotelean logic and Euclidean geometry were major and abiding contributions of the Greeks to this question, dealing, respectively, with two of its major aspects: reasoning in language (natural or formal) and drawing inferences from diagrams or other pictorial sources.

That reasoning using language and using diagrams were different, at least in important respects, was brought home by the Pythagorean discovery of irrational numbers. Although irrationals found no place among the integers or fractions, they were essential for representing the lengths of lines in geometric diagrams: for example, the ratio of the diagonal to the side of the square and of the circumference to the diameter of the circle. It has even been suggested that this ability of diagrams to represent irrationals that arithmetic could not handle was a main motive for Euclid's developing his scheme of geometrical reasoning.

Linguistic (algebraic) and diagrammatic representations found common ground for a time with Descartes' invention of analytic geometry. And, with the legitimation of the irrational (real) numbers in the 19th Century by Dedekind, symbolic mathematics threatened to swallow up geometry, especially its diagrams. In fact, because certain paradoxes could be derived from cleverly (or carelessly) constructed diagrams, the use of diagrams to carry out proofs, even in geometry, became increasingly unfashionable. Rigor, it was believed, called for reasoning to be formalized in symbols arranged in sentences or equations. Even natural language was insufficient, and around the turn of this Century, logic and mathematics were wedded by the work of Frege and of Whitehead and Russell. Rigorous reasoning came to mean reasoning in the formal languages of logic and mathematics.

Justice Oliver Wendell Holmes declared that "rigor is not the life of the law." It is equally the case that rigor is not the life of thought. Most thinking in which human beings engage, even in highly mathematical fields like physics or economics, is not rigorous in the sense in which logicians and pure mathematicians use that term. Words, equations, and diagrams are not just a machinery to guarantee that our conclusions follow from their premises. In their everyday use, their real importance lies in the aid they give us in reaching the conclusions in the first place.

Noting how radically our reasoning differs from the standards of formal logic, we call it "intuitive." Sometimes we even say that it requires "insight" or (in our less modest moments) "creativity." The inference processes we use are heuristic processes that aid search and discovery. They often reach the desired end, relatively seldom deceive us, but are fallible enough so that it is usually worth while to check them, at least qualitatively, by more formal methods or against factual evidence.

For example: *I notice a balance beam, with a weight hanging from a two-foot arm. The other arm is one foot long. How much force must I apply to it to balance the weight?* Do we know what kind of reasoning we use to answer this question? Is it verbal reasoning? If so, what are its axioms and rules of inference, and where do they come from? Are the axioms logical, or do they embody laws of physics? Do we make use of the diagram of the balance that we (most of us) can see in our Minds' Eyes? If so, what processes do we use to conclude that, as the one arm of the balance is twice as long as the other, the force on the short arm must be twice as great as the weight?

Whatever processes we use in solving problems like these, they are processes for *finding* answers, and the *assurance* they give that the answers are correct, while important, is only secondary. Until we find answers, their correctness is hardly in contention.

However much, thanks to Descartes and Dedekind and others, we can see the logical identity (knowledge equivalence) of symbolic and diagrammatic representations of a given problem, that identity does not imply that it is equally easy to reason in both kinds of representations, or that we will be able to draw the same inferences from both. Representations may be equivalent in the knowledge embedded in them without being equivalent in the power and speed of the inference processes they enable. They may be informationally equivalent without being computationally equivalent.

This book reports nearly two dozen recent investigations into the logical, and especially the computational, characteristics of diagrammatic representations and the reasoning that can be done with them. Its chapters provide a view of the recent history of the subject, survey and extend the underlying theory of diagrammatic representation, and provide numerous examples of diagrammatic reasoning, human and mechanical, that illustrate its powers (and limitations).

Research in diagrammatic reasoning has two goals, beyond the fundamental goal of understanding the phenomena and their processes. The first is to deepen our understanding of ourselves and the ways in which we think. That deeper understanding is already beginning to enhance our sophistication and effectiveness in using visual displays, in books and on computer screens, to communicate and teach. The second goal is to provide an essential scientific base for constructing representations of diagrammatic information that can be stored and processed by computers, enabling computers to achieve some of the computational efficiencies in their thinking that diagrams now provide to human beings.

As we progress toward these two goals, understanding diagrammatic thinking will be of special importance to those who design human-computer interfaces, where the diagrams presented on computer screens must find their way to the Mind's Eye, there to be processed and reasoned about. In a society that is preoccupied with "Information Superhighways," a deep understanding of diagrammatic reasoning will be essential to keep the traffic moving on those highways, and even more, to give us tools to help cope with, and even make constructive use of, the mass of information that we now know how to generate.