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Book review

The Essence of Chaos by Edward N. Lorenz (University of Washington Press, 1993). ISBN 0-295-97270-X, 227 pp, $US19.95.

In 1990 Prof. Lorenz was invited to give the Jessie and John Danz public lectures at the University of Washington. The topic he chose was one that has absorbed his interest for more than thirty years, *The Essence of Chaos*. This book, which is an expanded version of his lectures, allows both the beginner and expert to learn from a master. Clearly a lot of thought has gone into the presentation.

In the first chapter Lorenz carefully builds up a definition of chaos and uses several familiar, real-life examples, a flapping flag, a pinball machine, the beating of a heart to illustrate basic concepts, such as randomness, determinism, sensitivity to initial conditions, non-periodicity and compactness. In the second chapter he introduces the examples of a runaway ski or skiboard (which is subject to friction, but has no steering) and a sled (which has brakes, but no steering system). Both of these travel down a mogul hill (i.e. a hill covered by a pattern of regular humps and valleys). With these examples Lorenz graphically demonstrates what sensitivity to initial conditions means and illustrates the concepts of strange attractors, phase space, orbits, Poincaré sections, and basins of attraction. He also examines the dynamics of Hamiltonian systems (conservative systems without dissipative processes) with his runaway ski by eliminating the friction and the downhill slope. Lastly he uses his ski slope example to show how a process can move into and out of chaos.

With this foundation Lorenz is ready to examine the question of predictability in Chapter 3. 'Why can't we make better weather forecasts?' Can we show that the atmosphere is chaotic? The global weather system, he explains, is so complicated that to conclude that it is a compact system would take an enormous (but finite) number of variables. Observations of weather variations which, when the periodic or suspected periodic signals are removed, leave a strong irregular signal and the impression that the atmosphere is chaotic. Searching for additional evidence, he describes the dishpan and annuli analogue experiments of the atmosphere performed by Dave Fultz, Raymond Hyde and Alan Faller which exhibit uniform wave motion, but also irregular behaviour. The other line of investigation that he pursues is numerical simulation of the atmosphere from Jacob Bjerknes and Lewis Richardson to the ECMWF model (which as of 1991 had five million variables). These numerical models show sensitive dependence on initial conditions. Increasing the global model resolution to very small scales capable of properly representing individual thunderstorms, he argues, will only extend the predictability of the model by a few hours. Instead he recommends better resolution of the synoptic-scale structures already present in today's models, better parametrisation of physical processes and the use of ensemble (Monte Carlo) forecasting, where the forecast is repeated many times with slightly different initial conditions.

In Chapter 4 Lorenz turns his attention to the chaotic orbital motion of the planets, especially noting the work of Poincaré and Hill. He then gives a brief history of the development of chaos theory and includes a fascinating section on his personal involvement. Unlike other mathematical investigators who found that chaos interfered with the subject they were studying, Lorenz set about finding a system of equations and parameters that would generate the chaotic patterns seen in the dishpan experiments. He used a 12-variable dissipative system of equations resembling the behaviour of a heated atmosphere, rather than the simpler conservative system governing the motion of the planets. At one point he repeated some of his computations, but found that the solutions differed from those he had obtained previously. It was then he realised that he had rounded off the input data to the accuracy of his printout and what he was seeing was the sensitivity of the solution to the initial conditions. The implication of his finding was that long-range weather forecasting was impossible. A few years later Lorenz's search for a simple system of equations that would allow him to look at an attractor was realised when he discovered the 'Lorenz equations'. The solution to these equations led to what has become one of the icons of chaos, the 'butterfly pattern' of the Lorenz strange attractor. The rest of the chapter discusses encounters with chaos taken from other fields of study.

The last chapter is similar to the first. In it Lorenz is concerned with carefully defining various terms (nonlinearity, complexity, fractality) and discussing their relationship to chaos. There are also three appendixes. The first contains the complete text of Lorenz's talk on 'The Butterfly Effect'; the second gives the mathematical background for his discussions in the text; and the third is a glossary of terms.

This is a book that I enjoyed reading very much, both for the history and for the science, and one that I would recommend to all *Australian Meteorological Magazine* readers. I was particularly interested in his discussion of the review process for his paper, 'Deterministic Nonperiodic Flow'. Not all of Lorenz's colleagues at MIT accepted or understood his result. Fortunately Jule Charney did recognise the importance of the paper and brought it to the attention of the wider meteorological community.

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