Guest Editors' Introduction to the Special Section on Energy Minimization Methods in Computer Vision and Pattern Recognition

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ENERGY minimization techniques are central to many methods in computer vision and pattern recognition. Stated simply, if a task can be posed as the minimization of an energy measure, which may, for instance, be the negative logarithm of a probability or an entropy, then a variety of optimization methods may be applied to locate the solution. The solution may be a vector of parameters representing the shapes of a curve, a surface, or a volume, it may be a set of symbolic labels representing the semantic or syntactic content of a signal, or it may be a graph representing arrangement or structure. The optimization methods that can be applied to the cost function to recover the solution include gradient descent, simulated annealing, mean-field annealing, evolutionary search, and tabu search, to mention just a few.

Many of the classical methods in the fields of computer vision and pattern recognition make use of energy minimization techniques. Familiar examples include relaxation labeling, regularization, active contours, and Markov models. More recent examples include the use of graph-cuts, spectral graph theory, and semidefinite programming. Energy minimization techniques have also been pivotal in the development of algorithms for learning, inference, and classification.

One of the characteristics of this field is that it draws strongly on recent developments in other disciplines such as mathematics, statistics, operations research, biology, and economics. Moreover, the basic methodology is being developed at a great rate in these related disciplines. In this respect, energy minimization is different from other widely used techniques such as geometry or probability, where the basic methods have been available in the mathematics literature for well over 100 years. It is probably fair to say that the problems of optimization and, in particular, combinatorial optimization, are ones of a computational nature and have hence only emerged over the past few decades.

Our own involvement in this field has been, in part, through a biennial series of workshops (EMMVCPR) that commenced in 1997 and which have been aimed at providing a focus for research in this area. From the interest shown in these workshops and the number of papers on the topic appearing in the main conferences (CVPR, ECCV, ICCV), it seemed to us that a special edition of *IEEE Transactions on Pattern Analysis and Machine Intelligence* would be both timely and valuable to the community.

The call for papers was issued in mid-2001 and we received 50 papers by the deadline on 1 May 2002. Each paper was reviewed by at least three reviewers according to the standard *TPAMI* reviewing procedure. This meant that we needed the assistance of some 150 reviewers. By late October 2002, we had first reviews for all of the papers and met in Venice to make initial decisions. Based on the reviews, and giving authors the chance to revise their papers in the light of reviewers comments, we selected the six papers that appear in the current special section, together with three papers that will appear in a subsequent special section. The papers span a diverse set of methods and applications. The techniques covered include semidefinite programming, Markov models, and simulated annealing, while the problems addressed include deformable models, shape-from-shading, and clustering.

The first regular paper in this special section is "Binary Partitioning, Perceptual Grouping, and Restoration with Semidefinite Programming" by J. Keuchel, C. Schnörr, C. Schellewald, and D. Cremers. The authors describe a new optimization method based on semidefinite programming relaxations. The method is applied to the computer vision problems of unsupervised partitioning, figure-ground discrimination, and binary restoration. The interesting feature of the proposed method is that it does not require any parameter tuning. Moreover, apart from the symmetry condition, no assumptions are made concerning the objective criterion.

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In their paper "Hidden Markov Measure Field Models for Image Segmentation," J.L. Marroquin, E.A. Santana, and S. Botello present a novel Bayesian formulation of parametric image segmentation using a doubly stochastic prior model for the label field. Exact optimal estimators for both the label field and the model parameters are obtained by an efficient minimization algorithm. The applications of segmentation of Magnetic Resonance volumes and motion segmentation are explored.

In their paper "Generating Discriminating Cartoon Faces Using Interaction Snakes," R-.L. Hsu and A.K. Jain describe a new method for manipulating interacting snakes in the face recognition domain. The authors propose the use of semantic face graphs which employ interacting snakes to align the general facial topology onto the sensed face images. Good classification performance is demonstrated using cartoon faces.

S. Ghebreab and A.W.M. Smeulders introduce a new class of deformable model that they refer to as a string in "Strings: Variational Deformable Models of Multivariate Continuous Boundary Features." This model is characterized in a functional setting and does not rely on vectors of labeled landmark points as input. The method is used to learn closed boundary curves by performing principal components analysis on the functional representation. When compared with existing deformable models, the technique offers a number of advantages. For instance, it does not require accurate landmark correspondence and can deal with missing landmark points.

The first short paper in this section is "Bagging for Path-Based Clustering" by B. Fischer and J.M. Buhmann. It contains a mathematical description of the method of Path-Based Clustering. The paper focuses on the use of the bootstrap resampling technique for agglomerative clustering, which is necessary for making the method work. The proposed method is evaluated on a large color image data set of human segmentations.

A. Crouzil, X. Descombes, and J.-D. Durou tackle the classical problem of shape from shading in "A Multiresolution Approach for Shape from Shading Coupling Deterministic and Stochastic Optimization." They develop a multiresolution approach to the problem. By using simulated annealing, they overcome problems associated with local minima. They demonstrate that the underlying cost function is related to the energy of an MRF. The method is shown to offer advantages for surfaces involving complex patterns of concave and convex structure.

We hope that the collection of papers assembled in this special section will provide a timely and interesting sample of research in the field of energy minimization. In addition to the authors and reviewers, we received considerable help and support from a number of individuals in bringing it to fruition. These include Kevin Boyer, Rama Chellappa, and David Kriegman who, as EICs, supported our proposal, Hilda Hosillos and Suzanne Werner at the IEEE Computer Society who helped with the collection of papers, undertook the final preparation of the special section, and kept us on schedule, and Corinne Zuzia, who assisted with the processing of the reviews.

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Guest Editors

Mário A.T. Figueiredo (S'87-M'95-SM'2000) received the EE, MSc, and PhD degrees in electrical and computer engineering, all from the Instituto Superior Técnico (I.S.T.), the engineering school of the Technical University of Lisbon, Portugal, in 1985, 1990, and 1994, respectively. Since 1994, he has been with the Department of Electrical and Computer Engineering, I.S.T. He is also a researcher and area coordinator at the Institute of Telecommunications, Lisbon. In 1998, he held a visiting position with the Department of Computer Science and Engineering of Michigan State University, East Lansing. His scientific interests include image processing and analysis, computer vision, statistical pattern recognition, and statistical learning. He received the Portuguese IBM Scientific Prize in 1995 for his work on unsupervised image restoration. He is an associate editor of the journals *Pattern Recognition Letters*, *IEEE Transactions on Image Processing*, and *IEEE Transactions on Mobile Computing*; he is also a guest coeditor of special issues of the journals *IEEE Transactions on Pattern Analysis and Machine Intelligence* and *IEEE Transactions on Signal Processing*. He was cochair of two workshops on energy minimization methods in computer Vision and pattern recognition (EMMCVPR '01, held in Sophia Antipolis, France, and EMMCVPR '03, held in Lisbon, Portugal). He is a senior member of the IEEE.

Edwin R. Hancock studied physics as an undergraduate at the University of Durham and graduated with honors in 1977. He remained at Durham to complete the PhD degree in the area of high-energy physics in 1981. Following this, he worked for 10 years as a researcher in the fields of high-energy nuclear physics and pattern recognition at the Rutherford-Appleton Laboratory (now the Central Research Laboratory of the Research Councils). During this period, he also held adjunct teaching posts at the University of Surrey and the Open University. In 1991, he moved to the University of York as a lecturer in the Department of Computer Science. He was promoted to senior lecturer in 1997 and to reader in 1998. In 1998, he was appointed to a chair in computer vision. Professor Hancock now leads a group of some 15 faculty, research staff, and PhD students working in the areas of computer vision and pattern recognition. His main research interests are in the use of optimization and probabilistic methods for high and intermediate level vision. He is also interested in the methodology of structural and statistical pattern recognition. He is currently working on graph-matching, shape-from-X, image databases, and statistical learning theory. His work has found applications in areas such as radar terrain analysis, seismic section analysis, remote sensing, and medical imaging. He has published more than 80 journal papers and 300 refereed conference publications. He was awarded the Pattern Recognition Society medal in 1991 and an outstanding paper award in 1997 by the journal *Pattern Recognition*. In 1998, he became a fellow of the International Association for Pattern Recognition. He has been a member of the editorial boards of the journals *IEEE Transactions on Pattern Analysis and Machine Intelligence* and *Pattern Recognition*. He has also been a guest editor for special editions of the journals *Image and Vision Computing* and *Pattern Recognition*. He has been on the program committees for numerous national and international meetings. In 1997, with Marcello Pelillo, he established a new series of international meetings on energy minimization methods in computer vision and pattern recognition.

Marcello Pelillo received the "Laurea" degree with honors in computer science from the University of Bari, Italy, in 1989. From 1988 to 1989, he was at the IBM Scientific Center in Rome, where he was involved in studies on natural language and speech processing. In 1991, he joined the faculty of the University of Bari, Italy, as an assistant professor of computer science. Since 1995, he has been with the University of Venice, Italy, where he is currently an associate professor of computer science. He held visiting research positions at Yale University, University College London (England), McGill University (Canada), the University of Vienna (Austria), and York University (England). His research interests are in the area of computer vision, pattern recognition, and neural computation, where he has published more than 90 papers in refereed journals, handbooks, and conference proceedings. He has organized a number of scientific events, including the Neural Information Processing Systems (NIPS) 1999 Workshop on Complexity and Neural Computation: The Average and the Worst Case (Breckenridge, Colorado, December 1999). In 1997, he established a new series of international workshops devoted to energy minimization methods in computer vision and pattern recognition (EMMCVPR) and, in 2000, he was a guest coeditor of a special issue of the journal *Pattern Recognition* on this theme. In 2001, he was a guest coeditor of a special issue of the *IEEE Transactions on Pattern Analysis and Machine Intelligence* devoted to "graph algorithms in computer vision." He has been on the program committees of several international conferences and workshops and serves on the editorial board for the journal *Pattern Recognition*. Professor Pelillo is a member of the IEEE Computer Society, the International Association for Pattern Recognition, and the Pattern Recognition Society.

Josiane Zerubia received the MSc degree from the Department of Electrical Engineering at ENSIEG, Grenoble, France, in 1981, and the Doctor Engineer degree in 1986, the PhD degree in 1988, and an "Habilitation" in 1994, all from the University of Nice Sophia-Antipolis, France. She has been permanent research scientist at INRIA since 1989. She has been director of research since July 1995. She was head of a remote sensing laboratory (PASTIS, INRIA Sophia-Antipolis) from mid-1995 to 1997. Since January 1998, she has been in charge of a new research group working on remote sensing (ARIANA, INRIA-CNRS-University of Nice). She has been an adjunct professor at Sup'Aero (ENSAE) in Toulouse since 1999. Before that, she was with the Signal and Image Processing Institute at the University of Southern California (USC) in Los Angeles as a postdoctoral researcher. She also worked as a researcher for LASSY (University of Nice and CNRS) from 1984 to 1988 and in the research lab of Hewlett Packard in France and in Palo Alto, California, from 1982 to 1984. She is a fellow of the IEEE. She was part of the IEEE IMDSP Technical Committee (SP Society) from 1997 to 2003, associate editor of the *IEEE Transactions on Image Processing* from 1998 to 2002. She has been member-at-large of the board of governors of the IEEE Signal Processing Society since 2002, area editor of *IEEE Transactions on Image Processing* since 2003. She has also been a member of the editorial board of the French Society for Photogrammetry and Remote Sensing (SFPT) since 1998. She has been cochair of two workshops on energy minimization methods in computer vision and pattern recognition (EMMCVPR '01, Sophia Antipolis, France, and EMMCVPR '03, Lisbon, Portugal), chair of a workshop on photogrammetry and remote sensing for urban areas, Marne La Vallee, France, 2003. Her current research interest is image processing using probabilistic models or variational methods. She also works on parameter estimation and optimization techniques.