

A Bibliography in Character Recognition: Techniques for Describing Characters

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A bibliography is presented in the field of character recognition. Many of the references are from the fields of engineering and psychology and deal with various techniques for describing machine and hand-printed characters.

The following bibliography lists references that we have compiled during two years of work on various aspects of character recognition. Our attempt at searching the literatures related to engineering, psychology, and character formation was to combine the relevant portions of all three so as to form a unified approach to the area of machine recognition of multifold and hand-printed alphanumeric characters.

In pursuing our research we have placed major emphasis on sources relating to the application of cognitive psychology to the character recognition problem. Consequently, we feel that the bibliography is not a totally balanced view of the entire character recognition field. The sources dealing with engineering-oriented techniques were chosen from the vast number of such articles so as to exhibit the range of thought which has been considered. A few references which we found particularly useful for investigating the relevance of character formation to character recognition were included.

References included under a specific heading may be applicable to other areas; for example, a listing under the hand-printing heading may provide techniques which are useful for the recognition of machine-printed characters. The authors would appreciate any additions to this bibliography.

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I. General References and Review Papers

A. *Engineering*

Andrews, Harry C. *Introduction to Mathematical Techniques in Pattern Recognition*. Wiley-Interscience, New York, 1972.

Casey, R., and G. Nagy. "Advances in Pattern Recognition." *Sci. Am.*, 224 (1971), 56-71.

Chodrow, Mark M. "A Study of Handprinted Character Recognition Techniques." Information Dynamics Corp., Reading, Mass., February 1966.

Grasselli, A. (ed). *Automatic Interpretation and Classification of Images*. Academic Press, New York, 1969.

Grenander, U. "A Unified Theory of Patterns," *Advances in Computers*. Academic Press, New York, 1970; 10, 175-216.

Harmon, Leon D. "Automatic Recognition of Print and Script." *Proc. IEEE*, 60 (1972), 1165-1176.

Ho, Yu-Chi and Ashok K. Agrawala, "On Pattern Classification Algorithms, Introduction and Survey." *Proc. IEEE*, 56 (1968), 2101-2114.

- IEEE Proceedings, First International Joint Conference on Pattern Recognition, October-November 1973, Washington, D.C. IEEE Order Department, New York; 73-CH0821-9C.
- Kanal, Laveen N. (ed.), *Pattern Recognition*. Thompson Book Company, Washington, D.C., 1968.
- Kovalevsky, V. A. *Character Readers and Pattern Recognition*. Spartan Books, New York, 1968.
- Levine, M. D. "Feature Extraction: A Survey." Proc. IEEE, 57 (1969), 1391-1407.
- Meisel, William S. *Computer-Oriented Approaches to Pattern Recognition*. Academic Press, New York, 1972.
- Mendel, J. M. and K. S. Fu. *Adaptive, Learning, and Pattern Recognition System, Theory and Application*. Academic Press, New York, 1970.
- Minsky, M. L. and S. Papert, *Perceptrons*. M.I.T. Press, Cambridge, Mass., 1969.
- Nagy, George, "State of the Art in Pattern Recognition." Proc. IEEE, 56 (1968), 836-862.
- Nilsson, N. J. *Learning Machines*. McGraw-Hill, New York, 1965.
- Tippett, James T., et al. (eds.) *Optical and Electro-Optical Information Processing*. M.I.T. Press, Cambridge, Mass., 1965.
- Uhr, L. (ed.). *Pattern Recognition*. John Wiley and Sons, New York, 1966.
- Uhr, L. *Pattern Recognition, Learning, and Thought*. Prentice-Hall, Englewood Cliffs, New Jersey, 1973.
- Ullman, J. R. *Pattern Recognition Techniques*. Crane, Russak, New York, 1973.
- Watanabe, Satoshi (ed.). *Methodologies of Pattern Recognition*. Academic Press, New York, 1969.
- Watanabe, Satoshi (ed.). *Frontiers of Pattern Recognition*. Academic Press, New York, 1972.

B. *Psychology*

- Cornsweet, T. N. *Visual Perception*. Academic Press, New York, 1970.
- Dodwell, P. C. *Visual Pattern Recognition*. Holt, Rinehart and Winston, New York, 1970.
- Gawróński, R. (ed.) *Bionics*. Elsevier, New York, 1971.
- Gibson, Eleanor J. *Principles of Perceptual Learning and Development*. Appleton-Century-Crofts, New York, 1969.
- Julesz, B. *Foundations of Cyclopean Perception*. University of Chicago Press, Chicago, 1971.
- Koffka, K. *Principles of Gestalt Psychology*. Harcourt Brace and World, New York, 1935.

- Kolers, Paul A. and Murray Eden (eds.). *Recognizing Patterns: Studies in Living and Automatic Systems*. M.I.T. Press, Cambridge, Mass., 1968
- Neisser, Ulric. *Cognitive Psychology*. Meredith Publishing, New York, 1967.
- Wathen-Dunn, W. (ed.). *Models for the Perception of Speech and Visual Form*. M.I.T. Press, Cambridge, Mass., 1967.
- Zusne, Leonard. *Visual Perception of Form*. Academic Press, New York, 1970.

II. Engineering Descriptions of Characters

A. *Techniques Applied to Machine-Printed Characters*

(For sources earlier than 1962 see the review articles of Stevens [1961] and Thomas [1962])

Ahlgren, R. C., H. F. Ryan, and C. W. Swonger. "A Character Recognition Application of an Iterative Procedure for Feature Selection." *IEEE Trans. on Computers, C-20*, No. 9 (1971), 1067-1075.

Andrews, Harry C. "Multidimensional Rotations in Feature Selection." *IEEE Trans. on Computers, C-20*, No. 9 (1971), 1045-1051.

Arkadev, A. G., and E. M. Braverman (W. Turski and J. D. Cowan, translators). *Computers and Pattern Recognition*. Thompson Book Company, Washington, D.C., 1967.

Auerbach on OCR. Auerbach Corporation, Philadelphia, 1972.

Becker, Peter W., and Knud A. Nielsen. "Pattern Recognition Using Dynamic Pictorial Information." *IEEE Trans. on Systems, Man and Cybernetics, SMC-2*, No. 3 (1972), 434-437.

Bell, Donald A. "Shape Analysis and Character Recognition." *Com. Sci.*, No. 47. National Physical Laboratory, Teddington, England, March 1971.

Belmont, Peter A. "Font Recognition." Applied Research Laboratory, Sylvania Electronic Systems—East, Waltham, Mass., October 1967.

British Computer Society. *Character Recognition*. London, 1966.

Casey, R., and G. Nagy. "An Autonomous Reading Machine." *IEEE Trans. on Computers, C-17*, No. 5 (1968), 492-502.

Chandrasekaran, B., and Kanal, L. "On Linguistic, Statistical, and Mixed Models for Pattern Recognition." Computer and Information Science Research Center, Ohio State University, Columbus; OSU-CISRC-TR-71-3; Technical Report PB-198-279.

Chang, S.-K. "Analysis and Synthesis of Two-Dimensional Patterns Using Picture Processing Grammars." Ph. D. thesis, University of California at Berkeley, 1969; 69-18,893.

Datapro Research Corporation. "All About Optical Readers." Feature Report 70F-320-01a, 1972.

- Dolby, James L. "Some Statistical Aspects of Character Recognition." Department of Statistics, Stanford University, Palo Alto, Calif., May 1966.
- Fischer, G. L. (ed.). Symposium on Optical Character Recognition. Spartan Book Co., Washington, D.C., 1962.
- Fischler, Martin A. "Machine Perception and Description of Pictorial Data." Proc. International Joint Conference on Artificial Intelligence, Washington, D.C., May 1969, pp. 629-639.
- Frank, A. I. "Multiple-Font Reading, a System Description." IEEE Systems Design, 7, No. 3, (1964), 21-25.
- Gabor, D. "Character Recognition by Holography." Nature, 208 (1965), 422-423.
- Glucksman, Herbert A. "Multicategory Classification of Patterns Represented by High-Order Vectors of Multilevel Measurements." IEEE Trans. on Computers, C-20, No. 12 (1971), 1593-1598.
- Gray, S. B. "A Highly Flexible, Many-font General-purpose Page Reader." American Documentation Institute, 26th Annual Meeting, Chicago, October 1963, pp. 85-86.
- Inigo, R. M. "Threshold Logic Multifont Character Recognition System." Ph.D. thesis, University of Virginia, Charlottesville, 1966; 67-3777.
- Kamentsky, L. A., and C. N. Liu. "Computer-Automated Design of Multifont Print Recognition Logic." IBM J. Res. Develop., 7, No. 1 (1963), 2-13.
- Kozlay, Douglas. "Feature Extraction in an Optical Character Recognition Machine." IEEE Trans. on Computers, C-20, No. 9 (1971), 1063-1067.
- Liu, C. N. "A Programmed Algorithm for Designing Multifont Character Recognition Logics." IEEE Trans. on Electronic Computers, EC-13, No. 5 (1964), 586-593.
- Liu, C. N., and G. L. Shelton, Jr. "An Experimental Investigation of a Mixed-Font Print Recognition System." IEEE Trans. on Electronic Computers, EC-15, No. 6 (1966), 916-925.
- Mason, S., and J. Clemens. "Character Recognition in an Experimental Reading Machine for the Blind," in P. A. Kolars and M. Eden (eds.), *Recognizing Patterns*. M.I.T. Press, Cambridge, Mass., 1968, pp. 156-167.
- McNee, Francis J. "Optical Computer-Based Character Recognition Technique." Report R-606, Coordinated Science Laboratory, University of Illinois, Urbana, May 1973.
- Nadler, M. "Engineering Problems of Optical Character Recognition." Computer Group News, July 1969, pp. 2-9.

- Nagy, G., and G. L. Shelton, Jr. "Self-corrective Character Recognition System." *IEEE Trans. on Information Theory, IT-12*, No. 2 (1966), 215-222.
- Parks, J. R. "Automatic Recognition of Low-Quality Printed Characters Using Analogue Techniques." *Radio and Electronic Engineering*, 34, No. 2 (1967), 67.
- Riseman, E. M. "Logical Networks for Feature Extraction." *IEEE Trans. on Systems, Man and Cybernetics, SMC-1*, No. 1 (1971), 43-55.
- Rosenberg, B. "Character Recognition and Visual Processing." *Int. J. Man-Machine Studies*, 3 (1971), 189-200.
- Sezaki, N. et al. "Character Recognition by Follow Method." *Proc. IEEE*, 53 (1965), 510.
- Stevens, Mary E. "Automatic Character Recognition—A State-of-the-Art Report." National Bureau of Standards Technical Note No. 112, Washington, D.C., 1961.
- Thomas, F. J. "Character Recognition Literature—Bibliography and Classification." IBM Res. Report RC-693, June 1962.
- Townsend, P. L. "A Simplified Approach to Character Recognition." Master's Thesis, Naval Postgraduate School, June 1971; AD-728-668.
- Uhr, Leonard. "Layered 'Recognition Cone' Networks That Preprocess, Classify, and Describe." *IEEE Trans. on Computers, C-21*, No. 7 (1972), 758-763.
- Zahn, Charles T. "Graph-Theoretical Methods of Detecting and Describing Gestalt Clusters." *IEEE Trans. on Computers, C-20*, No. 1 (1971), 68-86.

B. *Techniques Applied to Hand-Printed Characters*

(For sources earlier than 1966 see the review article of Chodrow, et al. [1966].)

- Bakis, Raimo, Noel M. Herbst, and George Nagy. "An Experimental Study of Machine Recognition of Hand-Printed Numerals." *IEEE Trans. on Systems Science and Cybernetics, SSC-4*, No. 2 (1968), 119-132.
- Bernstein, M. I. "Computer Recognition of On-line, Hand-written Characters." Memo. RM-3758, RAND Corp., Santa Monica, Calif., October 1964.
- Brown, R. M. "On-line Computer Recognition of Handprinted Characters." *IEEE Trans. on Electronic Computers, EC-13*, No. 6 (1964), 750-752.

- Caskey, D. L. and C. L. Coates. "Machine Recognition of Handprinted Characters." Tech. Report No. 126, Information Systems Laboratory, University of Texas at Austin, May 1972.
- Chodrow, Mark M., William A. Bivona, and Gail M. Walsh. "A Study of Handprinted Character Recognition Techniques." Air Force Systems Command, Rome Air Development Center, Griffiss Air Force Base, New York, RADC-TR-65-444, February 1966; AD-479-049.
- Devoe, D. D. and D. N. Graham. "Evaluation of Hand-Printed Character Recognition Techniques." Final Report, Sylvania Electronic Systems, January 1968; AD-670-196.
- Doyle, W. "Recognition of Sloppy, Hand-Printed Characters." Proc. Western Joint Computer Conference, 17 (1960), 133-142.
- Genchi, H., K. I. Mori, S. Watanabe, and S. Katsuragi, "Recognition of Handwritten Numerical Characters for Automatic Letter Sorting." Proc. IEEE, 56 (1968), 1292-1301.
- Golshan, N., and C. C. Hsu. "A Recognition Algorithm for Handprinted Arabic Numerals." IEEE Trans. on Systems Science and Cybernetics, SSC-6, No. 3 (1970), 246-250.
- Granlund, G. H. "Fourier Preprocessing for Hand Print Character Recognition." IEEE Trans. on Computers, C-21, No. 2 (1972), 195-201.
- Greanias, E. C., P. F. Meagher, R. J. Norman, and P. Essinger. "The Recognition of Handwritten Numerals by Contour Analysis." IBM J. Res. Develop., 7 (1963), 14-22.
- Henckels, Lutz P. "A Parametric Method for Developing and Evaluating Handprinting Character Recognition Algorithms." Sc.D. thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., September 1971.
- Hassain, A. B. S., G. T. Toussaint, and R. W. Donaldson. "Results Obtained Using a Simple Character Recognition Procedure on Munson's Handprinted Data." IEEE Trans. on Computers, C-21, No. 2 (1972), 201-205.
- Knoll, Arnold L. "Experiments with 'Characteristic Loci' for Recognition of Handprinted Characters." IEEE Trans. on Computers, C-18, No. 4 (1969), 366-372.
- Min, P. J. and B. E. Nolan. "Recognition of Handprinted Symbols for Computeraided Mapping." National Technical Information Service, U.S. Dept. of Commerce, Springfield, Va. 22151; AD-742-443.
- Mori, Ken-Ichi, Hiroshi Genchi, Sadakazu Watanabe, and Sumio Katsuragi. "Microprogram Controlled Pattern Processing in a Handwritten Mail Reader-Sorter." Pattern Recognition, 2 (1970), 175-185.

- Munson, John H. "Computer Recognition of Hand-Printed Text." *J. Typographic Res. (now Visible Language)*, 3, No. 1 (1969), 31-62.
- Munson, J. H., R. O. Duda, and P. E. Hart, "Experiments with Highleyman's Data." *IEEE Trans. on Computers*, C-17, No. 4 (1968), 399-401.
- Noe, P. S. "Machine Recognition of Handprinted Characters." Ph.D. Thesis, University of Texas at Austin, 1970.
- Parks, J. R. "A Multilevel System of Analysis for Mixedfont and Hand-Blocked Printed Characters Recognition," *Automatic Interpretation and Classification of Images*, A. Grasselli (ed.). Academic Press, New York, 1969, pp. 295-322.
- Powers, Michael. "Handwritten Character Recognition from Pen Direction," National Technical Information Service, U.S. Dept. of Commerce, Springfield, Va. 22151: AD-743-046.
- Quarby, David J. and John Rastall. "Experiments on Handwritten Numeral Classification." *IEEE Trans. on Systems, Man and Cybernetics*, SMC-1, No. 4 (1971), 331-338.
- Sammon, J. W., J. H. Sanders, R. J. McGrath, and D. B. Connell. "Handprinted Character Recognition." *Pattern Analysis and Recognition Corp.*, RADC TR-72-329, January 1973; AD-755-936.
- Spinrad, Robert J. "Machine Recognition of Hand Printed Block Letters." Ph.D. thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., 1965.
- Tou, J. T. and R. C. Gonzalez. "A New Approach to Automatic Recognition of Handwritten Character." *Proc. Two-Dimensional Digital Signal Processing Conf.*, Columbia, Missouri, October 1971, pp. 1-10.
- Tou, J. T. and R. C. Gonzalez. "Recognition of Handwritten Characters by Topological Feature Extraction and Multilevel Categorization." *IEEE Trans. on Computers*, C-21, No. 7 (1972), 776-785.
- Williams, T. G. "On-Line Parsing of Hand-Printed Mathematical Expressions." Final Report, System Development Corp., Santa Monica, Calif., SDC-TM-4158-000-00; AD-681-099.
- Wilmer, M. E. "A Study of Statistical Techniques in the Recognition of Hand-Printed Characters." Ph.D. thesis, Catholic University of America. Washington, D.C., 1968; 69-9121.

C. *Techniques Incorporating Contextual Information*

- Blair, C. R. "A Program for Correcting Spelling Errors." *Information and Control*, 3 (1960), 60-67.
- Chien, Y. T. and R. Ribak, "A New Data Base for Syntax-Directed Pattern Analysis and Recognition." *IEEE Trans. on Computers*, C-21, No 7 (1972), 790-801.

- Christensen, Carl S. "An Investigation of the Use of Context in Character Recognition . . ." Cornell University Center for Applied Mathematics, Ithaca, N.Y., November 1968.
- Chu, J. T. "Error Bounds for a Contextual Recognition." *IEEE Trans. on Computers*, *C-20*, No. 10 (1971), 1203-1207.
- Damerau, F. "A Technique for Computer Detection and Correction of Spelling Errors." *Comm. ACM*, 7, No. 3 (1964), 171-176.
- Davidson, L. "Retrieval of Misspelled Names in an Airlines Passenger Record System." *Comm. ACM*, 5, No. 3 (1962), 169-171.
- Donaldson, R. W., and G. T. Toussaint. "Use of Contextual Constraints in Recognition of Contour-Traced Handprinted Characters." *IEEE Trans. on Computers*, *C-19*, No. 11 (1970), 1096-1099.
- Duda, R. O., and P. E. Hart. "Experiments in the Recognition of Handprinted Text: Pt. II, Context Analysis," in 1968 Fall Joint Computer Conf., Proc. AFIPS, 33, Thompson Book Company, Washington, D.C., 1139-1149.
- Edwards, A. W., and R. L. Chambers. "Can A Priori Probabilities Help in Character Recognition?" *J. ACM* 2 (October 1964), 465-470.
- Ehrich, R. W., and E. M. Riseman. "Contextual Error Detection." COINS Tech. Report 70C-4, University of Massachusetts, Amherst, May 1971.
- Griffith, A. K. "Edge Detection in Simple Scenes Using A Priori Information." *IEEE Trans. on Computers*, *C-22*, No. 4 (1973), 371-381.
- Heinselman, R. C. "Computerized Detection and Correction of Spelling Errors in Fortran Programs." S.M. Thesis, Department of Information Sciences, University of Minnesota, Minneapolis, 1972.
- Morgan, H. L. "Spelling Correction in System Programming." *Comm. ACM*, 13, No. 2 (1970), 90-94.
- Riseman, E. M., and R. W. Ehrich. "Contextual Word Recognition Using Binary Diagrams." *IEEE Trans. on Computers*, *C-20*, No. 4 (1971), 397-403.
- Riseman, E. M., and A. R. Hanson. "A Contextual Postprocessing System for Error Detection and Correction in Character Recognition." Tech. Report 72C-1, Department of Computer and Information Science, University of Massachusetts, Amherst, October 1972.
- Salter, Kenneth G. "A Context Algorithm for Pattern Recognition and Image Interpretation." *IEEE Trans., Systems, Man and Cybernetics*, *SMC-1*, No. 1 (1971), 24-30.
- Stern, D. M., and D. W. C. Shen. "Character Recognition by Context-dependent Transformations." *Proc. IEEE*, 111 (1964), 1923-1964.

- Thomas, R. B., and M. Kassler. "Character Recognition in Context." *Information and Control*, 10 (1967), 43-64.
- Vossler, C. M., and N. M. Branston. "The Use of Context for Correcting Garbled English Text." *Proc. ACM 19th Natl. Conf.*, August 1964, pp. D2.4-1-13.

III. Psychological Descriptions of Characters

A. *Attempts to Identify the Distinctive Features of Printed Characters*

- Asso, D., and M. Wyke. "Discrimination of Spatially Confusable Letters by Young Children." *J. Exptl. Child Psychol.*, 11 (1971), 11-20.
- Beck, Jacob. "Perceptual Grouping Produced by Changes in Orientation and Shape." *Science*, 154 (1966), 538-540.
- Blessner, Barry, R. Shillman, C. Cox, T. Kuklinski, J. Ventura, and M. Eden. "Character Recognition Based on Phenomenological Attributes." *Visible Language*, 7, No. 3 (1973), pp. 209-223.
- Bouma, H. "Visual Recognition of Isolated Lower-case Letters." *Vision Research*, 11 (1971), 459-474.
- Brown, Robert, and K. T. Strongman. "Visual Search and Stimulus Orientation." *Perceptual and Motor Skills*, 23, (1966), 539-542.
- Bryden, M. P., "Left-Right Differences in Tachistoscopic Recognition." *J. Exptl. Psychol.*, 66, No. 6 (1963), 568-571.
- Bryden, M. P. "Symmetry of Letters as a Factor in Tachistoscopic Recognition." *Am. J. Psychol.*, 81 (1968), 513-524.
- Burdash, Elizabeth A., "Errors in the Recognition of Handwritten Letters." S.M. thesis, Department of Psychology, M.I.T., Cambridge, Mass., August 1964.
- Cairns, N. V., and M. S. Steward. "Young Children's Orientation of Letters as a Function of Axis of Symmetry and Stimulus Alignment." *Child Development*, 41 (1970), 993-1002.
- Caldwell, E. C., and V. C. Hall. "The Influence of Concept Training on Letter Discrimination." *Child Development*, 40 (1969), 63-71.
- Caldwell, E. C., and V. C. Hall. "Distinctive Features Versus Prototype Learning Re-examined." *J. Exptl. Psychol.*, 83, No. 1 (1970), 7-12.
- Clement, D. E., and J. S. Carpenter. "Relative Discriminability of Visually-Presented Letter Pairs Using a Same-Different Choice- \neq Reaction Time Task." *Psychonomic Sci.*, 20 (1970), 363-365.
- Crosby, R. M. N. "Recognizing the Marks on Paper." *J. Typographic Res. (now Visible Language)*, 3, No. 1 (1969), 63-78.
- Crovitz, H. F., and H. R. Schiffman. "Visual Field and the Letter Span." *J. Exptl. Psychol.*, 70, No. 1 (1965), 218-223.

- Dainoff, J. J. "Time Course of Visual and Auditory Encoding." *J. Exptl. Psychol.*, 86, No. 2 (1970), 214-224.
- Dearborn, George V. N. "Recognition Under Objective Reversal." *Psychological Rev.*, 6 (1899), 395-406.
- Dick, A. O. "Stimulus Variables in Single-Letter Recognition." *Psychonomic Sci.*, 20 (1970), 195-196.
- Dunn-Rankin, P. "The Similarity of Lower-case Letters of the English Alphabet." *J. Verbal Learning and Verbal Behavior*, 7 (1968), 990-995.
- Dunn-Rankin, P., and D. A. Lenton. "Hierarchical Grouping Procedures for Comparing Indices of Letter Similarity." *Perceptual and Motor Skills*, 27 (1968), 457-458.
- Dunn-Rankin, P., D. A. Lenton, and Velma F. Shelton. "Congruency Factors Related to Visual Confusion of English Letters." *Perceptual and Motor Skills*, 26 (1968), 659-666.
- Eichelman, W. H. "Stimulus and Response Repetition Effects for Naming Letters at Two Response-Stimulus Intervals." *Perception and Psychophysics*, 7, No. 2 (1970), 94-96.
- Evans, C. R. "Fragmentation of Patterns Occurring With Tachistoscopic Presentation." *Proc. IEEE NPL Conference on Pattern Recognition*, 1968, pp. 250-263.
- Fisher, D. F., R. A. Monty, and S. Glucksbert. "Visual Confusion Matrices: Fact or Artifact?" *J. Psychol.*, 71 (1969), 111-125.
- Frith, U. "Why Do Children Reverse Letters?" *British J. Psychol.*, 62 (1971), 459-468.
- Gibson, Eleanor J., J. J. Gibson, Anne D. Pick, and H. Osser. "A Developmental Study of the Discrimination of Letter-like Forms." *J. Comp. Physiol. Psychol.*, 55 (1962), 897-905.
- Gibson, E., H. Osser, W. Schiff, and J. Smith. "An Analysis of Critical Features of Letters, Tested by a Confusion Matrix." *Final Report on Cooperative Research Project No. 639, Office of Education, Department of Health, Education and Welfare, Washington D.C.*, 1963.
- Gould, J. D. "Eye-Movement Parameters in Pattern Recognition." *J. Exptl. Psychol.*, 74, No. 2 (1967), 225-229.
- Guralnick, M. J. "Alphabet Discrimination and Distinctive Features: Research Review and Education Implications." *J. Learning Disabilities*, 6, No. 7 (August 1972), 427-434.
- Haber, R. N. "The Effect of Repetition on the Perception of Single Letters." *Perception and Psychophysics*, 1 (October 1966), 347-350.
- Haber, R. N. "Repetition Versus Luminance as a Determinant of Recognition." *Canadian J. Psychol.*, 23 (1968), 442-448.

- Harcum, E. R. "Interactive Effects within Visual Patterns on the Discriminability of Individual Elements." *J. Exptl. Psychol.*, 68, No. 4 (1964), 351-356.
- Harcum, E. R., and N. S. Smith. "Stability of Error Distributions within Tachistoscopic Patterns." *Psychonomic Sci.*, 6 (1966), 287-288.
- Henderson, Leslie, "Facilitation of Foveal Letter Recognition by Meta-contrast." *Psychonomic Sci.*, 23, No. 2 (1971), 153-155.
- Hershberger, W. A., P. R. Trantina, and K. Cosgrove. "Letter-naming Time as a Function of Set Familiarity and Symbol Distinctiveness." *Quart. J. Exptl. Psychol.*, 20, No. 4 (1968), 395-399.
- Hershenson, M. "Perception of Letter Arrays as a Function of Absolute Retinal Locus." *J. Exptl. Psychol.*, 80, No. 1 (1969), 201-202.
- Hutko, P., and D. Smothergill. "Effects of Stimulus Characteristics on Recognition Memory in Elementary School Children." *Perceptual and Motor Skills*, 33 (1971), 531-534.
- Kolers, P. A. "Clues to a Letter's Recognition: Implications for the Design of Characters." *J. Typographic Res. (now Visible Language)*, 3, No. 2 (1969), 145-168.
- Kolers, P. A., and D. N. Perkins. "Orientation of Letters and Errors in Their Recognition." *Perception and Psychophysics*, 5, No. 5 (1969), 265-269.
- Kolers, P. A., and D. N. Perkins. "Orientation of Letters and Their Speed of Recognition." *Perception and Psychophysics*, 5, No. 5 (1969), 275-280.
- Kuennapas, T. "Visual Perception of Capital Letters." *Scand. J. Psychol.*, 7 (1966), 189-196.
- Kuennapas, T., and A. J. Janson. "Multidimensional Similarity of Letters." *Perceptual and Motor Skills*, 28 (1969), 3-12.
- Mercer, Robert. "A Tachistoscopic Study of Perception of Alphabetic Stimuli." Ph.D. Dissertation, New York University, 1964; *Diss. Abs. Int* 65-6649.
- Miller, G. A. "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information." *Psychological Rev.*, 63 (1956), 81-97.
- Miller, L. K. "Letter Recognition: Effects of Interitem Similarity and Report Requirements." *Perception and Psychophysics*, 11, No. 3 (1972), 252-256.
- Neisser, U., and P. Weene. "A Note on Human Recognition of Hand-Printed Characters." *Information and Control*, 3 (1960), 191-196.
- Nodine, Calvin F., and Borma L. Steuerle. "Development of Perceptual and Cognitive Strategies for Differentiating Graphemes." *J. Exptl. Psychol.* 97, No. 2 (1973), 158-166.

- Nodine, C. F., and J. D. Evans. "Eye Movements of Prereaders to Pseudowords Containing Letters of High and Low Confusability." *Perception and Psychophysics*, 6, No. 1 (1969), 39-41.
- Noton, David. "A Theory of Visual Pattern Perception." *IEEE Trans. on System Science and Cybernetics*, SSC-6, No. 4 (1970), 349-357.
- Noton, D., and L. Stark. "Eye Movements and Visual Perception." *Sci. Am.*, 224 (1971), 34-43.
- Robinson, D. O., M. Abbamonte, and S. H. Evans. "Why Serifs are Important: the Perception of Small Print." *Visible Language*, 4, No. 4 (1971), 353-359.
- Rudov, M. H. "Dimensionality in Human Information Storage." *J. Exptl. Psychol.*, 71, No. 2 (1966), 273-281.
- Samuels, S. J., and W. E. Jeffrey. "Discriminability of Words, and Letter Cues Used in Learning to Read." *J. Ed. Psychol.*, 57 (1966), 337-340.
- Sanford, E. "The Relative Legibility of Small Letters." *Am. J. Psychol.*, 1 (1888), 402-435.
- Sefkow, T. W. "Symmetry as An Aspect of Character Recognition." S.B. thesis, M.I.T., Cambridge, Mass., January 1973.
- Shillman, R. J., and B. A. Blesser. "The Use of Ambiguous Characters in Measuring Functional Invariants." *Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., Cambridge, Mass.*, 109 (1973), 155-158.
- Sternberg, Saul. "Two Operations in Character Recognition: Some Evidence from Reaction-Time Measurements." *Perception and Psychophysics*, 2 (1967), 45-53.
- Tawney, J. W. "Training Letter Discrimination in Four-Year-Old Children." Ph.D. Dissertation, University of Illinois, Champaign, 1969; *Diss. Abs. Int.* 69-15, 406.
- Thornburg, Kathy R., and Virginia L. Fisher. "Discrimination of 2-D Letters by Children after Play with 2- and 3-Dimensional Letter Forms." *Perceptual and Motor Skills*, 30 (1970), 979-986.
- Townsend, J. T. "Theoretical Analysis of an Alphabetic Confusion Matrix." *Perception and Psychophysics*, 9(1A) (1971), 40-50.
- Townsend, J. T. "Alphabetic Confusion: A Test of Models for Individuals." *Perception and Psychophysics*, 9 (1971), 449-454.
- Uttal, W. B., and P. Smith. "Recognition of Alphabetic Characters during Voluntary Eye Movements." *Perception and Psychophysics*, 3(4A) (1968), 257-264.
- Ventura, Joel. "Letter Recognition and the Analysis of Confusion Matrices." M.A. thesis, Brandeis University, Waltham, Mass., 1971.
- White, B. "Recognition of Familiar Characters Under an Unfamiliar Transformation." *Perceptual and Motor Skills*, 16 (1962), 105-116.

- Wickelgren, Wayne A. "Numerical Relations, Similarity, and Short-Term Recognition Memory for Pairs of Digits." *British J. Psychol.*, 57 (1966), 263-274.
- Williams, J. P., and M. D. Ackerman. "Simultaneous and Successive Discrimination of Similar Letters." *J. Ed. Psychol.*, 62 (1971), 132-137.
- B. *Attempts to Describe Character-Like Shapes*
- Arnoult, M. D. "Shape Discrimination as a Function of the Angular Orientation of the Stimuli." *J. Exptl. Psychol.*, 47, No. 5 (1954), 324-328.
- Attneave, Fred. "Dimensions of Similarity." *Am. J. Psychol.*, 63 (1950), 516-556.
- Attneave, Fred. "Physical Determinants of the Judge Complexity of Shapes." *J. Exptl. Psychol.*, 53, No. 4 (1957), 221-227.
- Attneave, F. and M. D. Arnoult. "The Quantitative Study of Shape and Pattern Perception." *Psychological Bull.*, 53, No. 6 (1956), 452-471.
- Bostrom, A. G. "Memory for Form: the Effects of Memory for Verbal Labels and Label Quality." Ph.D. Dissertation, Stanford University, California, 1970; *Diss. Abs. Int.* 71-12857.
- Bransford, John D. "Abstraction of Visual Patterns." *J. Exptl. Psychol.*, 90, No. 1 (1971), 65-74.
- Casperson, Roland C. "The Visual Discrimination of Geometric Forms." *J. Exptl. Psychol.*, 40, No. 5 (1950), 668-681.
- Clark, Herbert J. "Random Shape Recognition at Brief Exposure Durations." *Psychonomic Sci.*, 12, No. 6 (1968), 245-246.
- Cohen, G. "Differential Effects of Irrelevant Dimensions in Three Shape Recognition Tasks." *British J. Psychol.*, 62 (1971), 151-156.
- Deich, R. F. "Children's Perception of Differently Oriented Shapes: Word Recognition." *Perceptual and Motor Skills*, 32 (1971), 695-700.
- Ekman, G., T. Enger, T. Kuennapas, and R. Lindman. "A Quantitative Principle of Qualitative Similarity." *J. Exptl. Psychol.*, 68, No. 6 (1964) 530-536.
- Enterline, E. G. "Form Discrimination: Spatial Relationships between a Standard and Comparison Figure." *Perceptual and Motor Skills*, 30 (1970), 959-969.
- Foster J. J. "Directional Consistency in Form Identification." *J. Typographic Res. (now Visible Language)*, 4, No. 2 (1970), 138-145.
- Franks, J. J. "Visual Pattern Recognition: the Acquisition and Use of Arbitrary Relational Systems." Ph.D. thesis, University of Minnesota, Minneapolis, 1970.

- Frederiksen, John R. "The Role of Cognitive Factors in the Recognition of Ambiguous Visual Stimuli." Educational Testing Service Research Bulletin RB-65-23, July 1965.
- Gibson, James J. and Doris Robinson. "Orientation in Visual Perception; the Recognition of Familiar Plane Forms in Differing Orientations." Psychol. Monogr., 46, No. 6 (1935), 39-47.
- Gray, N. "A Study to Determine the Amount of Linear Contour Used to Identify Familiar Figures." Ed.D. Dissertation, Illinois State University, 1971; Diss. Abs. Int. 72-1068.
- Harcum, E. "Effects of Symmetry on the Perception of Tachistoscopic Patterns." Am. J. Psychol., 77 (1964), 600-606.
- Jones, Elvis C., and Mark E. Dennis. "Perceptual Closure as a Function of Gap Size." Perceptual and Motor Skills, 35 (1972), 126.
- Kaufman, L. and Richards, W. "Spontaneous Fixation Tendencies for Visual Forms." Perception and Psychophysics, 5, No. 2 (1969), 85-88.
- Radner, Minnie and James J. Gibson. "Orientation in Visual Perception; the Perception of Tip-Character in Forms." Psychol. Monogr., 46, No. 6 (1935), 48-65.
- Posner, Michael I., R. Goldsmith, and Kenneth E. Welton, Jr. "Perceived Distance and the Classification of Distorted Patterns." J. Exptl. Psychol., 73, No. 1 (1967), 28-38.
- Schaller, M. Joseph. "Form and its Orientation: Re-examination of a Child's-Eye View." Am. J. Psychol., 84 (1971), 218-234.
- Steinfeld, G. J. "The Effect of Retinal Orientation on the Recognition of Novel and Familiar Shapes." J. General Psychol., 82 (1970), 223-239.

IV. Insight Through the Study of Character Formation

- Catich, Edward M. *The Origin of the Serif, Brush Writing and Roman Letters*. Catfish Press, St. Ambrose College, Davenport, Iowa, 1968.
- Cornog, D. Y. and F. C. Rose. *Legibility of Alphanumeric Characters and other Symbols II. A Reference Handbook*. National Bureau of Standards Miscellaneous 262-2, U.S. Govt. Printing Office, Washington, D.C., 1967.
- Diringer, David, *The Alphabet*, 3rd Edition. Funk and Wagnalls Company, New York, 1965.
- Harary, F. "Typographs." Visible Language, 7, No. 3 (1973), 199-208.
- Herrick, Earl Myers. "A Taxonomy of Alphabets and Scripts." Visible Language, 8, No. 1 (1974), 5-32. See also "A Linguistic Description of Roman Alphabets." M.A. thesis, Hartford Seminary Foundation, Conn., 1966.

- Jaspert, W. P., W. T. Berry, and A. F. Johnson. *The Encyclopaedia of Type Faces*. McKnight & McKnight Publishing Company, Bloomington, Ill., 1952.
- Rengger, R. E. and J. R. Parks. "A Survey of Handprinting." *Auto. T.M.* (68), 9. National Physical Laboratory, Teddington, England, March 1968.
- Tinker, Miles A. *Legibility of Print*. Iowa State University Press, Ames, Iowa, 1963.
- Ullman, Berthold L. *Ancient Writing and Its Influence*. M.I.T. Press, Cambridge, Mass., 1969.
- Wright, G. G. Neill. *The Writing of Arabic Numerals*. Scottish Council for Research in Education Series, No. 33, University of London Press, England, 1952.

V. Relevant Journals

A. *Engineering*

Communications of the ACM
 Cybernetics
 IEEE Transactions on Computers
 IEEE Transactions on Systems, Man and Cybernetics
 Computer Graphics and Image Processing
 Information and Control
 International Journal of Man-Machine Studies
 Pattern Recognition
 Visible Language

B. *Psychology*

American Journal of Psychology
 Journal of Experimental Psychology
 Perception and Psychophysics
 Perceptual and Motor Skills
 Psychonomic Science
 Visible Language

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