

Chapter 8

Conclusion

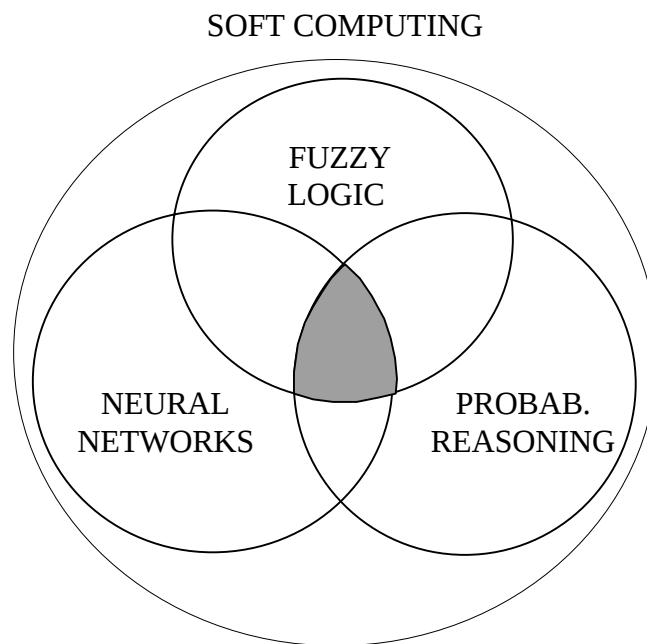


Figure 8.1 Soft computing as a union of fuzzy logic, neural networks and probabilistic reasoning. Intersections include neurofuzzy techniques, probabilistic view on neural networks (especially classification networks) and similar structures of fuzzy logic systems and Bayesian reasoning.

The strengthnesses of each methods are summarized in the following table:

Fuzzy Logic

- management of uncertainty
- knowledge representation (as rules)
- approximate reasoning

Neural Networks

- learning from examples (supervised, unsupervised)
- optimization

Probabilistic logic

- management of uncertainty (belief networks)

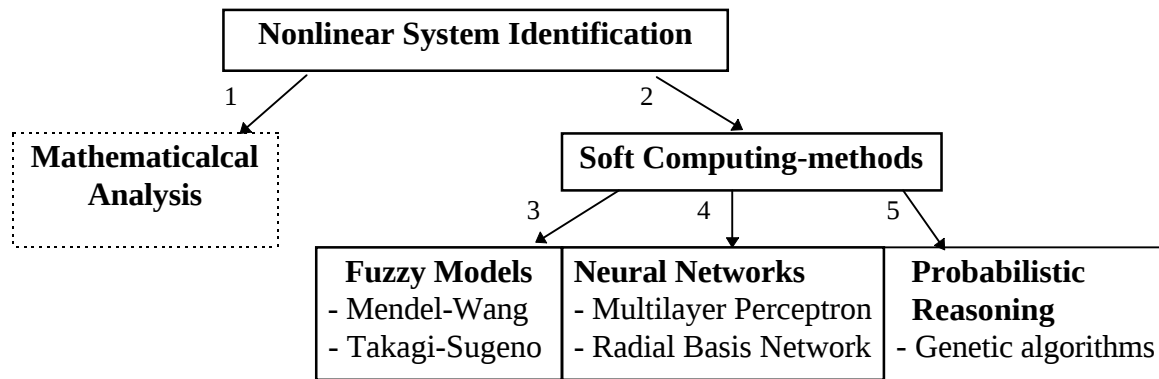


Figure 8.2 The choice of methods.

Explanation of arrows in Fig. 8.2:

1. Mathematics gives calculation methods as: differential equations, difference equations, matrices, linear and nonlinear mappings, etc. This direction is preferable, if the dependencies are well-defined and numerical analysis can be used.
2. If the dependencies are not well-defined or difficult. If the dependencies are well-defined, but we want more tolerance for the imprecision.
3. If-then rules can be formulated. If rules need calibration, neural net methods could be used.
4. Rules can not be formulated or the dimension of input space is high.
5. Probabilistic prior information is available.

Soft computing employs techniques which can reason about their environment in a flexible and robust manner. The main difference between AMNs and a certain class of fuzzy systems is the linguistic interpretation of the basis functions. There exists, however, fuzzy networks that do not use linguistic terms to describe their membership functions. In fact, fuzzy logic forms a unifying link between a number of approximation methods in soft computing and in function approximation in general.

References

1. Albus, J.S. (1975). A New Approach to Manipulator Control: The Cerebellar Model Articulation Controller (CMAC). *Trans. ASME. Journal of Dyn. Sys. Meas. and Control*, vol. 63, no. 3, 220-227.
2. Barron, A.R. (1993). Universal approximation bounds for superpositions of a sigmoidal function. *IEEE Trans. Inf. Theory*, vol. 39, no. 3, 930-945.
3. Berenji, H.R. (1992). Fuzzy Logic Controllers. In R.R.Yager, L.A. Zadeh (eds.) *An Introduction to Fuzzy Logic Applications and Intelligent Systems*. Kluwer Academic Publisher, Boston, MA, Chapter 4.
4. Bilgiç, T.; Türksen, I.B. (1997). Measurement of Membership Functions: Theoretical and Empirical Work. In Dubois and Prade (eds.): *Handbook of Fuzzy Sets and Systems* Vol. 1, Foundations.
5. Bishop, C.M. (1991). Improving the generalization properties of radial basis function neural networks. *Neural Computation*, vol. 3, 579-588.
6. Bishop, C.M. (1996). *Neural Networks for Pattern Recognition*. Clarendon Press, Oxford.
7. Bossley, K.M.; Brown, M.; Harris, C.J. (1995). Parsimonious Neurofuzzy Modelling. Technical report, University of Southampton, Department of Electronics and Computer Science.
8. Breiman, L. (1993). Hinging hyperplanes for regression, classification and function approximation. *IEEE Trans. Information Theory*, 39 (3), 999-1013.
9. Brown, M. and Harris C. (1994). *Neurofuzzy adaptive modelling and control*. Prentice Hall, New York.
10. Buckley, J.J; Hayashi, Y. (1993). Numerical relationships between neural networks, continuous functions, and fuzzy systems. *Fuzzy Sets and Systems*, 60, 1-8.
11. Buckley, J.J; Hayashi, Y. (1994). Fuzzy neural networks. In Zadeh; Yager (eds.): *Neural Networks and Soft Computing*. Van Nostrand Reinhold, New York, 233-249.
12. Buhmann and Powell, M.J.D. (1990). Radial Basis Function Interpolation on an Infinite Grid. In J.C..Mason, M.G. Cox (eds.): *Algorithms for Approximation II*, Chapman and Hall, London, 146-169.

13. Bulsari, A. (1992). Fuzzy Simulation by an Artificial Neural Network. *Eng. Appl. Artificial Intelligence*, vol. 5, no. 2, 401-406.
14. Carpenter, G.A.; Grossberg, S.; Rosen, D.B. (1991). Fuzzy ART: Fast Stable Learning and Categorization of Analog Patterns by an adaptive Resonance System. *Neural Networks*, vol. 1, 759-771.
15. Carroll, S.M.; Dickinson, B.W. (1989). Construction of neural nets using radon transform. In *Proc. IJCNN I*, 607-611.
16. Castro J. L. and Delgado M. (1996). Fuzzy Systems with Defuzzification are Universal Approximators. In *IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics*, vol. 26, no. 1.
17. Chameau, J.L.; Santamarina, J.C. (1987). Membership functions part I: Comparing method of measurement, *Int. Journal of Approximate Reasoning*, vol.1, 287-301, part II: 303-317.
18. Cheeseman P. (1986). Probabilistic versus Fuzzy Reasoning. In Kanal L. N. and Lemmer J. F. (eds.): *Uncertainty in Artificial Intelligence*. Elsevier Science Publishers, Amsterdam, Netherlands.
19. Chen S., Cowan F.N., Grant P.M (1991). Orthogonal least squares learning algorithm for radial basis function networks. *IEEE Transactions on Neural Networks*, vol. 2, no. 2, March 1991, 302-309.
20. Chen, T.; Chen, H.; Liu, R. (1990). A constructive proof of Cybenko's approximation theorem and its extension. In LePage; Page (eds.), *Computer Science and Statistics*, 163-168.
21. Chen T., Chen H. (1995). Universal Approximation to Nonlinear Operators by Neural Networks with Arbitrary Activation Functions and Its Application to Dynamical Systems. *IEEE Transactions on Neural Networks*, vol. 6, no. 4, July, 911-917.
22. Chen T., Chen H. (1995). Approximation Capability to Functions of Several Variables, Nonlinear Functionals, and Operators by Radial Basis Function Neural Networks. *IEEE Transactions on Neural Networks*, vol. 6, no. 4, July 1995, 904-910.
23. Chen T., Chen H. (1993). Approximation of Continuous Functionals by Neural Networks with Application to Dynamical Systems. *IEEE Transactions on Neural Networks*, vol. 4, no. 6, November 1993, 910-918.
24. Choi, J.J.; Arabhashi, P.; Marks, R.J.; Claudell T.P. (1992). Fuzzy parameter adaptation in neural systems. *Int. Joint Conference on Neural Networks*, vol. 1, 232-238.
25. Chui, C. (1992). Wavelets: a tutorial in theory and applications. Academic Press, San Diego.
26. Chung, F.L.; Lee, T. (1994). Fuzzy competitive learning. *Neural Networks*, vol. 7, no.3, 539-551.
27. Cox, E. (1992). Integrating Fuzzy Logic into Neural Nets, *AI expert*, June, 43-47.
28. Cybenko, G. (1989). Approximation by superpositions of a sigmoidal function. *Math. Contr., Signals Syst.*, vol. 2, no. 4, 303-314.
29. Daubechies, I. (1992). Ten lectures on wavelets. CBMS-NSF regional conference series in applied mathematics. Society for Industrial and Applied Mathematics, Philadelphia.
30. Driankov, D.; Hellendoorn, H.; Reinfrank, M. (1993). An introduction to fuzzy control. Springer, Berlin.

31. Dyn, N.. (1987). Interpolation of scattered data by radial functions. In Chui; Schumaker; Utreras (eds.): Topics in multivariate approximation. Academic Press, New York.
32. Efron, B.; Tibshirani, R.J. (1993). An introduction to the Bootstrap. Chapman and Hall.
33. Friedman, J.H. (1991). Multivariate adaptive regression splines. *Annals of Statistics* 19.
34. Friedman, J.H. (1993). An Overview of Predictive Learning and Function Approximation. In Cherkassky, V.; Friedman, J.H.; Wechsler, H. (eds): *From Statistics to Neural Networks*. Springer-Verlag.
35. Friedman, J.H.; Stuetzle, W. (1981). Projection pursuit regression. *Journal of the American Statistical Association* 76.
36. Fullér, R. (1995). Neural fuzzy systems. Åbo Akademi, Institute for Advanced Management Systems Research.
37. Funahashi, K. (1989). On the approximate realization of continuous mapping by neural networks. *Neural Networks*, vol. 2, 183-192.
38. Girosi, F. (1993). Regularization Theory, Radial Basis Functions and Networks. In Cherkassky, V.; Friedman, J.H.; Wechsler, H. (eds): *From Statistics to Neural Networks*. Springer-Verlag.
39. Girosi, F.; Jones, M; Poggio, T. (1995). Regularization theory and neural network architectures. *Neural Computation* 7, 219-269.
40. Golub, Gene H. (1989). Matrix computations. Johns Hopkins University Press, Baltimore.
41. Graps. (1995). An introduction to wavelets. IEEE Computational Science and Engineering, vol. 2, no. 2.
42. Hartman, E.J.; Keeler, J.D.; Kowalski, J.M. (1990). Layered neural networks with Gaussian hidden units as universal approximations. *Neural Computation*, vol. 2, no. 2, 210-215.
43. Hartman, E.J.; Keeler, J.D. (1991). Predicting the Future: Advantages of Semilocal Units. *Neural Computation*, vol. 3, no. 4, 566-578.
44. Hastie, T.J.; Tibshirani, R.J. (1990). Generalized Additive Models. Chapman & Hall, London.
45. Haykin, S. (1994). Neural Networks - A Comprehensive Foundation. Macmillan College Publishing Company, New York.
46. Hisdal, E. (1995). Are grades of membership probabilities? *Fuzzy Sets and Systems*, vol. 25, 325-348.
47. Hiew, H.,L.; Tsang, C.,P. (1997). Fuzzy chaos and recursive partitioning. In Kosko, B.: *Fuzzy Engineering*. Prentice-Hall, Upper Saddle River, New Jersey.
48. Hubbard, J.H.; West, B.H. (1991). Differential Equations - A Dynamical Systems Approach, Part 1: Ordinary Differential Equations. Springer-Verlag.
49. Huntsberger, T.L.; Ajjimarangsee, P. (1991). Neural networks for nonlinear internal model control. *IEEE Proc.-D*, vol. 138, no.5, 431-438.
50. Jager, R. (1995). Fuzzy logic in control. Diss., Delft University of Technology, The Netherlands.
51. Johansen, T.A. (1996). Identification of Non-linear Systems using Empirical Data and Prior Knowledge - An Optimization Approach. *Automatica*, vol. 32, 337-356.
52. Johansen, T.A. (1997a). On Tikhonov regularization, bias and variance in nonlinear system identification. *Automatica*, vol. 33, 441-446.

53. Johansen, T.A. (1996). Stability, Robustness, and Performance of Fuzzy Model Based Control. IEEE Conf. Decision and Control, Kobe, December 1996.
54. Johansen, T.A.; Foss B.A. (1997). Operating Regime Based Process Modeling and Identification. *Computers and Chemical Engineering*, vol. 21, 159-176.
55. Johnson, R.C. (1990). Fuzzy-Neural Hybrid Born. *Electr. Eng. Times*, Aug. 27, 29-33.
56. Jones, L.K. (1992). A simple lemma on greedy approximation in Hilbert space and convergence rates for Projection Pursuit Regression and neural network training. *Annals of Statistics*, vol. 20, no. 1, 608-613.
57. Joslyn, C. (1994). Possibilistic Processes for Complex Systems Modeling. UMI Dissertation Services, Ann Arbor MI: PhD dissertation, SUNY-Binghamton.
58. Juditsky, A.; Hjalmarsson, H.; Benveniste, A.; Delyon, B.; Ljung, L.; Sjöberg, J.; Zhang, Q. (1995). Nonlinear Black-Box Models in System Identification: Mathematical Foundations. Linköping University, Sweden.
59. Kanal, L.N.; Lemmer, J.F. (1986). Uncertainty in Artificial Intelligence. Elsevier, New York.
60. Kartalopoulos, S. V. (1996). Understanding neural networks and fuzzy logic: basic concepts and applications. IEEE Press, Piscataway, New York.
61. Kaufman, L.; Rousseeuw, P.J. (1990). Finding Groups in Data. An introduction to Cluster Analysis. Wiley, New York.
62. Kavli, T. (1994). ASMOD - an Algorithm for Adaptive Spline Modelling of Observation Data. In Harris, Taylor and Francis (eds): *Advances in Intelligent Control*. London.
63. Kawarada, H.; Suito, H. (1996). Fuzzy Optimization Method. Institute of Computational Fluid Dynamics, Chiba University, Japan.
64. Kirkpatrick; Wheeler (1992). Physic. A World View, Saunders.
65. Klir, G. (1988). Fuzzy sets, uncertainty, and information. Prentice Hall, Englewood Cliffs, New York.
66. Kohonen T. (1982). Self-organized formation of topologically correct feature maps. *Biological Cybernetics*, vol. 43, 59-69.
67. Kohonen T. (1990). Self-organizing map. *Proc. IEEE*, vol. 78, no. 9, 1464-1480.
68. Koivisto. (1995). A practical approach to model based neural network control. Dissertation, Tampere University of Technology.
69. Kong, S.-G.; Kosko, B. (1992). Adaptive fuzzy systems for backing up a truck-and-trailer. *IEEE Trans. Neural Networks*, vol. 3, no. 2, 211-223.
70. Kosko, B. (1990). Fuzziness vs. Probability. *Int. Journal of General Systems*, vol. 17:2-3, 211-240.
71. Kosko, B. (1992). Fuzzy Systems as Universal Approximators. *Proc. of the First IEEE Conference on Fuzzy Systems*, San Diego, March, 1153-1162.
72. Kosko, B. (1997). Fuzzy Engineering. Prentice-Hall, Upper Saddle River, New Jersey.
73. Kosko, B. (1993). Fuzzy thinking : the new science of fuzzy logic. Art House.
74. Kosko, B. (1995). Fuzzy thinking : the new science of fuzzy logic. London, Flamingo.
75. Kosko, B. (1992). Neural networks and fuzzy systems: a dynamical systems approach to machine intelligence. Englewood Cliffs (N.J.): Prentice-Hall International.

76. Kwon, T.M.; Zervakis, M.E. (1994). A self-organizing KNN fuzzy controller and its neural network structure. *Int. Journal of Adapt. Cont. and Signal Processing*, vol. 8, 407-431.
77. Larsen, J.; Hansen, L.K. (1994). Generalization performance of regularized neural network models. *Proc. IEEE Workshop on Neural Networks for Signal Processing*, Ermioni, Greece.
78. Lee, S.C.; Lee, E.T. (1975). Fuzzy neural networks. *Mathematical Biosciences*, vol. 23, 151-177.
79. Lin, C.-T.; Lee, C.S.G. (1991). Neural-network-based fuzzy logic control and decision system. *IEEE Trans. Computers*, vol. 40, n0. 12, 1320-1336.
80. Lippmann, R.P. (1993). Neural Networks, Bayesian a posteriori Probabilities, and Pettern Classification. In Cherkassky, V.; Friedman, J.H.; Wechsler, H. (eds): *From Statistics to Neural Networks*. Springer-Verlag.
81. Lloyd, S.P. (1982). Least squares quantization in PCM. *IEEE Trans. Information Theory*, vol. 28, no. 2, 129-137.
82. Mabuchi, S. (1992). An interpretation of membership functions and the properties of general probabilistic operators as fuzzy set operators. 1. case of type-1 fuzzy-sets. *Fuzzy Sets and Systems*, vol. 49, no. 3, 271-283.
83. MacKay, D. (1992) Bayesian interpolation. *Neural Computation*, vol. 4, no. 3. 415-447.
84. Mc Culloch, W.S. and Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biophysics* 5, 115-133.
85. Mills, D.J.; Harris, C.J. (1995). Neurofuzzy modelling and control of a six degree of freedom AUV. Technical report, University of Southampton, Department of Electronics and Computer Science, 1995/6 Research Journal.
86. Minsky, M. L. and Papert (1969). *Perceptrons*. Cambridge, MA: MIT Press.
87. Moody, J.; Darken, C.J. (1989). Fast learning in networks of lacally-tuned processing units. *Neural Computation*, vol. 1, no. 2, 281-294.
88. Mouzouris and Mendel. (1996). Designing fuzzy logic systems for uncertain environments. In *Fuzz-IEEE '96*, New Orleans, vol.1, 295-301.
89. Nadaraya, É. A. (1964). On estimating regression. *Theory of Probability and its Applications*. vol. 9, no. 1, 141-142.
90. Narendra, K.S.; Mukhopadhyay, S. (1997). Adaptive Control Using Neural Networks and Approximate Models. *IEEE Trans. Neural Networks*, vol. 8, no. 3, 475-485.
91. Narendra, K.S.; Parthasarathy, K. (1990). Identification and Control of Dynamic Systems Using Neural Networks. *IEEE Trans. Neural Networks*, vol. 1, no. 1, 4-27.
92. Nauck, D. (1994). A Fuzzy Perceptron as a Generic Model for Neuro-Fuzzy Approaches. In *Proc. Fuzzy Systeme'94*, Munich.
93. Nie, J.; Linkens, D.A. (1993). Learning control using fuzzified self-organizing radial basis function network. *IEEE Trans. Fuzzy Systems*, vol. 1, no. 4, 280-287.
94. Orr, M.J.L. (1995). Regularisation in the selection of radial basis function centres. *Neural Computation*, vol. 7, no. 3, 606-623.
95. Orr, M.J.L. (1997). Matlab Routines for Subset Selection and Ridge Regression in Linear Neural Networks. Edinburgh University. Available in World Wide Web: <http://www.cns.ed.ac.uk/people/mark.html>.

96. Pao, Y.H.; Phillips, S.M.; Sobajic, D.J. (1994). Neural-net Computing and Intelligent Control of Systems. In C.J. Harris, Taylor and Francis (eds.): *Advances in Intelligent Control*. London.
97. Park, J.; Sandberg I.W. (1991). Universal approximation using radial-basis-function networks. *Neural Computation*, vol. 3, 246-257.
98. Petrushev, P.; Popov, V. (1987). Rational Approximation of Real Functions. Cambridge University Press, Cambridge.
99. Pinkus, Allan. (1985). n-Widths in Approximation Theory. Springer-Verlag.
100. Poggio, T.; Girosi, F. (1990). Networks for Approximation and Learning. *Proc. IEEE*, vol. 78, no. 9, 1481-1497.
101. Powell, M.J.D. (1981). Approximation theory and methods. Cambridge University Press.
102. Powell, M.J.D. (1987). Radial Basis Functions. In J.C.Mason, M.G.Cox (eds.): *Algorithms for Approximation*. Oxford University Press, New York.
103. Press, W.H.; Teukolsky; Vetterling; Flannery. (1992). Numerical Recipes in C: The Art of Scientific Computing (2nd edition). Cambridge University Press.
104. Pucar, P.; Sjöberg, J. (1995). On the parameterization of hinging hyperplane models. Technical report, Dep. of Electrical Engineering, Linköping University, Sweden.
105. Raitamäki, J.; Viljamaa, P.; Koivo, H.; Neittaanmäki, P. (1996). Basis Functions in Soft Computing and in Finite Element Method. EUFIT'96 - Fourth European Congress on Intelligent Techniques and Soft Computing, Aachen, Germany, September 2-5, *Proceedings*, vol 1, 115-119.
106. Rasband, S. N. (1990). Chaotic Dynamics of Nonlinear Systems. John Wiley & Sons, New York.
107. Ripley, B. (1996). Pattern Recognition and Neural Networks. Cambridge University Press.
108. Roberts, J.M.; Mills, D.J.; Charnley, D.; Harris, C.J. (1995). Improved Kalman filter initialisation using neurofuzzy estimation. In *4th Int. Conf. on Artificial Neural Networks*, Cambridge, U.K. , 329-334.
109. Rosenblatt, F. (1962). Principles of Neurodynamics: Perceptrons and the theory of Brain Mechanism. Washington DC: Spartan.
110. Rumelhart, D. E.; Hinton, G. E.; Williams, R. J. (1986). Learning internal representations by error propagation. In *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*, vol.1: Foundations, Cambridge, MA: MIT Press, 318-362.
111. Saaty, T.L. (1974). Measuring the fuzziness of sets. *Journal of Cybernetics*, vol. 4, 53-61.
112. Sjöberg, Zhang, Ljung, Benveniste, Deloyn, Glorennec, Hjalmarsson, Juditsky. (1995). Nonlinear black-box modeling in system identification: a unified overview. *Automatica*, vol. 31, no. 12, December, 1691-1724.
113. Sugeno, M.; Murakami M. (1984). Fuzzy parking control of model car. In *Proceedings IEEE 23rd Conference on Decision and Control*, Las Vegas, USA.
114. Suykens, J.A.K.; De Moor, B.L.R.; Vandewalle, J. (1994). Static and dynamic stabilizing neural controllers, applicable to transition between equilibrium points. *Neural Networks*, vol. 7, 819-831.
115. Söderström, T.; Stoica, P. (1988). System Identification. Prentice Hall, Englewood Cliffs, NJ.

116. Takagi, T.; Sugeno, M. (1985). Fuzzy identification of systems and its application to modeling and control. *IEEE Trans. Systems, Man, and Cybernetics*, 15, 116-132.
117. Thomas, S.F. (1995). Fuzziness and Probability. ACG Press, Wichita, USA.
118. Thompson, M.L.; Kramer, M.A. (1994). Modeling chemical processes using prior knowledge and neural networks. *AIChE*, vol. 40, 1328-1340.
119. Tikhonov, A.N.; Arsenin, V.Y. (1977). Solutions of Ill-Posed Problems. Washington, DC, Winston.
120. Tsao, E.C.-K.; Bezdek, J.C.; Pal, N.R. (1994). Fuzzy Kohonen clustering networks. *Pattern recognition*, vol.27, no.5, 757-764.
121. Verhulst, F. (1990). Nonlinear Differential Equations and Dynamical Systems. Springer-Verlag, Berlin, Heidelberg.
122. Viljamaa, P. (1996). Fuzzy-säätäjän viritysmenetelmiä. Report 1. Tampere University of Technology, Control engineering laboratory, Tampere.
123. Viljamaa, P.; Raitamäki, J.; Neittaanmäki, P.; Koivo, H. (1996). Basis Functions in Soft Computing. WAC '96 - Second World Automation Congress, *Proceedings*, Montpellier, France.
124. Vuorimaa, P. (1994). Fuzzy self-organizing map, *Fuzzy Sets and Systems*, vol. 66, 223-231.
125. Wahba, G. (1990). Spline Models for Observational Data. SIAM, Philadelphia.
126. Wang, L.-X. (1994). Adaptive Fuzzy systems and control Design and stability analysis. Prentice Hall, New Jersey.
127. Wang, L.-X. (1992). Fuzzy systems are universal approximators. *IEEE Trans. Syst., Man, Cybern*, vol. SMC-7, no. 10, 1163-1170.
128. Webb, A.R. (1994). Functional approximation by feed-forward networks: a least squares approach to generalisation. *IEEE Trans. Neural Networks*, vol. 5., no. 3, 363-371.
129. Werntges, H.W. (1993). Partitions of Unity Improve Neural Function Approximation, *Proc. IEEE Int. Conf. Neural Networks*, San Francisco, vol. 2, 914-918.
130. White, D.; Bowers, A.; Iliff, K.; Noffz, G.; Gonda, M.; Menousek, J. (1992). Flight, Propulsion and Thermal Control of Advanced Aircraft and Hypersonic Vehicles. In White, D.; Sofge, D.A. (eds.): *Handbook of Intelligent Control*. Van Nostrand Reinhold, NY.
131. Zadeh, Lotfi A. (1992). Fuzzy logic: advanced concepts and structures. IEEE, Piscataway, New York.
132. Zadeh, Lotfi A. (1965). Fuzzy Sets. *Information and Control*, June 1965, 338-354.
133. Zadeh, Lotfi. A. (1994). Soft Computing and Fuzzy Logic. *IEEE Software*, vol. 11, no. 6, 48-56.
134. Zimmermann, H. J. (1993). Fuzzy sets, decision making, and expert systems. Kluwer, Boston.
135. Zysno, P. (1981). Modeling membership functions. In Rieger (ed.): *Empirical Semantics I, Vol. 1 of Quantitative Semantics*, vol. 12, Studienverlag Brockmeyer, Bochum, 350-375.