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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We developed several novel representational and processing techniques for use in connectionist systems designed for high-level AI-like applications such as commonsense reasoning and natural language understanding. The techniques were used, for instance, in a connectionist system (Conposit/SYLL) that implements Johnson-Laird's mental-model theory of human syllogistic reasoning. This theory was chosen as a case study for verifying the power of the techniques, because it was developed independently of the project, contains complex symbolic structures of various types, and requires complex sequences of operations. The resulting connectionist system is probably the most advanced, complex, and complete connectionist rule-based system in existence. It has a more complete scheme for binding rule-variables and for role binding than any other connectionist system. The representational techniques developed in the project were Relative-Position Encoding (RPE) and Pattern-Similarity Association (PSA). RPE allows structure to be encoded by the relative positioning of connectionist activation patterns within a subnetwork. PSA allows structure to be encoded by having different substructures include similar activation subpatterns. These techniques are similar to data structuring techniques used in computer memory (in particular, PSA is similar to associative addressing), but they had not previously been used in any non-trivial way in connectionism. The most distinctive processing technique developed in the project was the Temporal-Winner-Take-All (TWTA) method for selection in connectionist networks. This is more convenient and efficient for some purposes than conventional WTA methods. It works on the basis of signal-timing differences, as opposed to the activation-level differences used in conventional WTA. There were two other significant accomplishments in the project. First, we designed and started the implementation of a system (ABR-Conposit) that performs case/analogy-based reasoning using the above techniques and others. This system preserves the complex structure processing power of symbolic systems while also attaining advantages normally associated with connectionism, such as graceful degradation. ABR-Conposit includes a type of reduced representation to aid in structure matching an long-term memory retrieval. Secondly, we have commenced a unique study into the ways in which a connectionist system might represent and reason about the beliefs and other mental states of agents with which it is interacting. Belief representation/reasoning is a crucial topic within the study of commonsense reasoning and natural language understanding. We have looked in particular at the difficulties in doing belief representation/reasoning in connectionist systems that perform holistic processing of learned reduced representations.

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FINAL TECHNICAL REPORT

July 1992

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Complex Cognitive Information Processing:
A Computational Architecture with a Connectionist Implementation

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CONTENTS

SUMMARY

We developed several novel representational and processing techniques for use in connectionist systems designed for high-level AI-like applications such as commonsense reasoning and natural language understanding.

The techniques were used, for instance, in a connectionist system (Conposit/SYLL) that implements Johnson-Laird's mental-model theory of human syllogistic reasoning. This theory was chosen as a case study for verifying the power of the techniques, because it was developed independently of the project, contains complex symbolic structures of various types, and requires complex sequences of operations. The resulting connectionist system is probably the most advanced, complex, and complete connectionist rule-based system in existence. It has a more complete scheme for binding rule-variables and for role binding than any other connectionist system.

The representational techniques developed in the project were Relative-Position Encoding (RPE) and Pattern-Similarity Association (PSA). RPE allows structure to be encoded by the relative positioning of connectionist activation patterns within a subnetwork. PSA allows structure to be encoded by having different substructures include similar activation subpatterns. These techniques are similar to data structuring techniques used in computer memory — in particular, PSA is similar to associative addressing -- but they had not previously been used in any non-trivial way in connectionism.

The most distinctive processing technique developed in the project was the Temporal-Winner-Take-All (TWTA) method for selection in connectionist networks. This is more convenient and efficient for some purposes than conventional WTA methods. It works on the basis of signal-timing differences, as opposed to the activation-level differences used in conventional WTA.

There were three other significant accomplishments in the project. First, we designed and started the implementation of a system (ABR-Conposit) that performs *case/analogy-based reasoning* using the above techniques and others. This system preserves the complex structure processing power of symbolic systems while also attaining advantages normally associated with connectionism, such as graceful degradation. ABR-Conposit includes a type of *reduced representation* to aid in structure matching an long-term memory retrieval.

Secondly, we have commenced a unique study into the ways in which a connectionist system might represent and reason about the *beliefs* and other mental states of agents with which it is

interacting. Belief representation/reasoning is a crucial topic within the study of commonsense reasoning and natural language understanding. We have looked in particular at the difficulties in doing belief representation/reasoning in connectionist systems that perform holistic processing of learned reduced representations.

Thirdly, we have identified the problems raised by *variables within working memory items* (as opposed to variables in processing rules, which are the usual sort of variables commented on in connectionism). We have shown how *logical combinators* could be used to overcome the problems to a large extent.

The major tasks set out in the Statement of Work in the grant proposal were accomplished, except that:

(a) the work on interpreted rules was replaced by the more general and powerful notion of analogy/case-based reasoning;

(b) the work on spatial reasoning was set aside in favor of the work on analogy/case-based reasoning and on belief representation and reasoning.

EXPLANATIONS OF MAJOR ACCOMPLISHMENTS

Most of the accomplishments of the project have been reported in refereed journal articles, book chapters, refereed conference papers, technical reports, and a Ph.D. thesis. The following is therefore confined to giving brief explanations and pointers to the relevant articles. The articles are listed in later sections.

Relative-Position Encoding and Pattern-Similarity Association

These techniques are for realizing complex data structures, which might for instance be akin to semantic network fragments, in working memories in connectionist networks, in such a way as to support dynamic inferencing (i.e., the types of inferencing needed in commonsense reasoning and natural language understanding). *Relative-Position Encoding* (RPE) achieves dynamic associations between data structure components in working memory by putting the connectionist activation patterns encoding those components in suitable relative positions. The particular form of RPE we have studied most uses an array-structured connectionist subnetwork as the working memory of our Conposit system. The data structure components take the form of activation patterns that can appear anywhere in the array.

Degenerate, simplistic forms of RPE have appeared in many connectionist systems, notably in vision systems and system that have input or output layers divided into separate buffers. However, the full power of the technique had not previously been exploited. The power results from the convenience of being able to mutually structure data items by merely *positioning* them in *dynamically chosen* places, rather than by the more usual connectionist means of putting them in pre-assigned places or facilitating connection pathways (by changing weights or setting binding node activations). RPE is a generalization of the basic computer data structuring technique of placing related data fields in contiguous positions in main memory.

The only other connectionist research we are aware of that uses anything like a non-trivial form of RPE is the work on natural language parsing by Charniak and Santos and work on a connectionist Lisp-like system by Goebel.

Pattern-Similarity Association (PSA) achieves dynamic associations between data structure components in working memory by including in the components activation sub-patterns that act as associative keys. The keys are dynamically chosen or created, and have no pre-defined meaning.

Two components that contain the same key or sufficiently similar keys are deemed to be associated with each other. This technique is a direct extrapolation from associative addressing in computers.

Associative addressing is at least as powerful as the pointer method for data structuring, and is a much more natural candidate for transfer into connectionism than pointers are. It is somewhat remarkable, therefore, that previous connectionist research has not adopted the idea. The only other connectionists research we know of that uses a form of PSA is the work of Shastri and Ajjanagadde on role binding by means of time-phase sharing. The time phases can be viewed as associative keys.

The type of PSA we have focused on is used in the array-structured working memories mentioned above, in a tight combination with RPE.

Both techniques are presented/discussed in Barnden (1988a, 1989a, 1991), Barnden and Srinivas (1991, 1992a) and elsewhere. In particular, Barnden and Srinivas (1991), article in the journal *Connection Science*, extensively discusses the relationships of the techniques to other connectionist information-structuring methods, and also to methods used in computers. The rich inter-relationships of these other connectionist and computer methods are also clarified.

Temporal-Winner-Take-All

Winner-Take-All (WTA) networks frequently appear in neural network models. They are primarily used for decision making and selection. As an alternative to the conventional activation based Winner-Take-All mechanisms (AWTA), we present a *time-based* Temporal-Winner-Take-All (TWTA) mechanism with $O(n)$ space complexity and roughly $O(log_n)$ time complexity. The mechanism exploits systematic and stochastic differences between time delays within different units and connections. The TWTA and the AWTA networks are shown to be logically equivalent, but the TWTA mechanism is more suitable than the latter for various selection tasks, especially the selection of an arbitrary unit from a set (e.g. as in unit recruitment). TWTA avoids various problems with conventional WTA, notably the difficulty of making it converge rapidly over a large range of conditions. We have performed a probabilistic analysis of the TWTA mechanism and obtained experimental data from numerous massively simulations of the TWTA mechanism on a Connection Machine.

TWTA is used for various selection purposes in the Conposit system.

The method is presented and discussed in Barnden (1991), Barnden and Srinivas (in press), Barnden, Srinivas, & Dharmavaratha (1990), Srinivas & Barnden (1990), and Srinivas's Ph.D. dissertation.

Rule-Based Reasoning System (Conposit)

Conposit is a structured (but not classically localist) connectionist rule-based system. Its rules operate on an array-structured working memory of the sort mentioned above, using the Relative-Position Encoding and Pattern-Similarity Association data structuring techniques. The action part of each rule is implemented as a flowchart-like connectionist subnetwork that changes the contents of working memory by sending streams of signals to it. The action part is triggered by the output of a subnetwork that can detect the presence of specific data structure fragments in the working memory. This detection module is highly parallel and efficient. Temporal-Winner-Take-All is used in Conposit for rule selection, random decisions to exit from loops within action parts, selection of data structure fragments to work on within the working memory, and recruitment of free space in working memory for new data structure fragments.

The main version of the Conposit system is Conposit/SYLL, which implements syllogistic reasoning through Johnson-Laird mental models, though with major modifications to the way they are processed. There was no immediate intention to extend the Johnson-Laird approach as a psychological theory. Rather, the exercise was undertaken in order to test the power of the RPE, PSA and TWTA techniques.

The application of these techniques to mental-model manipulation raises some broad issues. One is the usefulness of marker-passing over dynamically-arising, virtual networks arising in the activation state of working memory at a high level of description, rather than over static networks at the basic architectural level of the system. Another is the way in which the particular nature of the techniques affects what it is natural to do at the symbolic level of description. In particular, the techniques predispose the system towards random as opposed to pre-ordered sequencing of subtasks, and towards associative linking as opposed to use of explicit linking constructs.

Conposit is elaborate, and is geared towards procedurely more elaborate reasoning tasks than those tackled by other connectionist reasoning systems. It is described and discussed primarily in Barnden (1989a, 1990, 1991). See also Barnden and Srinivas (1991).

Connectionist Analogy/Case-Based Reasoning

This work addressed the question of how we are to gain both the standard advantages of connectionism and those of symbolic systems, without adopting hybrid symbolic/connectionist systems. Fully connectionist systems that support analogy-based reasoning are proposed as an answer, at least in the realm of high-level cognitive processing. This domain includes commonsense reasoning and the semantic/pragmatic aspects of natural language processing. The proposed type of system, purely by being *analogy*-based, gains forms of graceful degradation, representation completion, similarity-based generalization, learning, rule-emergence and exception-emergence. The system therefore gains advantages commonly associated with connectionism, although the precise forms of the benefits are different. At the same time, through being fully connectionist, the system also gains the traditional connectionist variants of those advantages, as well as gaining further advantages not provided by analogy-based reasoning per se. And, because the system is in part an implementation of a form of symbolic processing, it preserves the flexible handling of complex, temporary structures that are well supported in traditional artificial intelligence and which are essential for high-level cognitive processing. The work is in part a reaction against the excessive polarization of the connectionism/symbolicism debate. This polarization is seen as resulting from over-simplified, monolithic views both of what symbolic processing encompasses and of the nature of the benefits that connectionism provides.

The system is a new version of Conposit, called ABR-Conposit. It has been partially implemented. A preliminary design is reported in Barnden and Srinivas (1992a). See also Barnden (forthcoming, a, b).

ABR-Conposit replaces the arbitrary "associative keys" used for PSA in the older Conposit versions by associative keys that are dynamically computed from their local contexts in the working memory. These keys are a form of (non-learned) reduced representation.

Belief Representation/Reasoning

The systematicity and structure-sensitivity of high-level cognition, notably commonsense reasoning and natural language understanding, are widely recognized to present a challenge to connectionism. However, an aspect of systematicity and structure-sensitivity has not been adequately addressed by either side of the symbolicist/connectionist debate. A system must have a way of embedding reasoning within various types of context. For instance, a system must be able to reason ***within the***

context of another agent's beliefs. This requirement present particular challenges to connectionist systems that work by learned holistic processing of compressed encodings (reduced representations). Such systems have been shown to have considerable promise for providing systematicity and structure-sensitivity while avoiding a straightforward implementation of traditional symbol manipulation. However, there are reasons to think that such systems will have great difficulty doing belief representation/reasoning *holistically*, that is without breaking structures down into parts as is done in symbolic systems. A preliminary simulation study by Balogh, one of the students supported by the grant, has provided preliminary verification of this contention, but the necessary experimental program is large and will be very time-consuming.

The topic of belief representation/reasoning has barely been touched on in other connectionist work. It is to be carefully distinguished from quasi-connectionist work that has been done misleadingly under the heading of "belief," in which what is at issue is merely the "belief" set of the system itself.

Our work on connectionism and beliefs is reported in Barnden (1992a, b, c, d).

Avoiding Variables by means of Logical Combinators

The connectionist problem of achieving the quantificational effect of symbolic variables is well recognized. However, one relatively neglected issue is that of variables in *working memory representations* (arising, for instance, from natural language inputs), as opposed to variables in rules. Working memory variables present difficulties, centering on the arbitrariness of the set of variables used in any given expression, and on non-uniformity in expressions and manipulations. However, the variables can in principle be avoided, for instance by using *logical combinators*. These are special functions much studied within the symbol processing arena. The use of combinators makes structures less arbitrary and more uniform. The reduced arbitrariness ameliorates an important systematicity problem, and the added uniformity could facilitate high-level parallelism. We do not claim that the combinator approach is definitely the right one to adopt, because of some problems. Nevertheless, combinators need to be borne in mind, and the symbolic/connectionist debate has been over-simplified in ignoring them. We have investigated several ways in which combinator-based working memory items could be implemented in connectionism, with special attention to reduced-representation implementations. (Also, combinators could easily be implemented in Conposit.)

This work has so far been largely theoretical, and is discussed briefly in Barnden and Srinivas (1990) and extensively in Barnden and Srinivas (1992b).

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Barnden, J.A. (1988a). The right of free association: relative-position encoding for connectionist data structures. In *Procs. 10th Annual Conference of the Cognitive Science Society.* Hillsdale, N.J.: Lawrence Erlbaum. pp.503–509.

Barnden, J.A. (1989a). Neural-net implementation of complex symbol-processing in a mental model approach to syllogistic reasoning. In *Procs. 11th Int. Joint Conf. on Artificial Intelligence* (Detroit, August 1989). San Mateo, CA: Morgan Kaufmann. pp.568–573.

Barnden, J.A. & Srinivas, K. (1991). Encoding techniques for complex information structures in connectionist systems. *Connection Science, 3* (3), pp.263–309.

This article has been chosen for inclusion in a book (J. Hendler, Ed.) that will contain selected reprints of *Connection Science* articles.

Barnden, J.A. & Srinivas, K. (1992a). Overcoming rule-based rigidity and connectionist limitations through massively-parallel case-based reasoning. *Int. J. Man-Machine Studies, 36*, pp.221–246.

Barnden, J.A. & Srinivas, K. (in press). Temporal winner-take-all networks: a time-based mechanism for fast selection in neural networks. *IEEE Trans. Neural Networks.*

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Barnden, J.A. (1991). Encoding complex symbolic data structures with some unusual connectionist techniques. In J.A. Barnden & J.B. Pollack (Eds), *Advances in Connectionist and Neural Computation Theory, Vol. 1: High Level Connectionist Models*, pp.180–240. Norwood, N.J.: Ablex Publishing Corp.

Barnden, J.A. (1992a). Connectionism, generalization and propositional attitudes: a catalogue of challenging issues. In J. Dinsmore (ed), *The Symbolic and Connectionist Paradigms: Closing the Gap*. Hillsdale, N.J.: Lawrence Erlbaum. pp.149–178.

Barnden, J.A. (forthcoming, a). On using analogy to reconcile connections and symbols. To appear in D.S. Levine & M. Aparicio (Eds), *Neural Networks for Knowledge Representation and Inference*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Barnden, J.A. (forthcoming, b). On the connectionist implementation of analogy and working memory matching. To appear in K.J. Holyoak & J.A. Barnden (Eds), *Advances in Connectionist and Neural Computation Theory, Vol. 2: Analogical Connections*. Norwood, N.J.: Ablex Publishing Corp.

Barnden, J.A. & Pollack, J.B. (1991). Introduction: problems for high-level connectionism. In J.A. Barnden & J.B. Pollack (Eds), *Advances in Connectionist and Neural Computation Theory, Vol. 1: High Level Connectionist Models*, pp.1–16. Norwood, N.J.: Ablex Publishing Corp.

Barnden, J.A. & Srinivas, K. (forthcoming). Encoding techniques for complex information structures in connectionist systems. To appear in a book (J. Hendler, Ed.) that will contain selected reprints of *Connection Science* articles.

OTHER PUBLICATIONS

Barnden, J.A. (1988b). Commonsense reasoning in *Conposit*, a quasi-connectionist register-array model. *Neural Networks, 1*, Suppl. 1, p.161. Abstract of presentation at 1988 Meeting of the International Neural Network Society.

Barnden, J.A. (1988c). Conposit, a neural net system for high-level symbolic processing: overview of research and description of register-machine level. *Memoranda in Computer and Cognitive Science*, No. MCCS–88–145. Computing Research Laboratory, New Mexico State University, Las Cruces, NM 88003.

Barnden, J.A. (1989b). Simulations of *Conposit*, a supra-connectionist architecture for commonsense reasoning. In *Procs. 2nd Symp. on the Frontiers of Massively Parallel Computation*, IEEE Computer Society Press: Washington, DC, 1988. pp.311–315.

Barnden, J.A. (1990). Syllogistic mental models: exercising some connectionist representation and control methods. *Memoranda in Computer and Cognitive Science*, No. MCCS–90–204, Computing Research Laboratory, New Mexico State University, Las Cruces, NM 88003.

Barnden, J.A. (1991b). Connectionism and propositional attitudes: problems and opportunities. In *Working Notes of Symp. on Connectionist Natural Language Processing* (pp.117–126), AAAI Spring Symposium Series, Stanford University, March 1991.

Barnden, J.A. (1992b). Connectionism, structure-sensitivity, and systematicity: refining the task requirements. *Memoranda in Computer and Cognitive Science*, No. MCCS–92–227, Computing Research Laboratory, New Mexico State University, Las Cruces, NM 88003.

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Barnden, J.A. & Srinivas, K. (1990). Dissolving variables in connectionist combinatory logic. In *Procs. International Joint Conference on Neural Networks* (San Diego, CA, June 1990). Vol. III, pp.709–714.

Barnden, J.A. & Srinivas, K. (1992b). Working memory variables, logical combinators and systematicity. *Memoranda in Computer and Cognitive Science*, No. MCCS–92–245, Computing Research Laboratory, New Mexico State University, Las Cruces, NM 88003. Submitted to *Connection Science*.

Barnden, J.A., Srinivas, K. & Dharmavaratha, D. (1990). Winner-take-all networks: time-based versus activation-based mechanisms for various selection goals. *Procs. IEEE International Symposium on Circuits and Systems* (New Orleans, May 1990). pp.215–218.

Srinivas, K. & Barnden, J.A. (1989). Temporal-winner-take-all networks for arbitrary selection in connectionist and neural networks. Abstract in *Procs. 1st Int. Joint Conf. on Neural Networks*, (Washington, D.C., June 1989), p.II-599, published by IEEE.

Srinivas, K. & Barnden, J.A. (1990). Competition and selection in neural networks with distributed representations. In *Procs. Rocky Mountain Conference on Artificial Intelligence* (New Mexico State University, June 1990). pp.117–121.

CONNECTIONIST BOOK SERIES

Barnden is Series Editor of *Advances in Connectionist and Neural Computation Theory,* Ablex Publishing Corp.: Norwood, N.J. Two books have so far being created, with Barnden as one co-editor of each.

The inspiration for the books arose from the work conducted under the grant. In particular, Barnden's conception for the second volume, which is on links between Connectionism and Analogy, was a direct result of his work on connectionist analogy-based reasoning described above. The book is unique in its coverage, and we expect it to inspire fruitful research on an under-represented area.

The first volume is becoming a standard reference in articles on high-level connectionism.

Barnden, J.A. & Pollack, J.B. (Eds). (1991). *Advances in Connectionist and Neural Computation Theory, Vol. 1: High Level Connectionist Models.* Norwood, N.J.: Ablex Publishing Corp. ISBN 0-89391-687-0.

Holyoak, K.J. & Barnden, J.A. (Eds). (forthcoming). *Advances in Connectionist and Neural Computation Theory, Vol. 2: Analogical Connections.* Norwood, N.J.: Ablex Publishing Corp. ISBN 0-89391-821-0. Manuscript mailed to publisher in July 1992.

REVIEWS

Barnden, J.A. (in press). Symbols, sub and non. Invited review for *Neural Network Review, 4* (3 & 4), Hillsdale, N.J.: Lawrence Erlbaum. (10 pages).

Barnden, J.A. (in press). Invited review of G. Hinton (ed.), *Connectionist Symbol Processing*, Cambridge, MA: MIT press. To appear in *Neural Networks*, July 1992.

PRESENTATIONS

National/International

"Encoding Complex Symbolic Data Structures with Some Unusual Connectionist Techniques."
Oral presentation at *Workshop on High-Level Connectionist Models*, NMSU, April 1988. (I was co-organizer of the workshop, which was attended by prominent researchers from across the country.)

"The Right of Free Association: Relative-Position Encoding for Connectionist Data Structures."
Poster paper at *10th Annual Conference of the Cognitive Science Society*, Montreal, August 1988.

"Commonsense Reasoning in *Conposit*, a Quasi-Connectionist Register-Array Model."
Oral presentation at *1st. Annual Meeting of the International Neural Network Society*, Boston, September 1988.

"Simulations of *Conposit*, a Supra-Connectionist Architecture for Commonsense Reasoning."
Poster paper at *Second Symposium on the Frontiers of Massively Parallel Computation*, Fairfax, VA, October 1988.

Invited Discussion of a paper on "Logic and Connectionism" by Bechtel.
Oral presentation at *Annual Meeting of the Society for Philosophy and Psychology*, Tucson, April 1989.

"Temporal-Winner-Take-All Networks for Arbitrary Selection in Connectionist and Neural Networks."
Poster presentation at *1st International Joint Conference on Neural Networks*, Washington, D.C., June 1989.

"Neural-Net Implementation of Complex Symbol-Processing in a Mental Model Approach to Syllogistic Reasoning."
Oral presentation at *11th International Joint Conference on Artificial Intelligence*, Detroit, August 1989.

"Handling of Noise, Irrelevance and Inferential Conflict in a Connectionistically Implemented Case-Based Reasoning System."

Oral presentation at *Workshop on Symbolic Problem Solving in Noisy, Novel and Uncertain Environments*, 11th International Joint Conference on Artificial Intelligence, Detroit, August 1989.

Presentation of discussion points while acting as moderator of a session at ***Workshop on Connectionist Artificial Intelligence*** at the 11th International Joint Conference on Artificial Intelligence, Detroit, August 1989.

(**Note**: Barnden was one of only 25 researchers invited to participate in this workshop.)

"Dissolving Variables in Connectionist Combinatory Logic."

Poster paper at *International Joint Conference on Neural Networks*, San Diego, June 1990.

"A Case-Based Reasoning Approach to the Symbols vs. Connectionism Debate."

Invited oral presentation at Computer Science Department, University of Exeter, U.K., August 1990.

"A Case-Based Reasoning Approach to the Symbols vs. Connectionism Debate."

Invited oral presentation at *4th Annual Workshop of the Metroplex Institute for Neural Dynamics*, Dallas, October 1990. (Workshop title: Neural Networks for Knowledge Representation and Inference.)

"Connectionism and Propositional Attitudes."

Invited oral presentation at *Post-Meeting Workshop on Connectionism and Natural Language Processing*, 4th Annual Conference on Neural Information Processing Systems, Keystone, Colorado, November/December 1990.

"Connectionism and Propositional Attitudes: Problems and Opportunities."

Oral presentation at *Symposium on Connectionist Natural Language Processing*, AAAI Spring Symposium Series, Stanford University, March 1991.

"Secrecy, Separation, Singleness: The Modules of Modularity."

Invited oral presentation at *Post-Conference Workshop on Modularity in Connectionist Models of Cognition*, 5th Annual Conference on Neural Information Processing Systems, Vail, Colorado, December 1991.

"Beliefs, Connectionism, Meta-Representation, Vagueness: Stirring the Pot."

Oral presentation at *Symposium on Propositional Knowledge Representation*, AAAI Spring Symposium Series, Stanford University, March 1992.

"Belief representation and connectionism."

Oral presentation at *AAAI-92 Workshop on Integrating Neural and Symbolic Processes—The Cognitive Dimension*, San Jose, CA, July 1992.

Regional/Local

"Simulations of a cognitive model on the Massively Parallel Processor."

Oral presentation in Computer Science Department colloquium series, NMSU, September 1987.

"High-Level Reasoning in a Quasi-Connectionist Register-Array Model."

Oral presentation at *3rd New Mexico Computer Science Conference*, UNM, Albuquerque, April 1988.

"The Right of Free Association: Encoding Techniques for Connectionist Data Structures."

Oral presentation in ACM Colloquium Series, Computer Science Department, NMSU, December 1988.

"From High-Level Cognition to Neural Networks".

Invited oral presentation at the session on Neural Computing Networks at *Regional Meeting of the American Association for the Advancement of Science*, Las Cruces, April 1989.

"Temporal-Winner-Take-All Networks for Arbitrary Selection in Connectionist and Neural Networks."

Oral presentation at *4th New Mexico Computer Conference*, NMIMT, Socorro, April 89.

"Conposit, a Neural Network System for Symbolic Processing."

Invited oral presentation at meeting of the Rio Grande Chapter of the Association for Computing Machinery, UNM, Albuquerque, September 1989.

"High-Level Cognitive Processing in Connectionist/Neural Networks."

Invited oral presentation to Statistics Group, Mathematics Department, NMSU, April 1990.

"Connections by Analogy to Symbols."

Colloquium, Computer Science Department, New Mexico State University, November 1991.

Presentations by Co-Authors

The following presentations were given by grant-supported students who co-authored the papers with me.

"Cross-Fertilization between Connectionist Networks and Highly Parallel Architectures."

Oral presentation by K. Srinivas at *5th IASTED International Conference on Expert Systems and Neural Networks*, Honolulu, August 1989. (IASTED = International Association of Science and Technology for Development.)

"Winner-Take-All Networks: Time-Based versus Activation-Based Mechanisms for Various Selection Goals."

Oral presentation by K. Srinivas at *IEEE International Symposium on Circuits and Systems*, New Orleans, May 1990.

"Competition and Selection in Neural Networks with Distributed Representations."

Oral presentation by K. Srinivas at *Rocky Mountain Conference on Artificial Intelligence*, NMSU, June 1990.

"Applications of Connectionism to Analogical Reasoning."

Oral presentation by T.C. Eskridge at *3rd Midwest Artificial Intelligence and Cognitive Science Conference*, Southern Illinois University at Carbondale, April 1991.

PERSONNEL

Barnden, J.A., *Associate Professor*, Computer Science Department & Computing Research Laboratory, New Mexico State University, Las Cruces, NM.

Srinivas, K., *Ph.D. Student*, Computer Science Department, New Mexico State University.

Obtained Ph.D. in 1991. Dissertation entitled *Selection in massively parallel connectionist networks.*

Balogh, I., *Ph.D. Student*, Computer Science Department, New Mexico State University.

Ph.D. expected in 1992/3 academic year. His dissertation will investigate the possibilities of using holistic processing of reduced representations, and will have as a major component a study of belief representation/reasoning (see above).

Eskridge, T.C., *Ph.D. Student*, Computer Science Department, New Mexico State University.

Ph.D. expected in 1993/4. His dissertation will investigate connectionist analogy-based reasoning (see above).

Pfeiffer, H.D., *Ph.D. Student*, Computer Science Department, New Mexico State University.

Ph.D. expected in 1993/4. Her dissertation is also planned to be on connectionist analogy-based reasoning (see above).

Dharmavaratha, D., *M.S. Student*, Computer Science Department, New Mexico State University.

M.S. obtained in 1993/4. Her Master's thesis was on a simulation of the Temporal-Winner-Take-All method (see above).