AFRL-AFOSR-VA-TR-2015-0354

A Dynamic Model for Decision Making During Memory Retrieval

Richard Shiffrin
TRUSTEES OF INDIANA UNIVERSITY

10/26/2015
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTA2
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
29-10-2015

2. REPORT TYPE
Final Performance

3. DATES COVERED *(From - To)*
15-05-2012 to 14-05-2015

4. TITLE AND SUBTITLE
A Dynamic Model for Decision Making During Memory Retrieval

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-12-1-0255

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
Richard Shiffrin

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
TRUSTEES OF INDIANA UNIVERSITY
205C BRYAN HALL 105 N INIANA AVE
BLOOMINGTON, IN 47405-1106 US

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AF Office of Scientific Research
875 N. Randolph St. Room 3112
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/AFOSR RTA2

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
A DISTRIBUTION UNLIMITED: PB Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Information processing and evidence collection as we try to retrieve from memory evolves dynamically as memory probes change during
perception of a test item, as low and high level features of the test item are retrieved from knowledge during the dynamic process of perception, and
as content, content, and associative information about the test item are retrieved from event memory. This interaction occurs dynamically so that
evidence leading to a task decision changes its character as new features become available at every level from perceptual features to semantic
associations. We have studied this dynamic process empirically in a variety of paradigms and on the basis of the data have developed a general
model of memory storage and retrieval that explains the interaction of event memory and knowledge as it develops over short periods of time
(under a second). This represents a major advance in a field that usually treats retrieval of events and knowledge as separate domains of research,
and that does not track the changing degree of task evidence as the dynamics change. Other major contributions were made in the domains of
statistical learning, attention and perception, the dynamics of short-term recognition memory, and quantum probability decision making.

15. SUBJECT TERMS
Cognitive Modeling, Recognition Memory, Response Times, Decision Making

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

DISTRIBUTION A: Distribution approved for public release.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Richard Shiffrin
Unclassified	Unclassified	Unclassified	UU		19b. TELEPHONE NUMBER *(Include area code)* 812-855-4972

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

DISTRIBUTION A: Distribution approved for public release.

Final Report FA9550-12-1-0255

This grant supported empirical research and development of dynamical models of memory retrieval. In this period this subject was explored primarily in seven related domains: 1) the evolution of the interaction of storage and retrieval of event memories and knowledge; 2) the rapid dynamics of the way task evidence changes as perception and retrieval occur from both knowledge and event memories; 3) the dynamical process of decision making in short-term recognition memory; 4) short term memory for attributes of visual stimuli presented simultaneously; 5) the process of accumulating evidence about associations across trials when individual trials are each ambiguous; 6) how memory retrieval is harmed by the act of storing information during testing; 7) how seemingly irrational decision making can be interpreted in terms of humans knowledge of probability being rooted in quantum probability theory.

The first project had results summarized in a publication in our field's major theoretical journal: Nelson, A. B. and Shiffrin, R.M. (2013). The co-evolution of knowledge and event memory. P*sychological Review, 120(2); 356-394*. We reported a general model for the dynamic interaction of event memory and knowledge, based on several studies in which knowledge for novel (Chinese) characters was developed through extensive training. The interaction of this knowledge with event memory was assessed with a knowledge task (pseudo-lexical decision), a perceptual task (perceptual identification), and an episodic recognition task (recognition memory for occurrence of a test item on a studied list). This research represented a major advance because event memory and knowledge memory are usually treated independently. The essence of the model explained how knowledge evolves through repeated exposure to sufficiently similar events (consisting of content and context): The events are stored individually, but also accumulate in a separate trace we call knowledge (containing accumulated content and context). When any event later occurs, it consists of stimuli and context. The stimuli get processed by access to knowledge based on similarity of test probe to traces in knowledge-- the features in the knowledge trace gradually are perceived and are placed in short-term memory as a continually changing and growing probe. This probe in turn is used to retrieve additional information in knowledge, and also information from similar event traces. The model, termed SARKAE, specifies the time course of these interacting processes, and shows how they explain perception, knowledge retrieval, event retrieval and retrieval of associations of both types, modeling in detail both accuracy and response time data.

The second project is represented by the thesis of my PhD student, Greg Cox, and by our earlier paper Cox, G. E., & Shiffrin, R. M. (2012). Criterion setting and the dynamics of recognition memory. *Topics in Cognitive Science*, **4(1)**, 135-150. The thesis is presently in the process of certification at IU (although Greg is now on a 'postdoctoral' research appointment at Syracuse University) and is now being prepared for journal submission. This research involved production of a dynamic model for memory storage and particularly retrieval, a model capable of explaining event memory measured by accuracy and response time, and for a variety of tasks including recognition memory, with and without speed stress and speed cutoffs, and memory for associations. Most prior models for event memory that have been used to predict accuracy and response time jointly have dissociated the process of evidence collection and decision making from the processes of perception and memory access. Thus accuracy and response time are the result of a diffusion or random walk that moves at a constant drift rate to one or more response barriers. The present dynamic model changes the rate of evidence collection moment by moment as different types of features are extracted from the environment, from our stored knowledge and from event memories. The model explains previously known but largely ignored results, and new results collected in our laboratory, concerning the effects of priming, word frequency in event recognition, effects of speed vs accuracy instructions, the effects of changing test stimuli dynamically over brief periods of time so that the changes are not perceived consciously, the effects seen when the time of response is governed by a signal to respond, the effects of study time, list length and list strength, and the differences between memory for items and the memory for associations between items. The last of these phenomena is based on the idea that item features are collected first and associative features collected later in time. This modeling should represent a major change and advance in the way we understand the processes of memory retrieval.

The third line of research involves empirical studies and modeling of short-term recognition memory, a line of research famously modeled by Saul Sternberg in the 1960s as based on serial exhaustive scanning. Our recent research reveals that the pattern of data originally collected was due to extra time between study of a list of items and the recognition test item, extra time allowing the list items to be rehearsed in various ways. Our research uses a paradigm in which the test item immediately follows the study list: the data pattern changes, and the underlying processes are clarified. The data now show strong effects of lag (recency), and we have used and tested extensively a dynamic model that explains the accuracy and response time data. The results are reported in "Nosofsky, R. M., Cao, R., Cox, G. E., & Shiffrin R. M. (2014a). Familiarity and categorization processes in memory search. Cognitive Psychology*,* 75*,* 97-129", and "Nosofsky, R.M., Cox, G.E., Cao, R., & Shiffrin, R.M. (2014b). An exemplar-familiarity model predicts short- term and long-term probe recognition across diverse forms of memory search. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 40(6), 1524-1539".

The fourth line of research examines memory and precision of memory for attributes of visual stimuli presented simultaneously. A debate has been going on for some time concerning the issue of all-or-none forgetting of the presented visual objects. One class of models proposes all-or-none loss and guessing when the lost item is probed, and another class proposes gradual loss of information for all items in the visual display. Using both accuracy and response time measures, and careful quantitative modeling, we have been able to demonstrate convincingly that all-or-none loss coupled with guessing provides the best account of short-term loss of visual memory. The papers are: "Donkin, C., Nosofsky, R., Gold, J., and Shiffrin, R. M. (2013). Discrete-slots models of visual working-memory response times. *Psychological Review, 120(4), 873-902",* and "Donkin, C., Nosofsky, R., Gold, J., and Shiffrin, R. M. (2015). Verbal labeling, gradual decay, and sudden death in visual short-term memory. *Psychonomic Bulletin and Review*, 22, 170-178."

The fifth line of research data concerns statistical learning. Several stimuli (auditory and visual) are presented together on each trial. There is a one to one mapping of sound to vision, but the correct associations on each trial are ambiguous. Over several trials using the same mappings, the correct associations become evident through statistical accumulation. This line of research explores the type of learning we almost always encounter during development, such as the correct word to object mappings in language learning. Our research has explored the mechanisms of statistical learning and allowed us develop a model that explains in detail the interacting processes that allow statistical learning to occur. Much of this research is due to my PhD student George Kachergis (whose PhD thesis won a Glushko prize for best dissertation) and my colleague Chen Yu. The model uses two primary and interacting processes. It assumes that learners do not attend equally to all possible word-object pairings and store all co-occurrences. Rather, selective storage is guided by several factors: attention is given to pairings on the current trial, and particularly those that are familiar from previous co-occurrence. However, this factor is in competition with selective attention directed toward stimuli not already known. The papers are: " Kachergis, G. (2012). Learning Nouns with Domain-General Associative Learning Mechanisms. In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), Proceedings of the 34th Annual Conference of the Cognitive Science Society (pp. 533-538). Austin, TX: Cognitive Science Society.", "Kachergis, G., Yu, C. & Shiffrin, R. M. (2014). Developing semantic knowledge through crosssituational learning. Proceedings of the 36th Annual Conference of the Cognitive Science Society.", "Kachergis, G., Yu, C., & Shiffrin, R. M. (2013). Actively Learning Object Names Across Ambiguous Situations. Topics in Cognitive Science, 5(1), 200-213.", "Kachergis, G., Yu, C., & Shiffrin, R. M. (2012a). An Associative Model of Adaptive Inference for Learning Word-Referent Mappings. Psychonomic Bulletin & Review, 19(2), 317-324.", "Kachergis, G., Yu, C., & Shiffrin, R. M. (2012b). Cross-situational Word Learning is Better Modeled by Associations than Hypotheses. IEEE Conference on Development and Learning / EpiRob 2012. San Diego, CA: IEEE.", and "Kachergis, G., Yu, C., & Shiffrin, R. M. (in press). A bootstrapping model of frequency and context effects in word learning. *Cognitive Science*."

The sixth project examines the effects of testing event memory. The basic idea is that tests of items that might or might not have been on a just studied list are also events that are stored in memory. Such storage produces interference by the usual mechanisms of forgetting based on competition/interference. The result is a continuous degradation of event memory performance as testing continues (note that performance decreases for new items that are tested; when a previously tested item is tested again, of course performance increases). We have explored and modeled this effect in several experiments, and the results help explain the processes of forgetting of events. The papers are: "Criss, A. H., Malmberg, K.J., & Shiffrin, R.M. (2011). Output interference in recognition memory testing. *Journal of Memory and Language, 64(4), 316-326.", "*Malmberg, K. J., Criss, A. H., Gangwani, T. H., & Shiffrin, R. M. (2012). Overcoming the negative consequences of interference that results from recognition memory testing. *Psychological Science,* **23(2),** 115-119.", "Annis, J., Malmberg, K. J., Criss, A. H., and Shiffrin, R. M. (2013). Sources of interference in recognition testing. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 39, 1365-1376*.", "*Malmberg, K.J., Lehman, M., Annis, J., Criss, A.H., & Shiffrin, R.M. (2014). Consequences of testing memory. *Psychology of Learning & Motivation - Advances in Research and Theory, 61*, 285-313."

The seventh project is aimed to explain seemingly irrational decision making by humans by proposing a new model that assumes humans understanding of probability is based on the rules of quantum probability rather than traditional probability. The most astounding result of those reported was published in PNAS--it tested a prediction derived from the quantum probability model that applies universally and without parameters. The prediction involved the effects of changing the order of two binary questions asked in succession. The order changes the results, of course, but the quantum theory predicted a particular relation for the changes that no one had previously noticed. Once the prediction was derived we looked back at the roughly 75 national surveys, starting about 1990, carried out by Gallup and Pew that had this manipulation. The prediction held in every such survey (and in two laboratory studies we carried out as an additional test). In addition we note that thus far no one has been able to find a traditional probability theory that can explain these findings, though even should one be found the a priori universal prediction that was confirmed in past data provides a good deal of support for the theory. We also carried out other studies of the quantum theory, and thus far it holds up as a viable account of human understanding of probability and the way that understanding governs decision making. The papers are: "Pothos, E. M., Shiffrin, R. M., & Busemeyer, J. R. (2014). The dynamics of decision making when probabilities are vaguely specified. *Journal of Mathematical Psychology*, 59, 6-17. ", "Wang, Z., Soloway, T., Shiffrin, R. M., & Busmeyer, J. R. (2014). Context effects produced by question orders reveal quantum nature of human judgments. *Proceedings of the National Academy of Sciences*, 111(26), 9431-9436.", "Busemeyer, J. R., Zheng, W., & Shiffrin, R. M. (2015). Bayesian model comparison favors quantum over standard decision theory account of dynamic inconsistency. *Decision*, 2, 1-12. "

Although the above projects are the main ones bearing on the project, there were several others that have a less direct but nonetheless relevant connection, in areas such as attention and memory….. I just list these here without commentary: "Denton, S. E., and Shiffrin, R.M. (2013). Short-term visual priming across eye movements. In C. Chubb, B. Dosher, Z.-L. Lu, & R. Shiffrin (Eds.), *Human Information Processing: Vision, Memory, Attention*. American Psychological Association, Washington DC.", "Shiffrin, R. M. (2013). Memory. In Z.-L. Lu & Y. Luo. (Eds.) *Progress in Cognitive Science: From Cellular Mechanisms to Computational Theories*. Peking University Press, Beijing, China (pgs 142-147).", "Kumar, K. N., Chandramouli, S. H., & Shiffrin, R. M. (2015). Salience, perceptual dimensions, and the diversion of attention. American Journal of Psychology, 128(2), 253-265.", "Hotaling, J. M., Cohen, A. L., Shiffrin, R. M., & Busemeyer, J. R. (2015). The dilution effect and information integration in perceptual decision making. PLoS ONE, 10(9), 1-19.", "Shiffrin, R. M., & Chandramouli, S. H. (in press). Model selection, data distributions, and reproducibility. In H. Atmanspacher and S. Maasen (Eds.) *Reproducibility: Principles, Problems, and Practices.* John Wiley, New York.".

1.

1. Report Type

Final Report

Primary Contact E-mail

Contact email if there is a problem with the report.

shiffrin@indiana.edu

Primary Contact Phone Number

Contact phone number if there is a problem with the report

812-855-4972

Organization / Institution name

Trustees of Indiana University

Grant/Contract Title

The full title of the funded effort.

A dynamic Model for decision making during memory retrieval.

Grant/Contract Number

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0255

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

Richard M. Shiffrin

Program Manager

The AFOSR Program Manager currently assigned to the award

James Lawton

Reporting Period Start Date

05/15/2012

Reporting Period End Date

05/14/2015

Abstract

There were four major areas of accomplishment, and several important but subsidiary ones. The first two were closely related. The first was represented by the publication in Psychological Review of the paper reporting research supported by the grant, titled: " The co-evolution of knowledge and event memory". The second is represented in the thesis by my PhD student Greg Cox titled: " Dynamic modeling of memory storage and retrieval". This research is now being prepared for submission to Psychological Review. The first represents a general model for the dynamic interaction of event memory and knowledge, based on several studies in which knowledge for novel (Chinese) characters was developed through extensive training. The interaction of this knowledge with event memory was assessed with a knowledge task (pseudo-lexical decision), a perceptual task (perceptual identification), and an episodic recognition task (recognition memory for occurrence of a test item on a studied list). This research represented a major advance because event memory and knowledge memory are usually treated independently. The second major contribution, thus far represented by the thesis and the publications titled "Criterion setting and the dynamics of recognition memory", involved production of a dynamic model for accuracy and response time by which evidence relevant for event memory judgment is collected moment by moment, changing as different features are extracted from the test item and knowledge memory. The results, based both on free response tasks and time limited response tasks, provide important insights into the time course of, and the

effects of, study time, natural language word frequency, list length and strength, associative memory, recognition memory, and recall. The third area of accomplishment is new data supporting development of a new dynamic model of short-term recognition memory explaining lag effects, trial-to-trial effects, list length effects, and use of knowledge, for both accuracy and response time measures. The fourth major area of accomplishment is data and modeling of statistical learning, by which responding correctly concerning the pairings of stimuli becomes increasingly accurate as information is accumulated over trials, although each trial is ambiguous. Other supported research examined recognition decision making based on mouse tracking measurements using Gaussian process regression, the negative effects of testing caused by memory for earlier test items, the dynamics of attention and perception, and several papers supporting a quantum probability model for human decision making.

Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form

Please attach your SF298 form. A blank SF298 can be found here. Please do not password protect or secure the PDF The maximum file size for an SF298 is 50MB.

AFD-070820-035.rms.pdf

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.

AFOSR Final Report 2015.pdf

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

Archival Publications (published) during reporting period:

Malmberg, K. J., Criss, A. H., Gangwani, T. H., & Shiffrin, R. M. (2012). Overcoming the negative consequences of interference that results from recognition memory testing. Psychological Science, 23(2), 115-119.

Denton, S. E., & Shiffrin, R. M. (2012). Primes and flankers: Source confusions and discounting. Attention, Perception, & Psychophysics, 74 (5), 852-856.

Kachergis, G., Yu, C., & Shiffrin, R.M. (2012). An associative model of adaptive inference for learning word-referent mappings. Psychonomic Bulletin & Review, 19(2), 317-324.

Cox, G. E., & Shiffrin, R. M. (2012). Criterion setting and the dynamics of recognition memory. Topics in Cognitive Science, 4(1), 135-150.

Cox, G. E., Kachergis, G., and Shiffrin, R. M. (2012). Gaussian process regression for trajectory analysis. In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), Proceedings of the 34th Annual Conference of the Cognitive Science Society (pp. 1440-1445). Austin, TX: Cognitive Science Society.

Kachergis, G., Yu, C., and Shiffrin, R. M. (2013). Actively learning object names across ambiguous situations. Topics in Cognitive Science, 5, 200-213.

Denton, S. E., and Shiffrin, R.M. (2013). Short-term visual priming across eye movements. In C. Chubb, B. Dosher, Z.-L. Lu, & R. Shiffrin (Eds.), Human Information Processing: Vision, Memory, Attention. American Psychological Association, Washington DC.

Kachergis, G., Yu, C., and Shiffrin, R. M. (2013). Cross-situational word earning is better modeled by associations than hypotheses. IEEE Conference on Development and Learning-EpiRob 2012.

Nelson, A. B. and Shiffrin, R.M. (2013). The co-evolution of knowledge and event memory. Psychological Review, 120(2); 356-394.

Annis, J., Malmberg, K. J., Criss, A. H., and Shiffrin, R. M. (2013). Sources of interference in recognition testing. Journal of Experimental Psychology: Learning, Memory, and Cognition, 39, 1365-1376.

Donkin, C., Nosofsky, R., Gold, J., and Shiffrin, R. M. (2013). Discrete-slots models of visual working-memory response times. Psychological Review, 120(4), 873-902 .

Malmberg, K.J., Lehman, M., Annis, J., Criss, A.H., & Shiffrin, R.M. (2014). Consequences of testing memory. Psychology of Learning & Motivation - Advances in Research and Theory, 61, 285-312.

Nosofsky, R. M., Cao, R., Cox, G. E., & Shiffrin R. M. (2014a). Familiarity and categorization processes in memory search. Cognitive Psychology, 75, 97-129.

Nosofsky, R.M., Cox, G.E., Cao, R., & Shiffrin, R.M. (2014b). An exemplar-familiarity model predicts short-term and long-term probe recognition across diverse forms of memory search. Journal of Experimental Psychology: Learning, Memory and Cognition, 40(6), 1524-1539.

Pothos, E. M., Shiffrin, R. M., & Busemeyer, J. R. (2014). The dynamics of decision making when probabilities are vaguely specified. Journal of Mathematical Psychology, 59, 6-17.

Wang, Z., Soloway, T., Shiffrin, R. M., & Busmeyer, J. R. (2014). Context effects produced by question orders reveal quantum nature of human judgments. Proceedings of the National Academy of Sciences, 111(26), 9431-9436.

Busemeyer, J. R., Zheng, W., & Shiffrin, R. M. (2015). Bayesian model comparison favors quantum over standard decision theory account of dynamic inconsistency. Decision, 2, 1-12.

Donkin, C., Nosofsky, R., Gold, J., and Shiffrin, R. M. (2015). Verbal labeling, gradual decay, and sudden death in visual short-term memory. Psychonomic Bulletin and Review, 22, 170-178.

Kumar, K. N., Chandramouli, S. H., & Shiffrin, R. M. (2015). Salience, perceptual dimensions, and the diversion of attention. American Journal of Psychology, 128(2), 253-265.

Hotaling, J. M., Cohen, A. L., Shiffrin, R. M., & Busemeyer, J. R. (2015). The dilution effect and information integration in perceptual decision making. PLoS ONE, 10(9), 1-19.

Shiffrin, R. M., & Chandramouli, S. H. (in press). Model selection, data distributions, and reproducibility. In H. Atmanspacher and S. Maasen (Eds.) Reproducibility: Principles, Problems, and Practices. John Wiley, New York.

Kachergis, G., Yu, Y., & Shiffrin. R. M. (in press). Cross-situational word learning is both implicit an strategic. Frontiers in Psychology.

Changes in research objectives (if any):

None

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Oct 14, 2015 08:40:10 Success: Email Sent to: shiffrin@indiana.edu