

**A methodology and software environment
for testing process model's sequential predictions
with protocols**

Frank E. Ritter

20 December 1992

CMU-CS-93-101

School of Computer Science
Carnegie Mellon University
Pittsburgh, PA 15213

*Submitted to the Carnegie-Mellon University Department of Psychology in
partial fulfillment of the requirements for the degree of Doctor of Philosophy
in Psychology in the AI and Psychology program*

This research was partially sponsored by a training grant from the Air Force Office of Scientific Research, Bolling AFB, DC; in part by the Avionics Laboratory, Wright Research and Development Center, Aeronautical Systems Division (AFSC), U. S. Air Force, Wright-Patterson AFB, OH 45433-6543 under Contract F33615-90-C-1465, Arpa Order No. 7597, and in part by the School of Computer Science, Carnegie-Mellon University. The research was also supported in part by Digital Equipment Corporation through an equipment grant. The views and conclusions contained in this document are those of the author and should not be interpreted as representing the official policies, either expressed or implied, of U. S. Government or Digital Equipment Corporation.

Table of Contents

<u>I Introduction to TBPA</u>	1
1. Testing process models through protocol analysis	2
1.1 The need for routinely testing process models' sequential predictions	3
1.1.1 The potential benefits of routinely testing process models' sequential predictions	3
1.1.2 The difficulty of testing sequential predictions	4
1.2 The steps of testing process models' sequential predictions with protocol data	5
1.3 Developing a methodology for routinely testing process models' sequential predictions	6
1.3.1 A detailed specification of what is necessary for routine testing of process models with protocol data	6
1.3.2 An environment to support the needs of routine testing of process models	7
1.3.2.1 A tool supporting the interpretation and alignment of the data with respect to the model's predictions	7
1.3.2.2 A measurement system for telling where a model needs improvement	7
1.3.2.3 An interface for tracing, understanding, and modifying models	7
1.3.3 Documentation of the utility of the environment and methodology	8
1.3.4 Testing and extending the sequentiality assumption of verbal protocol generation	8
2. Testing process models with protocol data: Review of past work	9
2.1 The possible relationships between process models and protocols	9
2.2 Review of creating and testing models with protocol data	13
2.2.1 Exploratory analysis leading to process models	13
2.2.2 General testing of process models	16
2.2.3 Trace based protocol analysis	17
2.2.4 Summary of important data features	19
2.3 Tools related to process model testing	21
2.3.1 Tools for building models from protocols	21
2.3.1.1 Declarative knowledge coding tools	21
2.3.1.2 Exploratory protocol analysis tools	21
2.3.2 Model testing tools	23
2.3.2.1 Strategy classification tools based on process models	23
2.3.2.2 Model tracing modules within intelligent tutoring systems	23
2.3.2.3 Tools for aligning the sequential predictions with data	24
2.3.3 Tools for building and understanding models	26
2.3.3.1 Process model induction tools	26
2.3.3.2 Tools for understanding and building symbolic cognitive models	26
2.3.3.3 Knowledge acquisition tools	28
2.3.4 Summary of useful tool features	29
2.4 Measures of model to data comparison	31
2.4.1 Using criteria to develop a set of measurements	33
2.4.2 Description of measurement inputs	35
2.4.3 Non-numeric descriptive measures	39
2.4.4 Simple numeric measures	41
2.4.5 Measures of component utility	44
2.4.6 Inferential measures	45
2.4.7 A unified view: Criterion based model evaluation	47
2.4.8 Summary of measures	48
2.5 Previous models of process model testing	50
2.6 Summary of lessons for process model testing methodology and tools	53

Appendix to Chapter 2: Review of the Card model alignment algorithm	55
3. Requirements for testing process models using trace based protocol analysis	57
3.1 Definition of trace based protocol analysis (TBPA)	57
3.1.1 The inputs to TBPA	57
3.1.1.1 A 0 th order functional model	57
3.1.1.2 Transcribed protocol data	58
3.1.2 The TBPA loop and its requirements	58
3.1.2.1 Step 1: Run the model to create predictions	59
3.1.2.2 Step 2: Use the predictions to interpret the data	62
3.1.2.3 Step 3: Analyze the results of the comparison	63
3.1.2.4 Step 4: Revise the model to reduce the discrepancies	64
3.2 Supporting TBPA with an integrated computer environment	66
3.2.1 Why an integrated environment is needed	66
3.2.2 The environment must automate what it can	67
3.2.3 The environment must support the user for the rest	67
3.3 The role of an intelligent architecture in the testing process	68
3.3.1 Soar: The architecture used in this environment	68
3.3.2 Making functional models examinable	70
3.3.3 Using the architecture to automate the analysis	72
3.4 Summary of requirements and description of the environment's design	72
<u>II Supporting the TBPA methodology: A description of the Soar/MT environment</u>	76
4. A spreadsheet for comparing the model's predictions with the data	77
4.1 Displaying and editing the correspondences	78
4.2 Automatically aligning unambiguous segments	81
4.3 Interpreting ambiguous actions	83
4.4 Supporting the global requirements	84
4.4.1 Providing an integrated system	84
4.4.2 Automating what it can	84
4.4.3 Providing a uniform interface including a path to expertise	84
4.4.4 Providing general tools and a macro language	85
4.4.5 Displaying and manipulating large amounts of data	85
4.5 Summary	85
5. Visual, analytic measures of the predictions' fit to the data	87
5.1 Creating the operator support display automatically	87
5.2 Understanding the relative processing rate	89
5.2.1 A display for comparing the relative processing rate	89
5.2.2 Using the relative processing display to test the sequentiality assumption of verbal protocol production	94
5.3 Creating additional displays	95
5.3.1 S: An architecture for creating displays	95
5.3.2 S-mode: An integrated, structured editor for S	96
5.4 Supporting the global requirements	97
5.4.1 Providing an integrated system	97
5.4.2 Automating what it can	97
5.4.3 Providing a uniform interface including a path to expertise	97
5.4.4 Providing general tools and a macro language	97
5.4.5 Displaying and manipulating large amounts of data	98
5.5 Summary of measures and recommendations for use	98
6. The model manipulation tool -- the Developmental Soar Interface (DSI)	100
6.1 Providing the model's predictions in forms useful for later comparisons and	101

analysis	
6.1.1 Providing predictions for comparison with the data	102
6.1.2 Aggregating the model's performance	103
6.2 Displaying the model so that it can be understood	104
6.2.1 Normative displays of the model	106
6.2.2 Descriptive displays of the model's performance	109
6.2.3 The working memory walker	111
6.2.4 A pop-up menu and dialog boxes to drive the display	112
6.3 Creating and modifying the model	114
6.3.1 Soar-mode: An integrated, structured editor for Soar	114
6.3.2 Taql-mode: An integrated, structured editor for TAQL	115
6.3.3 The Soar Command Interpreter	115
6.4 Supporting the requirements based on the whole process and its size	116
6.4.1 Providing consistent representations and functionality	116
6.4.2 Automating what it can: Keystroke savings	117
6.4.3 Providing a uniform interface including a path to expertise	117
6.4.4 Providing a set of general tools and a macro language	118
6.4.5 Displaying and manipulating large amounts of information	119
6.5 Lessons learned from the DSI	119
6.5.1 The relatively large size of the TAQL grammar	119
6.5.2 Behavior in Soar models is not just search <i>in</i> problem spaces	119
6.5.3 Soar models do not have explicit operators	122
6.6 Summary	123
III Performance demonstrations of Soar/MT and Conclusions	125
7. Performance demonstration I: Analyzing the Browser-Soar model faster and more deeply	126
7.1 Description of Browser-Soar and its data	126
7.2 Producing richer analyses more quickly	133
7.2.1 The interpretation of data with respect to the model trace done faster and tighter	133
7.2.2 Operator support displays created automatically -- as a set they highlight periodicity in behavior	134
7.3 Where the model and subject process at different rates shown clearly	137
7.3.1 Processing rate display based on decision cycles shows that the quality of fit is high	137
7.3.2 The processing rate display can be based on other measures of the model's effort	140
7.4 High level features of the Browser-Soar model made apparent	141
7.4.1 Browser-Soar as routine behavior is made directly visible	141
7.4.2 Noting Browser-Soar's large goal depth	142
7.4.3 Modifying Browser-Soar	142
7.4.4 Testing the modified Browser-Soar	143
7.5 Testing and extending the sequentiality assumptions of protocol generation theory	144
7.5.1 Are verbalizations generated sequentially?	148
7.5.2 Are mouse actions generated sequentially?	148
7.5.3 Does the sequentiality assumption hold across verbalizations and mouse actions?	148
7.6 Conclusions about Browser-Soar and the TBPA methodology	150
7.6.1 Some conclusions about Browser-Soar	150
7.6.2 Some conclusions about the methodology	151
Appendixes to Chapter 7	152

1 Alignment of the Write episode of Browser-Soar	152
2 Displays of each analytical measure for each episode of Browser-Soar	158
8. Performance demonstration II: Use of Soar/MT components by others	164
8.1 Usage of the Developmental Soar Interface to develop Soar models	164
8.2 Usage of S-mode to create functions in S	166
Appendix to Chapter 8: Survey distributed to Soar users	168
9. Contributions and steps toward the vision of routine automatic model testing	172
9.1 A methodology for testing the sequential predictions of process models	173
9.2 Each step in the methodology was supported in a software environment	174
9.2.1 Interpreting and aligning the model's predictions and the data	174
9.2.2 Analyzing the results of the testing process	175
9.2.3 Steps related to manipulating the model: Prediction generation and modification	175
9.2.4 The synergy from integration	176
9.3 Validated and extended the sequentiality assumption of protocol generation theory	176
9.4 Progress toward the vision of routine applied theoretically guided protocol analysis	177
9.5 Concluding remarks	178
References	179
I. How to obtain the software described in this thesis	193