Final Technical Report
Contract Number: N00014-97-1-0249
Mathematical Foundations for Object Recognition
and Image Analysis
December, 2000

1 Summary of Accomplishments

1. An analysis of fundamental statistical limits for inference from images was begun. The idea is to develop Cramer-Rao type bounds for the estimation of various image functionals, such as the position and velocity of a target, or the type I/type II detection error in a recognition task.

2. A decision-theoretic framework for object detection was substantially extended, and tested on a variety of machine-vision tasks. These include face detection, hand-written character recognition, and object detection in complex, cluttered, scenes.

3. A compositional (hierarchical) approach to scene analysis was formulated. Emphasis was on developing a coherent model for invariant recognition and analysis. The approach was tested on hand-written characters, emphasizing recognition in cluttered backgrounds and under broad variations in shape and style.

4. Compositionality is widely believed to be a basic principle of cognitive organization. Indeed, the formal study of compositionality began with efforts to describe and understand natural language. A study of compositional representation in the nervous system was begun, with an emphasis on discovering representational and computational principles. This is a collaboration with neuroscientists, focused on analyzing data from the visual and motor cortex of awake and behaving monkeys. Recently developed micro-electrode arrays are yielding massive neuron-by-neuron data, and there is now the possibility for testing specific hypotheses about the mechanisms of neural computing.

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5. Substantial work was done on the method of deformable templates for object detection, recognition, and interpretation. New measures of deformation were introduced, and these yielded new and more efficient algorithms for template matching. Experiments were carried out for target tracking in radar imagery and for anatomical labeling in a variety of medical imaging applications.

6. A new detection and tracking algorithm was developed. The algorithm uses ideas from classical filtering, but in the context of a nonlinear model and modern computational tools. Experiments were performed on challenging imagery obtained by filming several fish swimming in a large fish tank containing an elaborate array of objects.

2 Technical Reports

1. S. Geman, D. Potter, and Z. Chi, Composition systems. Technical Report, Division of Applied Mathematics, Brown University, 1998.

2. S. Geman, A. Date, E. Bienenstock, On the temporal resolution of neural activity. Technical Report, Division of Applied Mathematics, Brown University, 1998.

3. S. Geman and M. Johnson, Probability and statistics in computational linguistics, a brief review. (Expanded version of "Probabilistic grammars and their applications," by Geman and Johnson, in the International Encyclopedia of the Social & Behavioral Sciences)

4. U. Grenander, Clutter 7. Technical Report, Division of Applied Mathematics, Brown University, 1999.

5. U. Grenander, Clutter 8. Technical Report, Division of Applied Mathematics, Brown University, 1999.

6. U. Grenander, Clutter 9. Technical Report, Division of Applied Mathematics, Brown University, 1999.

3 Publications

1. D. Geman and B. Jedynak, Model-based classification trees. Submitted for publication, 1998.

2. Y. Amit and D. Geman, A computational model for visual selection. Neural Computation, 1999 (to appear).

3. D. Geman and F. Fleuret, Graded learning for object detection. Proceedings, IEEE Workshop on Statistical and Computational Theories of Vision, Fort Collins, CO, June, 1999.

4. D. Geman and A. Koloydenko, Invariant statistics and coding of natural microimages. Proceedings, IEEE Workshop on Statistical and Computational Theories of Vision, Fort Collins, CO, June, 1999

5. U. Grenander, Strategies of Seeing. Proc. Intern.Congress of Mathematicians, Berlin, 1998.

6. U. Grenander and M.I. Miller, Computational Anatomy, An Emerging Discipline. Quart. Appl. Math. LVI, Number 4,617-694, December, 1998.

7. U. Grenander, Representing Clutter in Computer Vision. Proc. Intern. Stat. Inst., Helsinki, 1999.

8. B. Gidas and A. Murua, Optimal Transformations for Prediction in Conitnuous-Time Stochastic Processes. Stochastic Processes and Related Topics, pp. 20-37, Birkhausser 1998, eds: Karatzas, I., Rajput, B. Taqqu, M.

9. B. Gidas and A. Murua, Estimation and Consistency of Optimal Transformations for Prediction for Continuous-Time Processes from a Finite Data Set. Submitted for publication, 1999.

10. B. Gidas and C. Robertson, Detection and Tracking in Cluttered Enviroments via a Monte Coarlo Filter. Submitted for publication, 1999.

11. B. Gidas and A. Murua, Optimal Transformations for Prediction in Continuous-Time Stichastic Processes: II. Submitted for publication, 1999.

12. B. Gidas and A. Murua, Estimation and Consistency of Linear Predictors in Continuous Time Stochastic Processes from a Finite Data Set. Submitted for publication, 1999.

13. C. Raphael and S. Geman, A grammatical approach to mine detection. In: Detection and Remediation Technologies for Mines and Minelike Targets II, SPIE Vol. 3079, Proceedings of SPIE. A.C. Dubey and R.L. Barnard, Editors, 1997, 316-332.

14. Z. Chi and S. Geman, Estimation of probabilistic context-free grammars, *Computational Linguistics*, 24, 1997, 299-305.

15. S. Geman, E. Bienenstock, and D. Potter, Compositionality, MDL Priors, and Object Recognition. In: *Advances in Neural Information Processing Systems 9.* M.C. Mozer, M.I. Jordan, and T. Petsche, eds., MIT Press, 1998.

16. Z. Chi and S. Geman, On the consistency of minimum complexity nonparametric estimation. *IEEE Trans. Inf. Theory*, 44, 1998, 1968-1973.

17. S. Canon, Z. Chi, S. Geman, M. Johnson, and S. Riezler, Estimators for stochastic "unification-based" grammars. Proceedings of the Association for Computational Linguistics, 1999.

18. S. Geman, Compositionality. Brown University Faculty Bulletin, Spring, 1999.

19. S. Geman, Hierarchy in machine and natural vision. Proceedings of the 11th Scandinavian Conference on Image Analysis, 1999.

20. S. Geman and K. Kochanek, Dynamic programming and the graphical representation of error-correcting codes. *IEEE Trans. Inf. Theory*, Feb., 2001, to appear.

21. S. Geman and M. Johnson, Probabilistic grammars and their applications. International Encyclopedia of the Social & Behavioral Sciences, to appear.

22. B. Gidas and A. Zelic, Object Recognition via Hierarchical/Syntactic Models. Proceedings of the 13th International Conference on Digital Signal Processing, Santorini, Greece, 1997, Vol. II, pp.836-839.

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