On Human Memory:
Evolution, Progress, and Reflections on the 30th Anniversary of the Atkinson-Shiffrin Model

Edited by
Chizuko Izawa

With a Foreword by Richard C. Atkinson

Psychology Press

ON HUMAN MEMORY:
EVOLUTION, PROGRESS, AND REFLECTIONS ON THE 30TH ANNIVERSARY OF THE ATKINSON-SHIFFRIN MODEL

This page intentionally left blank

ON HUMAN MEMORY:
EVOLUTION, PROGRESS, AND REFLECTIONS ON THE 30TH ANNIVERSARY OF THE ATKINSON-SHIFFRIN MODEL

Edited by
CHIZUKO IZAWA
Tulane University

Psychology Press
Taylor & Francis Group
NEW YORK AND LONDON

First Published 1999 by Lawrence Erlbaum Associates, Inc.

This edition published 2014 by Psychology Press
711 Third Avenue, New York, NY 10017

and by Psychology Press
27 Church Road, Hove, East Sussex, BN3 2FA

Psychology Press is an imprint of the Taylor & Francis Group, an informa business

ISBN 978-0-805-82952-5 (hbk)
ISBN 978-1-410-60369-2 (eISBN)

Contents

Indices:

Foreword

Richard C. Atkinson
University of California, U. S. A.

An anniversary like this provides an occasion to reflect on science and on our lives. My own career has had three major phases: about two decades as a professor, mostly at Stanford University; 5 years at the National Science Foundation, having been appointed deputy director by President Ford and then director by President Carter; and the last two decades at the University of California, first as chancellor at UC San Diego, and now as president of the UC System. Each of these phases had its own challenges and rewards, but I recall with special fondness the exhilarating time I spent exploring the complexities of human memory and cognition in the company of some of the brightest young minds in the field.

The Atkinson and Shiffrin model discussed in this book achieved significance and fame far beyond anything we could have imagined at the time it was developed. In hindsight, I am sure that serendipity and timing played major roles. Even my collaboration with Rich Shiffrin arose somewhat by accident. Much of my career at Stanford was spent at the Institute for Mathematical Studies in the Social Sciences, housed in Ventura Hall. The institute was directed by Pat Suppes, a distinguished logician and philosopher, and served as the home for economists, psychologists, statisticians, computer scientists, and political scientists interested in mathematical models in the social sciences. Bill Estes and I, along with Pat Suppes, represented psychology in the institute's array of activities. The institute was a hotbed for the then-evolving field of mathematical psychology, and was populated by postdoctoral visitors and graduate students, too many to name in this foreword, a remarkable number of whom are leaders in the field today. In the early 1960s I began working on mathematical models of memory and used a computer-controlled system to conduct experiments that involved the continuous presentation and testing of items over extended periods of time. This experimental procedure proved to be very adaptable and generated large amounts of data on individual subjects; it was ideal for testing various assumptions embedded in the models. In the fall of 1964 a new graduate student, Richard Shiffrin, arrived at Stanford, having completed a double major at Yale University in psychology and mathematics. He came to work with Gordon Bower, who was housed in the psychology building elsewhere on campus. Shiffrin began developing models of memory applied to list paradigms, particularly free recall experiments. After Shiffrin's first year, Gordon Bower left for a sabbatical year in the United Kingdom, and asked if I would take over as Shiffrin's research advisor, since our more or less independently developed models seemed quite compatible. Thus began an intense and productive collaboration.

Within a few months Shiffrin and I became the hub of a group of students, postdoctoral visitors, and research associates carrying out a wide variety of memory studies suggested by an evolving theory of memory; many of these studies achieved independent publication. Then an invitation to contribute a chapter to *Psychology of Learning and Motivation* provided an opportunity to pull the various empirical and theoretical strands together into a larger framework. In the process, Shiffrin and I realized that the short-term buffer process that we were using in our various models was merely a stand-in for a more complicated set of processes representing short-term memory, leading us to broaden the conception of short-term memory to "control processes," a term standing in for "active memory" or "working memory." This conception in turn allowed us to put together a theoretical framework with relatively autonomous sensory processing, controlled processing in short-term memory, and a permanent long-term memory upon which control processes could operate to produce retrieval. The field was obviously ready to embrace this approach, and the publication of the chapter seemed to act like the nucleus that causes a solution in delicate equilibrium to precipitate.

That this model remains today a widely accepted description of human memory (and a subject for critical attack by continuing generations of theorists) is, I believe, more than a matter of a publication arriving on the scene at a propitious moment. The longevity of the model is most likely due to the parts of the chapter that are unknown to casual readers who learn of the model through secondary sources: namely, the quantitative fit of the model to a wide array of experimental paradigms and conditions. It was this rooting of the model in reality that forced it into a form that remains largely valid today. I believe this is the case for most of the lasting contributions to science, and provides perhaps the best argument for the collection of extensive parametric data and the testing of quantitative models.

It is indeed gratifying to witness this volume celebrating the 30th anniversary of the publication of our chapter. It is satisfying to see the many scientific outgrowths of that model and its use in one form or another in so many diverse fields. It is doubly satisfying to see the way in which Rich Shiffrin's own research has continued the evolution of those concepts, as in the SAM model (Raaijmakers & Shiffrin, 1980) and the REM model (Shiffrin & Steyvers, 1997). It is triply satisfying to see these theoretical efforts continuing into a third generation and beyond of PhDs. Chapters 5, 7, and 10 of the present volume, by Jeroen Raaijmakers, Scott Gronlund, Steve Clark, and their students and associates, provide excellent examples, as does an outstanding contribution by my student, Tom Wickens (Chapter 11). Another member of the circle of PhDs at Stanford in the 1960s, Mike Humphreys, also provides a valuable contribution to this volume (Chapter 7). A theoretical contribution of lasting value requires testing in the fire of intense critical evaluation, as noted by Chizuko Izawa in Chapter 1; over the years such testing has been provided by my friend and colleague, Ben Murdock (Chapter 3). Alice Healy and Tom Cunningham contribute Chapter 8, building upon the ideas of Estes' perturbation model (1972).

I cannot fail to acknowledge my close friend and colleague, Bill Estes, one of the great figures in our field and a recent recipient of the National Medal of Science. He is better placed than anyone to evaluate the last 30 years of progress in memory, and provides an incisive, critical, and telling retrospective in Chapter 4.

It is appropriate to end this foreword with special thanks to Chizuko Izawa, an outstanding scientist, whose idea led to this volume, and whose editing saw it to completion. I recall her as a shy graduate student who arrived at Stanford fresh from the University of Tokyo. She proceeded to surmount the obstacles of culture and language that faced her, and produced a wonderful PhD dissertation in 1965. She has utilized her own experiences involving language learning in her research on memory processes, and has produced significant advances in our understanding of the "efficiency of acquisition," as witnessed by her test trial potentiating model (1971), her retention interval model (1981), her identity model (1985) and her hypothesis concerning the Study-Test-rest (S-T-r) presentation program that is the subject of Chapter 9. Rich Shiffrin and I, as well as all the other contributors to this volume, owe her warm thanks and commendation for her efforts in our behalf.

This page intentionally left blank

Preface

The time was 1968, and the place, Ventura Hall, home of the Institute for Mathematical Studies in the Social Sciences at Stanford University. One of our fellow graduate students, Richard M. Shiffrin and his mentor, Richard C. Atkinson jointly devised a new memory model! On the face of it, this was nothing unusual; each graduate student, myself included, participated in creating a model as part of doctoral training.

What was unique about the Atkinson-Shiffrin model, which had been discussed earlier at the regular Friday afternoon Ventura Hall seminars, was its profound scope, depth, quality, and elegance. I clearly remember Rich Shiffrin proudly giving me the draft of his dissertation during one of the seminars I had been regularly attending after my doctorate at Stanford. At that time, I was at Berkeley doing my postdoctoral fellowship at the Institute of Human Learning. Although I did not entirely agree with the rehearsal mechanisms/processes postulated in the model (they did not quite correspond to my personal experiences in the learning of several languages over a number of years), I nonetheless could not help being deeply impressed by the Atkinson-Shiffrin model; an impression that was widely shared by my colleagues everywhere. The model was set forth in a book chapter, and was for decades, one of the most cited contributions to psychology and especially experimental psychology. The model's overall impact has been monumental.

Granted "Nihil est annis velocius [Nothing is swifter than the years] (Ovid, A.D. 7), it is hard to believe that 1998 marks the model's 30th Anniversary! The 1968 Atkinson-Shiffrin model is a resounding victory for the sciences of human learning and memory very close in stature to Ebbinghaus' 1885 *Ueber das Gedaechtnis* which started it all!

That is why Dick Atkinson and Rich Shiffrin's Ventura Hall associates, colleagues, classmates, students, and admirers joined in celebrating the Atkinson and Shiffrin rehearsal buffer model 30 years later. It was my good fortune to have shared the excitement of the model's birth with its creators and now to edit a tribute to this landmark event.

Acknowledgments

Preparation of this volume owes much to the selfless efforts of friends and student volunteers, all with a lively curiosity about research on learning and memory. Special thanks are due to Laura Brown, Emily S. Stitt, Eun-sil Lee, Brian L. Azcona, Jeremy Steckel, Althea Izawa-Hayden, and Lieuko Nguyen

who assisted with proofreading and references. The intensive involvement of the latter two are especially appreciated. Both subject and author indexes were greatly benefited from the competent ministrations of Althea Izawa-Hayden, Lieuko Nguyen, and Marc Matrana.

Chizuko Izawa

Chapter 1

On Human Memory: A Brief Introduction

Chizuko Izawa
Tulane University, U. S. A.

In the beginning, there was *Ueber das Gedaechtnis* [On Memory] by Hermann Ebbinghaus (1850-1909). It reflected his decade-long intense personal devotion to create a series of highly original experiments that set enduring precedents for the future scientific study of human learning and memory. It was the first such publication in the history of scientific psychology. The volume was the sweet fruit of highly disciplined hard labor, because after all, Experimenter and Subject were one. This original and masterful oeuvre had a commanding effect on the advancement of psychological science, in part because Wilhem Wundt (1832-1920), the founder of modern experimental psychology (first formal laboratory, Leipzig, 1879), asserted that higher mental processes, such as human memory, were beyond the scope of experimental investigation, and could only be explored through Voelkerpsychologie [folk psychology], which relied primarily on people's casual recollections and traditions, rather than empirical science.

This first definitive stepping stone for theorists and experimentalists of human learning and memory, *Ueber das Gedaechtnis* [On Memory] (1885), set the standard for research on human learning and memory for over three quarters of a century. Henceforth learning/memory was predominantly investigated and measured in reference to the list (the list-design). During the 1985 centennial, Ebbinghaus' unprecedented contributions were celebrated both at home and abroad, at conferences, and via special issues of journals and books (e.g., Gorfein and Hoffman published 1987).

The next decisive advance in human learning and memory was Atkinson and Shiffrin's 1968 rehearsal buffer model. The advent of the cognitive revolution around 1960 promoted human learning and memory workers' investigation of item-design (Brown, 1958; Peterson & Peterson, 1959), opening the path for this second conquest. In 1968, the 107 page chapter, entitled: "Human Memory: A Proposed System and its Control Processes," was the prominent contribution to *The Psychology of Learning and Motivation: Advances in Research and Theory* (Vol. 2 edited by Spence & Spence). It was jointly written by Richard M. Shiffrin, then an outstanding graduate student at Stanford, and his well-known advisor/mentor, Richard C. Atkinson, a professor of psychology at the Institute for Mathematical Studies in the Social Sciences, also at Stanford, a major center for advanced research in psychology.

This seminal masterpiece by Atkinson and Shiffrin (1968), just like Ebbinghaus', is a relatively short thesis packed with innovative ideas and sound methods for testing them. Highly impressive is their synthesis of earlier developments, for example, Estes (1955a, 1955b), Broadbent (1957, 1958), Greeno (1967), and Bower (1967), and the innovative constructions thereon. An effort requiring extensive knowledge of mathematics and statistics, and continuing mastery of the then rapidly developing high speed computer technology utilized as a hypothetical approximation of memory systems.

The Atkinson-Shiffrin model advanced both structural and control processes. First, in terms of memory structures, the model assumes three entities: Sensory register (SR), short-term store (STS, or STM), and long-term store (LTS, or LTM). External input/stimulus may be lost in any of the above three postulated structures which accounts for memory/information losses or forgetting (Fig. 1, Atkinson & Shiffrin, 1968, p. 93; reproduced on p. 18 of this volume as Fig. 2.1). Information in LTS can be transferred to STS, and vice versa.

Second, quite uniquely and importantly, the model emphasizes the role of processes controlled by the participants, for example, rehearsal, coding, and search strategies in human memory as the formal postulates of the theory. Most intriguingly, the model assumes a rehearsal buffer in STS where items may survive by virtue of rehearsals or transfer to LTS (Atkinson & Shiffrin, 1968, Fig. 2, p. 113). This postulate stimulated the imagination of many; because of it the Atkinson-Shiffrin model came to be referred to as "the rehearsal buffer model" or simply "the buffer model."

The buffer model's assumptions regarding coding processes and transfer between STS and LTS, storage in LTS, and long-term search processes are clearly spelled by then extant data. Most impressive of all were the rigorous empirical tests of these theoretical assumptions on 68 of 107 pages. Even today, it is very hard not to be impressed by this monumental early accomplishment. This signal contribution by Atkinson and Shiffrin testifies to the importance of the book chapter format to the advancement of outstanding scientific scholarship. Indeed, Atkinson and Shiffrin (1968) had set the direction for the field of memory during the last 30 years and far beyond.

The influence of the Atkinson-Shiffrin model has been profound; it has become one of the most cited references in experimental psychology. 1998 marks the model's 30th anniversary. Considering its exceptional mastery of the events addressed, a celebration seems eminently proper. According to the 1996 (newest) edition of the unabridged Webster's dictionary, "30" among numerical referents signifies "a mark or sign of completion." And according to the free-association norms I developed for numbers 0 to 100 using well over 400 college students (Izawa, pending), the number 30 immediately elicits associations to youth or youthfulness.

Thus, on this occasion, close associates, mentors, former classmates, colleagues, students, postdoctoral fellows, and all admirers of Dick Atkinson and

Rich Shiffrin are here, assembled to celebrate this 30th anniversary of the buffer model. This anniversary volume's uniqueness is enhanced by the model's architects' contributions to it, through authoring the foreword and the lead chapter (scientific contributions), respectively. The rest of the volume is filled with essays and new experiments of high caliber, including one by the winner of the 1997 National Medal of Science.

The Structure of the Volume

Our 30th anniversary celebration volume commemorates a significant victory for researchers in human memory. The foreword by Richard C. Atkinson was prepared despite his consuming schedule as President of the University of California System. Subsequently, in Chapter 2, Richard M. Shiffrin shares his current psychological and mathematical insights.

In Chapter 3, Bennet B. Murdock presents his 30 years' continued effort to improve on an alternative model, TODAM (theory of distributed associative model). In this editor's eyes, scientific debate is a must for the advancement of knowledge. Such scientific controversy facilitates the healthy growth of a discipline. For instance, the Hullian (response learning) vs. Tolmanian (cognitive map development) debates (Yale vs. Berkeley) in the 1930s-1950s, and the all-or-none (Estes/Bower) vs. gradual learning (Bush-Mosteller/Underwood-Postman) controversy (Stanford vs. Penn/Nortwestern-Berkeley) in 1960s-1970s added not only rigor to our research, they also led to new knowledge. Fortunately for readers, the rehearsal buffer model vs. TODAM (Indiana vs. Toronto) is cast in very much the same mold!

In Chapter 4, the arguably best cognitive psychologist today, William K. Estes, favors our readers with an exceptionally insightful discussion. It allows readers to assess the landscape of human memory models of the past three decades with far greater accuracy than has been possible hitherto.

Starting with Chapter 5, some of Atkinson and Shiffrin's colleagues will delve into current hot issues in their laboratories as part of our 30th Anniversary celebration.

Brief Personal Introduction to Contributors and Chapters

Universal concern with the Atkinson-Shiffrin rehearsal buffer model is well reflected by the diverse origins of contributors to this 30th anniversary volume. They are from Europe, Australia, North America, and Asia. This in itself is no small achievement! The following summarizes both the attributes of contributors to the volume and their chapters. More extensive career histories are, of course, publicly available, inclusive of the Internet. The entries follow the sequence of chapters in this volume, except for Chapter 1; its author and the volume editor is introduced along with Chapter 9, her scientific contribution.

Richard C. Atkinson

The foreword to this volume was written by Richard C. Atkinson, co-author with Richard Shiffrin of the model celebrated here. Since 1995, Dr. Atkinson has served as president of the University of California, one of the largest and most distinguished university systems in the world. Before becoming president of the UC System, he was chancellor of UC San Diego; during his 15-year tenure the campus doubled in size while increasing the distinction of its faculty and breadth of its programs.

From 1975 to 1980, Atkinson served at the National Science Foundation, having been appointed as deputy director by President Ford and then as director by President Carter. He had a wide range of responsibilities for science policy at a national and international level, including negotiating the first memorandum of understanding in history between the People's Republic of China and the United States, an agreement for the exchange of scientists and scholars.

Atkinson began his academic career at Stanford University and was a member of the faculty from 1956 to 1975, except for a 3-year period at UCLA. In addition to serving as professor of psychology at Stanford, he held appointments in the School of Engineering, School of Education, Applied Mathematics and Statistics Laboratories, and Institute for Mathematical Studies in the Social Sciences. Complementing the work discussed in this volume was his more applied work on learning in the classroom. In the early 1960s, he developed one of the first computer-controlled systems for instruction, which served as a prototype for the commercial development of computer-assisted instruction. Reading instruction under computer control for young school children has been an important application of the work.

Atkinson has been elected to the National Academy of Sciences, the Institute of Medicine, the National Academy of Education, and the American Philosophical Society. He is past president of the American Association for the Advancement of Science, former chair of the Association of American Universities, and the recipient of numerous honorary degrees. A mountain in Antarctica has been named in his honor.

Given the remarkable scope of his career, it is fitting to have Dick Atkinson reflect on our field on the 30th anniversary of his and Rich Shiffrin's paper, an exceptional collaboration between mentor and student.

Richard M. Shiffrin

Without him, this volume would never have been possible. In 1968, together with his mentor, Dick Atkinson, Richard M. Shiffrin, a young PhD candidate at Stanford published the Atkinson-Shiffrin buffer model, whose 30th anniversary we celebrate this year (1998). The ideas forged in 1966-1967 were the wellspring for a stream of brilliant contributions to research upon memory. Among others were the Search of Associative Model (SAM, 1980, also published in a volume of *The Psychology of Learning and Motivation*, and co-authored with Jeroen Raaijmakers, now Professor at the University of Amsterdam, who carried out his dissertation research with Shiffrin at Indiana in 1979) and Retrieving Effectively from Memory (REM, 1997).

After his undergraduate education at Yale and doctoral training at Stanford, Shiffrin immediately began his permanent academic career at Indiana University in 1968. Currently, the Luther Dana Waterman Professor of Psychology, Shiffrin is the creator and first director of the Cognitive Science Program there. From 1981 to 1984, he edited the *Journal of Experimental Psychology: Learning, Memory, and Cognition*, and served as Associate Editor for the *Psychological Review* between 1976-1982. He continues to be a major consulting editor for cognitive, experimental, mathematical and theoretical journals, and served as co-editor of several important volumes including the 1992 two-volume Festschrift for William K. Estes. He continues active involvement in numerous scientific bodies for psychology, especially cognitive/mathematical psychology and was called on to chair the Psychonomic Society in 1988. His publications of major importance number about 100 and are growing rapidly.

Rich Shiffrin's work is internationally well known. As a result, he has held Visiting Professorships on three different continents, the University of Queensland in Australia (1988), the University of Amsterdam, the Netherlands (1994-1995) in Europe, and the Rockfeller University (1975-1976) in North America. An Honorary Doctorate from the University of Amsterdam was bestowed on him in 1996 (a Dutch journalist traveled to Bloomington to interview him), and in this country, he was inducted into both the National Academy of Sciences and the American Academy of Arts and Sciences in 1995.

Not surprisingly, Rich Shiffrin had a number of outstanding students. A few of the best known include Bill Geisler (Professor at Texas, a leading theorist in vision), Walter Schneider (Professor at Pittsburgh, and co-author with Shiffrin of the influential articles in *Psychological Review* on automatic and controlled processing), and Sue Dumais (now at Microsoft, and recently co-author with Tom Landauer of a model of the development of word meaning), plus those contributing to this volume, cited later.

Shiffrin presents his own account in Chapter 2, "30 Years of Memory." It commences with the original 1968 Atkinson-Shiffrin buffer model, depicts the evolution of SAM, and the subsequent REM. As is Shiffrin's wont, he continuously refines and advances his models to new levels of sophistication, and with each step, forges the next model. Chapter 2 provides tantalizing hints of forthcoming scientific advancements in human memory research, perhaps the most important ones since *Ueber das Gedaechtnis*.

Bennet B. Murdock

Among the most creative and intensely devoted memory researchers and learning theorists today, Bennet B. Murdock, offers an alternative approach to the Atkinson-Shiffrin buffer model, viz. the theory of distributed associative memory (TODAM). Murdock has also been working on his model and its refinements/improvements for nearly three decades. Among my friends, Ben Murdock is the only one who has had personal contact with Clark L. Hull (1884-1952), a giant who built the most comprehensive hypothetical-deductive theory of learning at Yale. Yale provided Ben Murdock's undergraduate and graduate education, awarding him the doctorate in 1951. After Wesleyan, Vermont, and Missouri, Murdock found a permanent home in 1965 at the University of Toronto. He served on editorial boards of several journals, and many professional organizations, including the presidency of the Mathematical Psychology Society (1993-1994). His volume of publications reached at least 125 as of last count. They include his very successful *Human Memory: Theory and Data* (1974). At his retirement from Toronto in 1991, his students, colleagues, and associates honored him with the *Festschrift, Relating Theory and Data: Essays on Human Memory in Honor of Bennet B. Murdock* (Hockey & Lewandowsky, 1991).

In Chapter 3, "The Buffer 30 Years Later: Working Memory in a Theory of Distributed Associative Memory (TODAM)," Murdock presents an excellent review of the field, and has offered a constructive alternative, TODAM (theory of distributed associative memory) to explain many of the same effects in a different theoretical framework, using a working memory of five storage registers. Here, he discusses both similarities and differences between the Atkinson-Shiffrin's rehearsal buffer and TODAM'S working memory.

William K. Estes

On April 30, 1997, President Clinton announced recipients of the National Medal of Science, the Nation's highest science and technology honor. Among those honored was William K. Estes. He was cited for "fundamental theories of cognition and learning that transformed the field of experimental psychology and led to the development of quantitative cognitive science. His pioneering method of quantitative modeling and insistence on rigor and precision established the standard for modern psychological science." Estes received the medal from President Clinton at the White House on December 15, 1997. (The National Medal of Science was established by the United States Congress in 1959, an American version of the Nobel Prize, publicly recognizing individuals for uniquely eminent contributions to science. Only 11 other psychologists were so honored before Estes.)

We are more than fortunate to have someone of Bill Estes' renown grace our volume. Bill Estes obtained his doctorate at the University of Minnesota in 1943, working with B. F. Skinner (a 1968 recipient of the National Medal of Science). Via Indiana, Stanford, and Rockfeller Universities, Estes came to Harvard in 1979, and retired there 10 years later as the Daniel and Amy Starch Professor Emeritus of Psychology. His nearly 200 publications which include 13 books continue to grow annually.

In the 1950s, Estes pioneered the foundation of the mathematical applications in cognitive psychology and demonstrated its utility for such diverse areas as learning, memory, visual perception, attention, categorization, and conceptualization among many others. In my opinion, his work *Toward a Statistical Theory of Learning* in 1950, and the *Stimulus Fluctuation Model* (1955a, 1955b) were definitive landmarks setting the stage for subsequent developments in cognition and my own research as well.

Estes has a record of notable leadership in all psychological associations and organizations related to his interests as a founder of the Psychonomic Society and the Society for Mathematical Psychology, which he served as Chair and President respectively. His work was recognized not only by the National Medal of Science in 1997 (see above), but also by APA's (American Psychological Association) Award for Distinguished Scientific Contributions (1962), and the Gold Medal for Life-Time Achievement in Psychological Science (1992); he was the first person designated by APS (American Psychological Society) to be a William James Fellow (1990) and numerous other honors.

In Chapter 4, Bill Estes makes a definitive assessment of "Models of Human Memory: A 30-Year Retrospective." Estes incisively summarizes the late 1960s-1970s focus of human memory models on STM processes within the modal model and the 1980s emphasis on LTM processes especially on formats, modes of representation and retrieval processes. Furthermore, he considers that the salient features of diverse current models reflect a composite approach likely to serve the same function as the earlier modal model.

Jeroen G. W. Raaijmakers and R. Hans Phaf

In 1977, an outstanding Dutch graduate student, fresh from his Master's Thesis at the University of Nijmegen came to Indiana University to work with Richard Shiffrin. This was the beginning of Jeroen Raaijmakers' close and productive association with Shiffrin. Together, these two creative minds developed new models, including, for example, SAM (Search of Associative Memory) and, very recently, REM (Retrieving Effectively from Memory). Aspects of SAM appeared in the *Psychology of Learning and Motivation* (1980, edited by Bower) and the *Psychological Review* (1981). An overview of the model was published in Vol. 2 of *From Learning Processes to Cognitive Processes: Essays in Honor of William K. Estes* (1992, edited by Healy, Kosslyn, & Shiffrin) and in the *Annual Review of Psychology* (1992, edited by Rosenzweig & Porter).

Jeroen Raaijimakers, who received his undergraduate and graduate education at the University of Nijmegen, subsequently accepted a faculty position at his alma mater. In 1985, he left the university and moved to the TNO Human Factors Research Institute, setting up a new group in applied cognitive psychology. But in 1992, he was welcomed to the University of Amsterdam, where he currently directs the Graduate Research Institute for Experimental Psychology. Today he is one of the Netherlands' leading psychologists. Raaijmakers' publications, in both English and Dutch, exceed 65 and include a successful graduate text on human memory, as well as some research reports on applied cognitive psychology.

R. Hans Phaf, one of Raaijmakers' best co-workers on memory, was educated at the Leiden University which awarded him a PhD in 1991. Currently an Associate Professor of Psychonomics at the University of Amsterdam, he already has an excellent publication record.

In Chapter 5, "Part-List Cuing Revisited: Testing the Sampling-Bias Hypothesis," Raaijmakers and Phaf report on a series of experiments that directly test SAM's predictions of the counterintuitive part-list cuing phenomenon. They confirm that the effect may be reversed under specific conditions as predicted. These experiments strongly support the SAM explanation for the part-list cuing effect, a gratifying outcome for a task well done.

Scott D. Gronlund and Daryl D. Ohrt

Another of Rich Shiffrin's former graduate students, Scott D. Gronlund, came to Indiana from the University of California at Irvine (B. A. in Psychology, Cum Laude). At Indiana, he pursued cognitive psychology with a minor in mathematics, and 1986 saw the completion of his dissertation. After postdoctoral work at Northwestern with Roger Ratcliff, another eminent cognitive psychologist, he joined the faculty at the University of Oklahoma at Norman. As an Associate Professor of Psychology there, he has been actively pursuing two lines of research: Investigations of the cognitive management of complex systems (especially air traffic control) and the empirical and theoretical evaluation of quantitative models of memory.

Given the importance of the list-length effect (LLE) for SAM, Scott Gronlund and his productive graduate student, Daryl D. Ohrt, who receives his PhD in Fall 1998, titled Chapter 6, "The List-Length Effect and Continuous Memory: Confounds and Solutions." They noted that the simplifying assumptions of Atkinson and Shiffrin (1968) regarding the isolation of the study list were challenged by Murdock and Kahana (1993a, 1993b), who claimed that the null LLE was attributable to confounding variables in prior experiments. The two Ohrt and Grunlund experiments demonstrated an LLE despite the elimination of said confounding factors. A modified version of SAM offered a refined explanation for the LLE and other empirical challenges.

Michael S. Humphreys and Gerald Tehan

After Reed College (B. A., 1964), Michael S. Humphreys received his doctorate in Psychology from Stanford, just at the height of pervasive excitement over the new Institute for Mathematical Studies in the Social Sciences at Ventura Hall where the Atkinson-Shiffrin model first saw the light of day. He became well acquainted with Atkinson then and there as a mentor, and came to know Shiffrin and this editor as classmates. After being on the faculty at British Columbia and Northwestern, he sought new frontiers in Australia. Currently Humphreys is Professor of Psychology at the University of Queensland and a former Head of the Department of Psychology. He is also a Fellow of the Academy of the Social Sciences in Australia. He is one of a few second generation psychologists, a son of famous psychologist, Lloyd G. Humphreys.

A prolific and excellent scientist, Mike Humphreys compiled nearly 80 publications and has served as Consulting Editor for *Journal of Experimental Psychology: Human Learning and Memory* (1976-1980, 1987-1989) and has also served as a referee for other journals in the field of human memory broadly conceived. Mike Humphreys' many research interests include the relationship between recognition and recall, role of context in human memory, memory tests, lexical access and the use of cues in STM, and representation of words. He continues to construct a general theory of human memory (a broad-gauged overview) by utilizing ideas from distributed storage and connectionist models. He is of the view that an understanding of memory tasks starts with an analysis of the bindings that are stored, the cues that are used, and the nature of the decision problem. This sentence describes the latest model, the Bind Cue Decide Model of Episodic Memory (BCDMEM).

Gerald Tehan received his B.A. from the University of Queensland in 1983. He then completed a PhD with Mike Humphreys in 1991. Two years prior to this, Tehan took up a faculty position at the University of Southern Queensland where he is now a senior lecturer. The work in Chapter 7 started with Tehan's PhD thesis and represents their continuing collaboration on the role of cues and codes in short term memory.

In Chapter 7, Mike Humphreys and Gerry Tehan discuss "Cues and Codes in Working Memory." The authors reviewed their recent work on retrieval cues and codes that produce proactive interference (PI) in STM in cued recall tasks. In this chapter, the authors report their findings that PI occurred at very short (2 to 4 sec) retention intervals, that PI depends on the cue, and that short phonological memory codes prevent PI. Their cueing and coding ideas have been extended to understand other working memory tasks.

Alice F. Healy and Thomas Cunningham

We are delighted to welcome one of the most productive cognitive psychologists, Alice F. Healy. A close associate of Shiffrin and the first PhD from William K. Estes at Rockfeller (1973), she did her undergraduate work at Vassar College (B. A., Summa Cum Laude, 1968). Formerly on the faculty of Yale, Professor Healy is currently at the University of Colorado, Boulder. Healy, former Editor of *Memory & Cognition* (1986-1989) and Associate Editor of *Journal of Experimental Psychology, Learning, Memory, and Cognition* (1982-1984), is a prolific author, having output at least 100 publications, including four books. Alice Healy was the senior editor for two volumes, honoring William K. Estes for his retirement from Harvard (in 1989, published in 1992). She served as President of the Rocky Mountain Psychological Association (1994-1995), Chair of the Psychology Section of the American Association for the Advancement of Science (1995-1996) and on the Governing Board of the Psychonomic Society (1987-1992) among many other leadership roles she has played, not to mention being on editorial boards of major cognitive and memory journals.

Truly remarkable is her ability to attract a countless number of students, colleagues, and associates in many areas of memory and cognitive processes, psycholinguistics and reading. A case in point: Thomas F. Cunningham, the co-author of Chapter 8, is a PhD from Oklahoma State University (1966), and post-doctoral at Ohio State (1975-1976), and has been busy at St. Lawrence

University as a faculty member, Associate Academic Dean, and Departmental Chair. Cunningham often publishes with Healy, as is the case here.

"Recall of Order Information: Evidence Requiring a Dual-Storage Memory Model" is the title of Chapter 8. After reviewing relevant literature extensively, Healy and Cunningham addressed the recall of order information and the fundamental distinction between STS and LTS by the Atkinson and Shiffrin buffer model (1968). The authors rightly pointed out that their theoretical base, Estes' perturbation model (1972), requires the second memory store (analogous to LTS) in addition to its original single memory store (comparable to STS). Data supported the authors' position.

Chizuko Izawa

As the editor of and contributor to the present volume, Chizuko Izawa wrote both Chapters 1 and 9; the former as the editor, the latter as a contributor to human learning and memory research. In addition to having the honor of being the first of Bill Estes' PhDs at Stanford (1965), this editor was fortunate to have Richard C. Atkinson as a mentor and a dissertation committee member at Stanford, and is doubly blessed to have Richard M. Shiffrin and Mike Humphreys (Chapter 7) as classmates. We all spent much time at the birthplace of the Atkinson and Shiffrin rehearsal buffer model, Stanford's Institute for Mathematical Studies in the Social Sciences, then housed in Ventura Hall. Izawa came to Stanford with a baccalaureate degree from the University of Tokyo and was subsequently awarded a postdoctoral fellowship at the Institute of Human Learning at the University of California, Berkeley (1967-1968).

Using both her native Japanese and acquired English professionally, she produced nearly 70 publications (including three books) and made about 95 presentations worldwide. Since assuming her Tulane faculty position in 1972, Izawa was elected Chair/President of the Southeastern Workers in Memory (1974-1975), and to the Executive Committees of both the Southwestern Psychological Association (SWPA, 1978-1980) and the Southeastern Psychological Association (SEPA, 1998-2001); and she continues to serve in a variety of ways on many other organizations in psychology.

Aspects of efficiency and optimization of learning and retention, and economy of time utilization have been the backbone of Izawa's work since leaving Stanford. She has extensively utilized her own real-life experiences as a learner of 5 languages (Izawa, 1989), in many of her other research endeavors (e.g., TV viewing effects on children's cognitive development, the psychology of numbers and numerical information processing, cognitive processes of cancer patients, minority and women's issues).

To honor her favorite friends, colleagues, mentor, classmate, Izawa reports on three new concurrent experiments (10 conditions) in Chapter 9 of this Volume. "Efficiency in Acquisition and Short-Term Memory: Study-Test-rest Presentation Program and Learning Difficulty." The total time effects and the total time hypothesis (TTH) were thoroughly examined to evaluate four families of hypotheses (composed of 13 single-factor and 1 multifactor individual hypotheses) by varying S (study), T (test), and r (rest) events under constant (or expanded) total time. Contradicted were all families of Bugelski's total time, presentation duration, and frequency hypotheses and their derivatives. However, Izawa's study-test-rest (S-T-r) presentation program hypothesis was supported. She discovered that efficiency in acquisition was learning-difficult dependent. That is, when learning is difficult, the new item-repetition presentation program is superior to the time honored list-repetition program, whereas the reverse holds when learning is easy. However, when learning is of intermediate difficulty or ease, the two programs differ little from each other.

Steven E. Clark

For decades now, there has been debate concerning the similarities and differences between recall and recognition with many interesting human learning and memory phenomena being pursued in consequence. One of the most recent endeavors was the subject of another young promising PhD (1988) in Richard M. Shiffrin's Indiana laboratory viz., Steven E. Clark, who provided Chapter 10. Clark came to Indiana from Illinois State University (B. S.), and he is now an Associate Professor of Psychology at the University of California, Riverside. His major research activities have been focused on developing and testing comprehensive mathematical models of memory, and he is currently working to develop a mathematical model for eyewitness identification. Supported by NSF, at present he is targeting relationships between recall and recognition, retrieval, search, representation of information, item-specific and associative information, eyewitness testimony, and category representation. He actively publishes and also presents his research at professional conferences, and is a consulting editor for *Memory & Cognition.*

In Chapter 10, Clark discusses an intriguing issue, "Recalling to Recognize and Recognizing Recall." After reviewing theory and data regarding recall processes in recognition memory, he concludes that arguments for recall processes often assume the theoretical alternative to be a very simple local-matching familiarity model. However, he views that recall assumptions for more complex familiarity models may be unnecessary; however, because these models take on many recall-like properties, it is difficult to make the distinction between familiarity and recall.

Thomas D. Wickens

The grand finale of our epochal celebration to honor the Atkinson-Shiffrin rehearsal buffer model is in the competent hands of Thomas D. Wickens who, during the 1970s, had daily contact with Dick Atkinson as a postdoctoral fellow at Ventura Hall at Stanford. For Tom Wickens, psychology is a family enterprise, for his parents were highly regarded psychologists, Delos and Carol Wickens, whose two sons followed their example. The elder of the two, Tom Wickens, was well-educated in both psychology and mathematics. He obtained his A. B. in mathematics at Harvard College in 1964 and his PhD in experimental psychology in 1969 from Brown University. After postdoctoral training with Atkinson at Stanford, he joined the psychology faculty of the University of California at Los Angeles, and is currently Professor and Vice Chair for Graduate Affairs at UCLA. His quality publications include three high-powered books and his research interests are best described as quantitative application in cognitive psychology (particularly perception and memory) and statistics.

In Chapter 11, Tom Wickens presents advanced discussions for those with an appetite for mathematical sophistication entitled: "Measuring the Time Course of Retention." He describes elegant probabilistic arguments to select functional form of time course of retention in human memory. He considers functions with declining hazard function to be more satisfactory than those with the flat or rising hazard functions.

References

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory, Vol.2* (pp. 89-195). New York: Academic Press.

Bower, G. B. (1967). A multi-component theory of the memory trace. In K. W.. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory*, Vol. I. (pp. 229-325), New York: Academic Press.

Broadbent, D. A. (1957). A mechanical model for human attention and immediate memory. *Psychological Review*, *64*, 205-215.

Broadbent, D. A. (1958). *Perception and Communication.* Oxford: Programming Press.

Brown, J. (1958). Some tests of decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10*, 12-21.

Ebbinghaus, H. (1885). *Ueber das Gedaechtnis: Untersuchungen zur experimentellen Psychologie* [On Memory: Investigations in experimental psychology]. Leipzig, Germany: Duncker & Humbolt.

Estes, W. K. (1955a). Statistical theory of distributional phenomena in learning. *Psychological Review, 62*, 369-377.

Estes, W. K. (1955b). Statistical theory of spontaneous recovery and regression. *Psychological Review, 62*, 145-154.

Estes, W. K. (1972). An associative basis for coding and organization in memory in A. W. Melton & E. Martin (Eds.), *Coding processes in human memory* (pp. 161-190). New York: Halsted Press.

Gorfein, D. S., & Hoffman, R. R. (1987). (Eds.), *Memory and learning: the Ebbinghaus centennial conference.* Hillside, NJ: Lawrence Erlbaum Associates.

Greeno, J. D. (1967). Paired-associate learning with short-term retention: Mathematical analysis and data regarding identification of parameters. *Journal of Mathematical Psychology, 4*, 430-472.

Hockey, W. K., & Lewandowsky, S. (Eds.). (1991). *Festschrift: Relating theory and data: Essays on human memory in honor of Bennet B. Murdock.* Hillside, NJ: Lawrence Erlbaum Associates.

Izawa, C. (1989). Introduction. Similarity and differences between anticipation and study-test item information presentation methods. In C. Izawa (Ed.), *Current issues in cognitive processes: The Tulane Flowerree symposium on cognition.* (pp. 201-209). Hillsdale, NJ: Lawrence Erlbaum Associates.

Izawa, C. (pending) The psychology of numbers and numerical information processing: Free association norms of Numbers 0 through 100.

Murdock, B. B., & Kahana, M. J. (1993a). Analysis of the list-strength effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 689-697.

Murdock, B. B., & Kahana, M. J. (1993b). List-strength and list-length effects: Reply to Shiffrin, Ratcliff, Murnane, and Nobel (1993). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 1450-1453.

Peterson, L. R., & Peterson, M. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*, 193-198.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1980). SAM: A theory of probabilistic search in associative memory. In G. H. Bower (Ed.), *The* *psychology of learning and motivation: Advances in research and theory. Vol. 14* (pp. 207-262). New York: Academic Press.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1992). Models for recall and recognition. *Annual Review of Psychology, 43,* 205-234.

Shiffrin, R. M., & Raaijmakers, J. G. W. (1992). The SAM retrieval model: A retrospective and prospective. In A. F. Healy, S. M. Kosslyn, & R. M. Shiffrin (Eds.), *From learning processes to cognitive processes: Essays in honor of William K. Estes, Vol. 2.* (pp. 69-86). Hillsdale, NJ: Lawrence Erlbaum Associates.

This page intentionally left blank