REVIEWS


Time reveals all things—Erasmus

The use of response times in elucidating perceptual and cognitive processes can be traced back more than a century, to the influential work of Donders and Wundt. During the first half of the twentieth century however, experimental psychology was dominated by a cognitively sterile form of behaviorism and interest in response times waned. The rise of the information processing approach in the early 1950's resulted in a renewed focus on response time. This resurgence was spearheaded by the important papers of Hick (1952), Hyman (1953), and Welford (1952). Later, several seminal papers by Sternberg (1966, 1969) carried the momentum through the 1960's and into the early 1970's. Today, the use of response times to infer the nature of perceptual and cognitive processes is fundamental in experimental psychology. Yet in spite of the major role that response time research has played, there have been only a few books written about response time theory. Luce's book is the first to attempt an overview of virtually the entire field.

Theorizing in this area is especially difficult. On each trial, only two sources of information are available—which response was emitted and how long it took the subject to respond. From these modest means the response time theorist attempts to answer very detailed questions about the nature of processing. For example, does processing consist of a series of discrete nonoverlapping stages or does information cascade through the system in a continuous fashion? When two response alternatives are available, does the subject accumulate evidence for the two responses separately or is there only one counter, which gets incremented when the evidence favors one alternative and decremented when it favors the other? These are very subtle but important distinctions and it is a surprisingly difficult task to design an experiment that will successfully test between them.

Response time research is categorized according to the number of stimuli and responses characterizing the experimental task. In a simple reaction time or detection task, there is one stimulus and one response. The subject initiates a response as soon as the stimulus is detected. Choice reaction time tasks are typically characterized by two stimuli and two responses. Matching, search, or scanning tasks have many stimuli, although usually only two responses. Luce's book covers these three areas in great depth. While his coverage of each of these topics is excellent, his treatment of simple reaction times is the best that I have read. Overall this is an outstanding book and a great contribution to the response time literature.

After a chapter reviewing probability theory, Luce divides his book into three separate parts. Part I consists of four chapters and covers simple reaction time tasks (including a chapter on vigilance). Part II is entitled "Identification Paradigms" and contains four chapters that deal primarily with choice reaction time tasks. Part III consists of two chapters that address matching paradigms. The book ends with three useful appendices. The first details several important asymptotic results for parallel and
serial response time models. The second is a short encyclopedia of 11 probability distributions that are important in response time research. Included are equations describing the density, moment generating, and hazard functions that characterize each distribution as well as the mean and variance. The third appendix gives fairly complete descriptions of 8 different data sets. This appendix will be especially useful to those wishing to test the validity of their favorite response time model.

Each of the three major parts begins with a chapter that very thoroughly reviews the relevant data. Luce discusses the results of hundreds of empirical studies and he reports the raw data from many of these studies in great detail. Because these chapters are devoid of mathematics, they will be a valuable resource to anyone interested in response times. The remaining chapters in each part evaluate the ability of various mathematical models to account for these data. Part III, dealing with matching tasks, is the most cursory of the three, perhaps because this is the area in which Luce has published the fewest papers. Even so, Luce does a fairly good job of identifying the important issues in the area and the reader interested in more detail can always turn to other sources, such as Townsend and Ashby's (1983) _Stochastic Modeling of Elementary Psychological Processes_.

Luce's book has much to offer to both the expert and the reader with little response time experience. Besides providing an abundance of good modeling advice that has been garnered from years of experience, he has many suggestions for future research. Some of the suggestions are quite general but many are very specific. In fact, I counted at least 18 times in which he carefully described a potentially important study that has never been conducted. For example, Luce notes that he is unaware of any visual detection studies that report response time distributions to white light or that examine the effects of stimulus intensity on the response time distributions to monochromatic visual signals.

In addition, when reporting data Luce does a good job of pointing out seemingly minor, but potentially important, details in experimental methodology. For example, he describes a study by Elliot (1968) that compared auditory and visual simple reaction times. Elliot reported that with large visual fields, the difference between visual and auditory simple reaction times was less than with small visual fields. Luce concluded that

\[ \ldots \text{it is unclear how well matched the signals were. The auditory ones were response terminated, 80-dB, 1000-Hz tones, whereas the visual ones were described only as "instantaneous, brief, extremely bright light" produced by an electronic flashgun. We know neither the intensity nor the duration, which, as we shall see in Section 2.3.3, are both necessary and important in understanding this result. (p. 64)} \]

This kind of attention to experimental detail is essential when trying to understand why two seemingly identical studies obtained different results.

Throughout the book, Luce attacks problems in a logical and orderly fashion. By considering every logical possibility he inevitably examines some hypotheses that the rest of the field has either ignored or overlooked. Although it is true that in most cases Luce ends up rejecting these hypotheses, the reader ultimately benefits from the exercise because the process makes it clear why certain alternatives need not be seriously considered. This approach will be especially helpful to those readers less familiar with the response time area.

One last strength of the book, which I especially appreciated, is its emphasis on the hazard function, both to characterize a model theoretically and to establish its empirical validity. Given a probability density function \( f(t) \) and a cumulative distribution function \( F(t) \), the hazard function \( h(t) = f(t)/(1 - F(t)) \) gives the conditional probability density
that a response occurs in the next instant given that it has not yet occurred. Given the hazard function, the density and cumulative distribution functions are easily derived (and vice versa, of course). However, in terms of dominance orderings, the hazard function is even more informative than the cumulative distribution function. Specifically, if one hazard function dominates another for all \( t \), then an ordering of the respective cumulative distribution functions is implied, but a distribution function ordering does not imply an ordering of the hazard functions (e.g., Townsend & Ashby, 1978, 1983).

Another appealing property of hazard functions is that they tend to be visually distinctive. Whereas all distribution functions look pretty much alike, a visual inspection of hazard functions is even more informative than an inspection of density functions. For example, the density functions of both a gamma distribution and a Rayleigh distribution are both nonzero only for positive \( t \). They are both unimodal and they are both skewed to the right. Visually, they appear very similar. Their hazard functions however, are strikingly dissimilar. The hazard function of the gamma distribution negatively accelerates to asymptote whereas the hazard function of the Rayleigh is linear with positive slope.

The hazard function, therefore, is a powerful tool for discriminating between alternative response time models and for establishing the empirical validity of individual models. Luce uses it heavily for these two purposes. Of course, to argue whether a model is empirically valid on the basis of its predicted hazard function requires a great deal of knowledge about the shape of the empirical hazard function. Luce examines this issue in great detail and concludes that, at least in the case of simple reaction times, the empirical hazard functions are ordered by signal intensity, and furthermore they rise monotonically to a peak (somewhere near the mean), fall, and then flatten to a constant tail. Luce then emphatically rejects any model incapable of predicting this pattern of hazard functions.

Unfortunately, the statistical problem of hazard function estimation is especially difficult. For example, no unbiased estimates are known. In fact, my own experience indicates that it is a difficult problem to determine whether an empirical hazard function is nondecreasing or nonmonotonic, even with individual subject sample sizes as large as 800. One method of estimation might seem to support monotonicity whereas another method might indicate nonmonotonicity. Because of this problem, it might be wise to be cautious when considering whether to reject a model on the basis of its hazard function predictions.

In any technical work of 500+ pages, one expects to find occasional errors and Luce's book is no exception. I counted 30 to 40 small errors, which were mostly typographical and not likely to cause much confusion. The most serious of the errors involves the figures. For example, two sets of figures were interchanged. Figure 1.6 was identified as 1.7 and Figure 1.7 was identified as 1.6. The same problem occurred with Figures 4.21 and 4.22. In addition, many of the figures were copied from other sources, and occasionally this caused difficulties. For example, in some cases the figure quality was poor and it was difficult to read the symbols (e.g., Figures 2.4, 6.1, and 6.2). In other cases the notation in the figures did not agree with the notation in the text (e.g., Figure 2.4).

These errors, however, are minor and should not detract from the important contribution that Luce's book makes. Reading it is "a must" for anyone seriously interested in response time research.
References


