

AI*IA 2003**Tutorial on Fusion of Multiple Pattern Classifiers by F. Roli****SELECTED REFERENCES**

Note: References in boldface have been mentioned during the Tutorial. Additional papers on multiple pattern classifiers and some of these references can be downloaded from www.diee.unica.it/informatica/prag

Part I

- [1]R.O.Duda, P.E.Hart, and D.G.Stork, Pattern Classification, John Wiley&Sons, 2001.
- [2]K.Fukunaga, Introduction to Statistical Pattern Recognition, Academic Press, NY, 2nd, edition, 1990.
- [3]P.A. Devijver and J.Kittler, Pattern Recognition: A Statistical Approach, Prentice-Hall, 1982.
- [4]S.Watanabe, Pattern Recognition: Human and Mechanical, John Wiley&Sons, 1985.
- [5]D.R.Tveter, The Pattern Recognition Basis of Artificial Intelligence, IEEE Computer Society Press, 1998
- [6]S.N.Srihari, and V.Govindaraju, Pattern Recognition, Encyclopedia of Computer Science, Chapman&Hall, 1993, pp. 1034-1041.
- [7]R.P.W. Duin, F. Roli and D. de Ridder, A note on core research issues for statistical pattern recognition, Pattern Recognition Letters, Volume 23, Issue 4, February 2002, pp. 493-499
- [8]S.Raudys, Statistical and neural classifiers: an integrated approach to design, Springer-Verlag, 2001
- [9]L.Devroye, L.Gyorfi, G.Lugosi, A probabilistic theory of pattern recognition, Springer-Verlag, 1996
- [10]B.V.Dasarathy, Decision Fusion, IEEE Computer Society Press, 1994
- [11]N.C. de Condorcet, Essai sur l'application de l'analyse à la probabilité des décisions rendues à la pluralité des voix, Imprimerie Royale, Paris, 1785
- [12]C.K.Chow, Statistical independence and threshold functions, IEEE Trans. Electronic Computers, EC-16:66-68, 1965
- [13]P.S. de Laplace, Deuxieme supplement a la theorie analytique des probabilites. Networks, 1818. Reprinted (1847) in Oeuvres Complete de Laplace, vol. 7 (Paris, Gauthier-Villars) 531-580
- [14]J. Von Neumann, Probabilistic logics and the synthesis of reliable organisms from unreliable components, In C.E. Shannon and J.McCarthy Eds., Automata Studies, pag. 43-98, Princeton Univ. press, 1956
- [15]R.T.Clemen, Combining forecasts: a review and annotated bibliography, International Journal of Forecasting, 5:559-583, 1989
- [16] K.J.Arrow, Social choice and individual values, John Wiley&Sons, Inc., NY, 1951, 2nd Edition 1963
- [17]B.Littlewood, D.R.Miller, Conceptual modelling of coincident failures in multiversion software, IEEE Trans. On Software Engineering, 15(12), Dec. 1989
- [18] B.V.Dasarathy, and B.V. Sheela, A composite classifier system design: concepts and methodology, Proceedings of the IEEE, 67, 5, May 1979, pag. 708-713
- [19]L.A.Rastring, and R.H.Erenstein, Method of Collective Recognition, Energoidzdat, Moscow, 1981 (in Russian). In English: ISSN0038-5328/81/0006-0022\$7.50/0, Scripta Publishing Co., 1982
- [20]L. Xu, A. Krzyzak, and C.Y. Suen, "Methods for combining multiple classifiers and their applications to handwriting recognition", IEEE Trans. on Systems, Man, and Cyb., Vol. 22, No. 3, May/June 1992, pp. 418-435
- [21]T.G.Dietterich, Ensemble learning in machine learning, Multiple Classifier Systems, Springer-Verlag, LNCS, Vol. 1857 (2000)
- [22]K. Tumer, K., Ghosh, J.: Analysis of Decision Boundaries in Linearly Combined Neural Classifiers. Pattern Recognition 29 (1996) 341-348
- [23]G. Giacinto and F. Roli, "Adaptive Selection Of Image Classifiers", ICIAP '97, 9th International Conference on Image Analysis and Processing, Florence, Italy, Sept 17 - 19, 1997, Lecture Notes in Computer Science 1310, Springer Verlag Ed., pp.38-45
- [24]Sharkey, A., Multi-Net Systems, Combining Artificial Neural Nets, Ensemble and Modular Multi-Net Systems, Springer-Verlag, 1999, pp. 1-27
- [25]Giacinto, G. and Roli, F., "An approach to the automatic design of multiple classifier systems", Pattern Recognition Letters , 22, 25-33 (2001)
- [26]Kuncheva, L.I., "Combinations of multiple classifiers using fuzzy sets", in Fuzzy Classifier Design, 233-267 Springer-Verlag, 2000
- [27]T.K. Ho, J.J. Hull and S.N. Srihari, "Decision combination in multiple classifiers systems", IEEE Trans. on PAMI, Vol.16, No.1, Jan. 1994, pp. 66-75
- [28]R. A. Jacobs, M.I. Jordan, S.J. Nowlan and G.E. Hinton, "Adaptive Mixtures of Local Experts", Neural computation 3, 1995, 79-87
- [29]Partridge, D. and Yates, W.B., "Engineering multiversion neural-net systems", Neural Computation, 8, 869-893 (1996)

- [30] Partridge, D. (1996). Network generalization differences quantified. *Neural Networks* 9, 263-271.
- [31] F. Roli, G. Giacinto, "Design of Multiple Classifier Systems", in H. Bunke and A. Kandel (Eds.), *Hybrid Methods in Pattern Recognition*, World Scientific Publishing, 2002.
- [32] T.K.Ho, "Complexity of classification problems and comparative advantages of combined classifiers", *Multiple Classifier Systems*, Springer-Verlag Pub., Lecture Notes in Computer Science, Vol. 1857, J.Kittler and F.Roli Eds., (2000), pp. 97-106.
- [33] G.L. Marcialis and F. Roli, "Fusion of Face Recognition Algorithms for Video-Based Surveillance Systems", in G.L. Foresti, C. Regazzoni, P. Varshney Eds., *Multisensor Surveillance Systems: The Fusion Perspective*, Kluwer Academic Publishers, 2003, in press.
- [34] F. Roli, G. Fumera, J. Kittler, "Fixed and Trained Combiners for Fusion of Unbalanced Pattern Classifiers", *Proc. of 5th Int. Conference on Information Fusion (IF 2002)*, Annapolis, Mariland (USA), July 7-11, 2002.

Part II

- [1] F. Roli, G. Giacinto, "Design of Multiple Classifier Systems", in H. Bunke and A. Kandel (Eds.), *Hybrid Methods in Pattern Recognition*, World Scientific Publishing, 2002.
- [2] R.E.Schapire, et al. Boosting the margin: a new explanation for the effectiveness of voting methods, In Fischer D. (Ed.), *Machine Learning: Proc. of the Fourteenth Int. Conference*, Morgan Kaufmann, 1997
- [3] Ho, T.K., "The random subspace method for constructing decision forests", *IEEE Trans. On Pattern Analysis and Machine Intelligence* 20, 832-844, 1998
- [4] E.M. Kleinberg, Stochastic Discrimination, *Annals of Mathematics and Artificial Intelligence*, 1, pag. 207-239, 1990
- [5] E.M. Kleinberg, On the algorithmic implementation of Stochastic Discrimination, *IEEE Trans. On Pattern Analysis and Machine Intelligence*, 22, 5, May 2000, 473-490
- [6] Breiman, L., "Bagging Predictors", *Machine Learning*, 24, 123-140, 1996.
- [7] B.Efron, R.Tibshirani, *An introduction to the Bootstrap*, Chapman and Hall, 1993
- [8] Freund Y., R.E. Schapire, A decision-theoretic generalization of on-line learning and an application to boosting, Tech. Rep. AT&T Bell Labs, Murray Hill, NJ, 1995
- [9] M.Skurichina, S.Raudys, R.P.W. Duin. K-nearest neighbours directed noise injection in multilayer perceptron training. *IEEE Trans. on Neural Networks*, Vol. 11, 2000, pp. 504-511
- [10] T.G.Dietterich, G.Bakiri, Solving multiclass learning problems via error-correcting output codes, *Journal of Artificial Intelligence Research*, 2, 263-286, 1995
- [11] L. Xu, A. Krzyzak, and C.Y. Suen, "Methods for combining multiple classifiers and their applications to handwriting recognition", *IEEE Trans. on Systems, Man, and Cyb.*, Vol. 22, No. 3, May/June 1992, pp. 418-435
- [12] Wolpert, D.H., "Stacked generalisation", *Neural Networks* 5, 241-259, 1992
- [13] J.Kittler and F.Roli (Eds.) *Multiple Classifier Systems*, Springer-Verlag, Lecture Notes in Computer Science, Vol. 1857, 2000
- [14] J.Kittler and F.Roli (Eds.), *Multiple Classifier Systems*, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2096, 2001
- [15] F.Roli, and J.Kittler (Eds.) *Multiple Classifier Systems*, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2364, 2002
- [16] T.Windeatt and F.Roli (Eds.), "Multiple Classifier Systems", Springer-Verlag, Lecture Notes in Computer Science, Vol. 2709, 2003
- [17] L.Breiman, Random Forests, *Machine Learning*, 45(1), 2001, pp. 5-32
- [18] L.I. Kuncheva, F. Roli, G.L. Marcialis and C.A. Shipp, "Complexity of Data Subsets Generated by the Random Subspace Method: an Experimental Investigation", *Proc. of 2nd Int. Workshop on Multiple Classifier Systems (MCS 2001)*, Cambridge, UK, June 2001, J.Kittler and F. Roli Eds., LNCS 2096, pp. 349-358.
- [19] F. Roli, S. Raudys and G.L. Marcialis, "An experimental comparison of fixed and trained fusion rules for crisp classifiers outputs", *Proc. 3rd Int. Workshop on Multiple Classifier Systems (MCS 2002)*, Cagliari, Italy, June 2002, F.Roli and J.Kittler Eds., LNCS 2364, pp. 232-241.
- [20] Raviv, Y. and N. Intrator (1996). Bootstrapping with noise: an effective regularization technique. *Connection Science* 8, 355-372.
- [21] G.Giacinto, and F.Roli, "Ensembles of Neural Networks for Soft Classification of Remote Sensing Images", *Proc. of the European Symposium on Intelligent Techniques*, March 20-21, 1997, Bari, Italy, 1997

Part III

- [1] L. K. Hansen, and P. Salamon, "Neural network ensembles", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 12, No. 10, October 1990, pp. 993-1001
- [2] Huang, Y.S. and Suen C.Y., A method of combining multiple experts for the recognition of unconstrained handwritten numerals, *IEEE Trans. on Pattern Analysis and Machine Intelligence* 17 (1995) 90-94
- [3] C.Y.Suen, L.Lam. Multiple classifier combination methodologies for different output levels, *First International Workshop on Multiple Classifier Systems (MCS 2000)*. Springer-Verlag Pub., Lecture Notes in Computer Science, Vol. 1857, J.Kittler and F.Roli Eds., (2000) 52-66

- [4]J.Kittler, M. Hatef, P.W. Duin and J. Matas, “On Combining Classifiers”, IEEE Trans. on PAMI, Vol.20, No.3, March 1998, pp. 226-239
- [5]Lam, L., Suen, C.Y.: Application of Majority Voting to Pattern Recognition: An Analysis of Its Behavior and Performance. IEEE Trans. on Systems, Man and Cybernetics - Part A 27 (1997) 553-568
- [6]Tumer, K., Ghosh, J.: Linear and Order Statistics Combiners for Pattern Classification. In: Sharkey, A.J.C. (ed.): Combining Artificial Neural Nets. Springer (1999) 127-161
- [7]Giacinto, G. and Roli, F., “Design of effective neural network ensembles for image classification purposes”, Image and Vision Computing Journal, 19(9-10), 2001, pp. 697-705
- [8]Giacinto, G. and Roli, F., “An approach to the automatic design of multiple classifier systems”, Pattern Recognition Letters 22, 25-33 2001.
- [9]Partridge, D. and Yates, W.B., “Engineering multiversion neural-net systems”, Neural Computation 8, 869-893, 1996
- [10]Sharkey, A.J.C., Sharkey, N.E., Gerecke, U., and Chandroth, G.O., “The ‘test and select’ approach to ensemble combination”, in Multiple Classifier Systems, LNCS 1857, J.Kittler and F.Roli Eds., 30-44 (Springer-Verlag, 2000).
- [11]Wang, W., Jones, P. and Partridge, D., “Diversity between neural networks and decision trees for building multiple classifier systems”, in Multiple Classifier Systems, LNCS 1857, J.Kittler and F.Roli Eds., 240-249 (Springer-Verlag, 2000).
- [12]Friedman J., T. Hastie, and R.Tibshirani, Additive logistic regression: a statistical view of boosting (with discussion). Annals of Statistics, 28, 307-337, 2000
- [13]F.Roli and G. Fumera, Analysis of linear and order statistics combiners for fusion of unbalanced classifiers, in F.Roli, and J.Kittler (Eds.) Multiple Classifier Systems, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2364, 2002
- [14]G. Giacinto and F. Roli , "Dynamic Classifier Selection Based on Multiple Classifier Behaviour", Pattern Recognition, 34(9), 2001, pp. 179-181.
- [15]G. Giacinto, F. Roli, G. Fumera, Selection of Image Classifiers, Electronics Letters, 36(5), 2000, pp. 420-422.
- [16]Tumer, K., Ghosh, J.: Linear and Order Statistics Combiners for Pattern Classification. In: Sharkey, A.J.C. (ed.): Combining Artificial Neural Nets. Springer (1999) 127-161
- [17]Kuncheva L.I., C.J. Whitaker. Measures of diversity in classifier ensembles, Machine Learning, 2002
- [18]Kuncheva L.I. A theoretical study on six classifier fusion strategies, IEEE Transactions on PAMI, 24, (2), 2002, 281-286.
- [20]J Kittler, Combining Classifiers: A theoretical framework, Pattern Analysis and Applications 1, 1998, pp 18-27
- [21]L. Xu, A. Krzyzak, and C.Y. Suen, “Methods for combining multiple classifiers and their applications to handwriting recognition”, IEEE Trans. on Systems, Man, and Cyb., Vol. 22, No. 3, May/June 1992, pp. 418-435
- [22]S. Raudys, F. Roli, "The Behavior Knowledge Space Fusion Method: Analysis of Generalization Error and Strategies for Performance Improvement", *4th Int. Workshop on Multiple Classifier Systems (MCS 2003)*, Guildford, United Kingdom, June 11-13 2003, T. Windeatt and F. Roli Eds., LNCS 2709, pp. 55-64.
- [23]H.J.Kang, S.W.Lee, A dependency-based framework of combining multiple experts for the recognition of unconstrained handwritten numerals, *Proc. 1999 Int. Conf. On Computer Vision and Pattern Recognition*, Fort Collins, Colorado, USA, June 1999, pp. 124-129
- [24]G. Fumera, F. Roli, "Linear Combiners for Classifier Fusion: Some Theoretical and Experimental Results", *4th Int. Workshop on Multiple Classifier Systems (MCS 2003)*, Guildford, United Kingdom, June 11-13 2003, T. Windeatt and F. Roli Eds., LNCS 2709, pp. 74-83.
- [25]F. Roli and G. Fumera, "Analysis of Linear and Order Statistics Combiners for Fusion of Imbalanced Classifiers", *Proc. 3rd Int. Workshop on Multiple Classifier Systems (MCS 2002)*, Cagliari, Italy, June 2002, F.Roli and J.Kittler Eds., LNCS 2364, pp. 252-261.
- [26]Wolpert, D.H., “Stacked generalisation”, Neural Networks 5, 241-259, 1992
- [27]S.Raudys, Experts' boasting in trainable fusion rules, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 25, No. 9, September 2003
- [28]Woods, K., Kegelmeyer, W.P., and Bowyer, K.: “Combination of multiple classifiers using local accuracy estimates”. IEEE Trans. on Pattern Analysis and Machine Intelligence, 1997, 19(4), pp. 405-410.

Part IV

- [1]G.J.Briem, J.A.Benediktsson, J.R.Sveinsson, Boosting, Bagging, and Consensus based Classification of Multisource Remote Sensing data, Multiple Classifier Systems, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2096, 2001, pp. 279-288
- [2]G.Giacinto, F.Roli, and L.Bruzzone. Combination of Neural and Statistical Algorithms for Supervised Classification of Remote-Sensing Images. Pattern Recognition Letters, May 2000, vol. 21, no. 5, pp. 385-397
- [3]F. Roli, G. Giacinto and S.B. Serpico, "Classifier Fusion for Multisensor Image Recognition", in Image and Signal Processing for Remote Sensing VI, Sebastiano B. Serpico, Editor, Proc. of SPIE Vol. 4170, 103-110 (2001).
- [4]A.K.Jain, S.Prabhakar, L.Hong, “A Multichannel Approach to Fingerprint Classification”, IEEE Transactions on Pattern Analysis and Machine Intelligence, vol.21, no.4, pp.348-358, 1999.
- [5]A. Ross, A. K. Jain, and Jian Zhong Qian, "Information Fusion in Biometrics", Proc. 3rd International Conference on Audio- and Video-Based Person Authentication (AVBPA), pp. 354-359, Sweden, June 6-8, 2001.

- [6]L. Hong, A. Jain and S. Pankanti, "Can Multibiometrics Improve performance?", Proceedings AutoID'99, Summit, NJ, Oct 1999, PP. 59-64.
- [7]A.K. Jain, L.Hong, Y. Kulkarni, "A Multimodal Biometric System using Fingerprints, Face and Speech", 2nd Int'l Conference on Audio- and Video-based Biometric Person Authentication, Washington D.C., pp. 182-187, March 22-24, 1999.
- [8]L. Hong and A.K. Jain, "Integrating Faces and Fingerprints For Personal Identification", IEEE Transactions PAMI, Vol.20, No.12, pp 1295-1307, 1998.
- [9]F.Roli, G.Fumera, and J.Kittler, Fixed and Trained Combiners for Fusion of Imbalanced Pattern Classifiers, Fusion 2002, The Fifth Int. Conference on Information Fusion, 2002
- [10]A.K. Jain, S.Prabhakar, S.Chen, Combining multiple matchers for a high security fingerprint verification system, Pattern Recognition Letters, 20, pp. 1371-1379, 1999
- [11]Y.Yao, G.L.Marcialis, M.Pontil, P.Frasconi, F.Roli, "Combining Flat and Structural Representations for Fingerprint Classification with Recursive Neural Networks and Support Vector Machine", Pattern Recognition, Vol. 36 (2), 2003, pp. 397-406.
- [12]G.L.Marcialis and F.Roli, "Fusion of PCA and LDA for Face Verification", Proc. of Post-ECCV Workshop on Biometric Authentication (BIOMET2002), Copenhagen, Denmark, June 2002
- [13]S.Prabhakar, and A.K.Jain, Decision-level fusion in fingerprint verification, Multiple Classifier Systems, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2096, 2001, pp. 88-98
- [14]F.Roli, J.Kittler, G.Fumera and D.Muntoni, An experimental comparison of classifier fusion methods for multimodal personal identity verification systems, in F.Roli, and J.Kittler (Eds.) Multiple Classifier Systems, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2364, 2002
- [15]K.Sirlantzis, M.C.Fairhurst, and M.S.Hoque, Genetic algorithms for multi-classifier system configuration: a case study in character recognition, Multiple Classifier Systems, Springer-Verlag, Lecture Notes in Computer Science, Vol. 2096, 2001, pp. 99-108
- [16]F. Roli, G. Giacinto, "Pattern Recognition for Intrusion Detection in Computer Networks", in D. Chen and X. Cheng (Eds.) "Pattern Recognition and String Matching", 2002
- [17]G. Giacinto and F. Roli, "Intrusion Detection in Computer Networks by Multiple Classifier Systems", Proc. of the 16th International Conference on Pattern Recognition, Quebec City, Canada, Aug 11 - 15, 2002
- [18]T.K.Ho, Multiple Classifier Combination: Lessons and Next Steps, in H. Bunke and A. Kandel (Eds.), Hybrid Methods in Pattern Recognition, World Scientific Publishing, 2002.
- [19]J Kittler, J Matas, K Jonsson and M U Ramos Sanchez, Combining evidence in personal identity verification systems, Pattern Recognition Letters, 18, 1997, pp 845-852.
- [20]G.L. Marcialis, F. Roli and A. Serrau, "Fusion of Statistical and Structural Fingerprint Classifier", *Proc. of the 4th Int. Conf. on Audio- and Video-Based Person Authentication*, June, 9-11, 2003, Guildford, U.K., J. Kittler and M.S. Nixon Eds., LNCS 2688, pp. 310-317.
- [21]G.L. Marcialis and F. Roli, "Experimental results on fusion of multiple fingerprint matchers", *Proc. of the 4th Int. Conf. on Audio- and Video-Based Person Authentication*, June, 9-11, 2003, Guildford, U.K., J. Kittler and M.S. Nixon Eds., LNCS 2688, pp. 814-820.
- [22]G.L. Marcialis and F.Roli, "Fusion of LDA and PCA for Face Recognition", *Proc. of the Workshop on Machine Vision and Perception*, held in the context of the 8th Meeting of the Italian Association of Artificial Intelligence (AI*IA), Siena, Italy, September 10-13, 2002.
- [23]G. Giacinto, F. Roli, L. Didaci, "Fusion of multiple classifiers for intrusion detection in computer networks", *Pattern Recognition Letters*, 24(12), 2003, pp. 1795-1803.
- [24]F. Roli, G. Fumera and G. Vernazza, "Analysis of Error-Reject Trade-off in Linearly Combined Classifiers", *Proc. of 16th Int. Conference on Pattern Recognition (ICPR 2002)*, August 11-15 2002, Québec City, Canada. IEEE Computer Society Ed., Vol. II, pp. 120-123.
- [25]G. Fumera, F. Roli, "Error rejection in linearly combined multiple classifiers", *Proc. of 2nd Int. Workshop on Multiple Classifier Systems (MCS 2001)*, Robinson College, Cambridge, UK, July 2-4 2001. Springer Ed., Lecture Notes in Computer Science, Vol. 2096, pp. 329-338.