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A Multilevel-Multiresolution Method for Image Processing, A Bayesian Framework for Reconstructing and Representing Shapes	DAAL03-90-G-0033
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The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

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13. ABSTRACT (Maximum 200 words)

During the period of the grant, 1/15/90 - 1/14/93, we have developed: 1) a coherent multiresolution framework for image analysis tasks, in particular, for estimating 3-D shapes from a single video or SAR image; the algorithm has been applied to constructing topographic maps of Venus' terrain, and to segmentation/classification of textures, 2) efficient procedures for estimating the parameters of Markov Random Fields (MRF's) from noisy and degraded data, 3) a fixed-length noiseless source coding for MRF's using large deviations, and 4) a multi-grid type algorithm for maximum-likelihood estimation in tomography. In addition, we have begun a new non-parametric approach to speech recognition.

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multiresolution, image analysis, texture classification, tomography, Markov random fields	9
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FINAL REPORT

Summary of Research

Our research supported by the ARO/SDI grant, has had several successes in Image Processing and Computer Vision. A general theme of our work is to guide the development of algorithms and the solutions of the computational problems by carefully articulated mathematical models. The modelling approaches have been strongly influenced by applications. The applications stimulate the mathematical research and, in turn, the algorithms derived from the mathematical analysis provide new methodological approaches for the applications. Our main projects and contributions to applications and theory, may be divided into five groups:

1) Shape Reconstruction: We have developed a coherent Bayesian framework for estimating 3D shapes (or topographic maps), and surface composition (albeto, or dielectric properties) from a single noisy Video or SAR image. Image 1 shows a reconstruction experiment with video data acquired under uncontrolled illumination; Figure 2 shows a surface reconstruction from simulated SAR data. The method has been applied to the estimation of topographic maps of Venus' terrain using SAR data from the Magellan spacecraft.

Our approach to the reconstruction of 3D shapes explores certain *random surface* models, and is formulated as a global optimization problem. To solve this problem, we developed a new multiresolution algorithm inspired from recent studies in the simulation of statistical mechanics systems at criticality. The algorithm appears to be useful in many image processing tasks, including texture segmentation/classification.

2) Texture Synthesis and Classification: We have introduced a appealing class of Markov Random Fields (MRF's) models for texture synthesis and segmentation/classification. The models are defined at all levels of resolution and are convenient for scale and rotation invariant segmentation/discrimination. Image 3 shows the synthesis of a wood-like texture; Image 4 shows the segmentation/classification of four textures. We have two segmentation procedures one *supervised* and on *unsupervised.* The modelling of textures via MRFs involves the estimation of certain parameters from training data. We have developed practical statistical procedures for parameter learning, that apply to a host of other applications. The mathematical study of consistency and asymptotic normality has lead to a number of mathematical problems and to an interesting interplay between statistical inference and the phenomena of phase transitions. We have settled these problems in a number of publications.

3) Tomography: We have introduced a *two-stage* EM algorithm for 3D emission tomography to account for blur due to 2D scientilation cameras; the procedure makes the 3D problem computationally feasible. Also, we developed a *multi-grid* type algorithm for maximum likelihood and back-projections estimation. To our knowledge, this is the first multiresolution procedure in the tomography problem.

4) Coding Theory for MRFs (work by Y. Amit who was partially supported by this grant): the theory of large deviations was used to show the number of bits per symbol for Ziv-Lempel codes is given by the maximum entropy of all MRFs with the same potentials. The work provides also a new way for looking at the classical 1-D Markov source coding problem.

5) Speech Recognition: During this grant, we undertook a systematic study of speech recognition, by exploring a new framework which is conceptually similar to, but considerably different in details from the Hidden Markov Model (HMM) approach. Our results to date will appear in a series of articles (during 1993/94). Our procedure aims at changing the *acoustic model* in the HMM approach in a fundamental way, by using modern non-parametric/nonlinear prediction techniques to model the acoustic waveform in the time domain. Our program has lead to an effective algorithm for discriminating the *stop consonants* of English, and to two interesting mathematical problems, one of which is a conceptually new form of the classical Wiener-Kolmogorou prediction theory.

LIST OF IMAGES

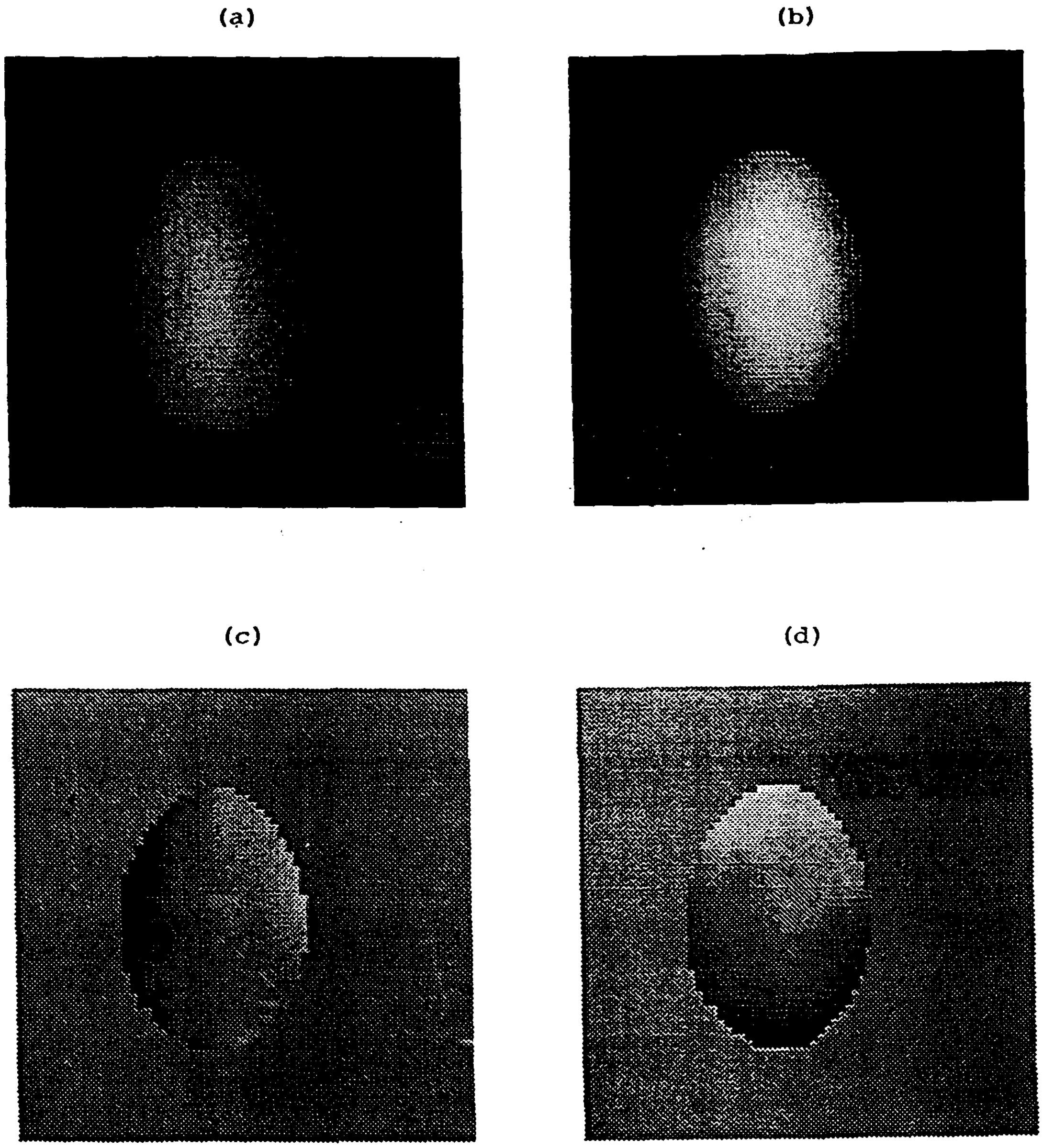
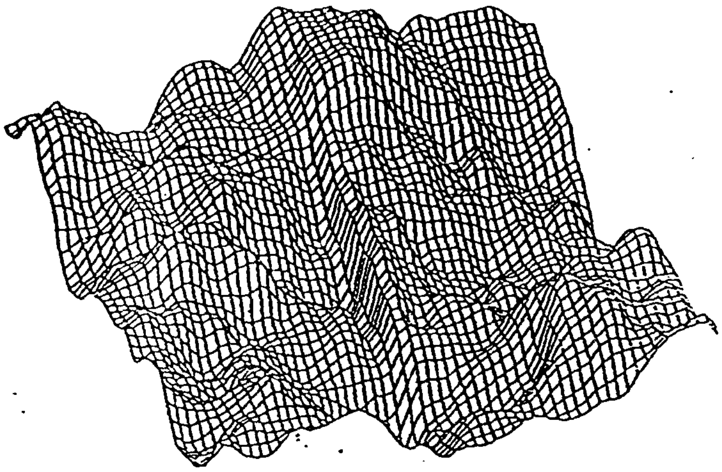


Image 1: real egg, uncontrolled illumination

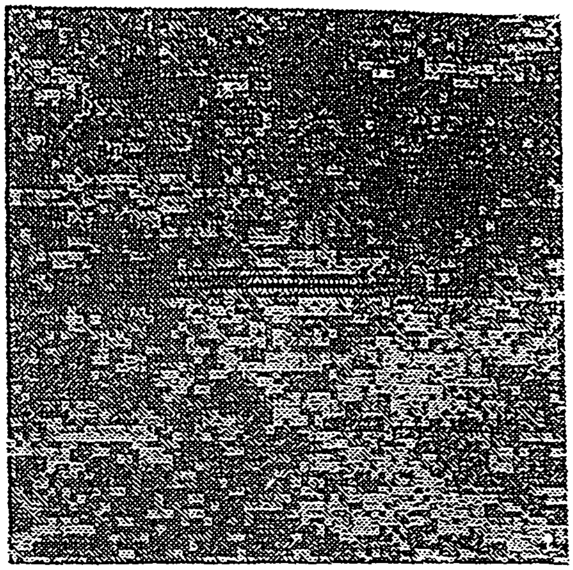
(a) original, (b) reconstruction

(c) illumination from x-direction

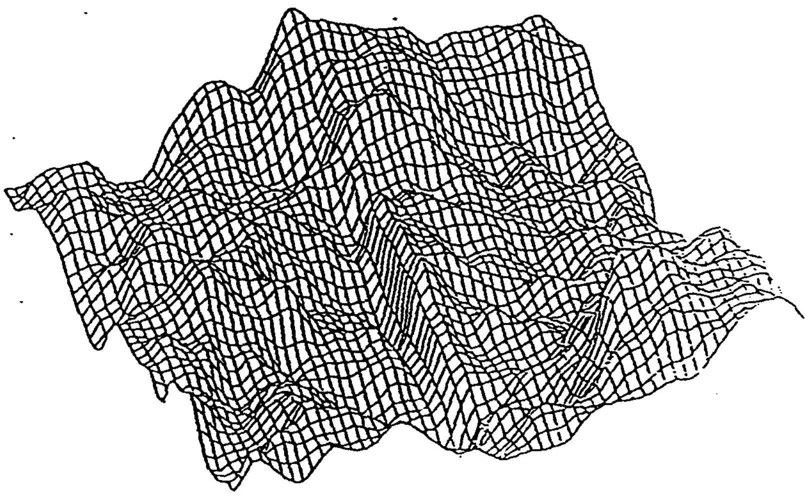
(d) illumination from y-direction



(a) plot of original surface



(b) 32-look SAR image of (a)



(C) plot of reconstructed surface

Image 2

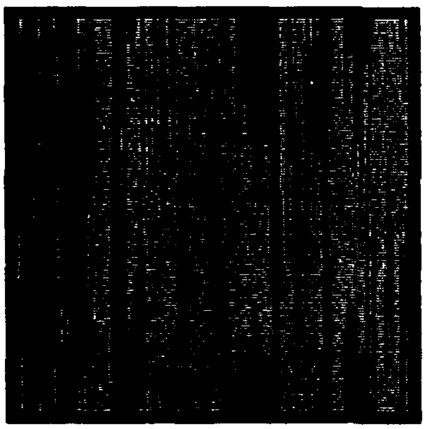
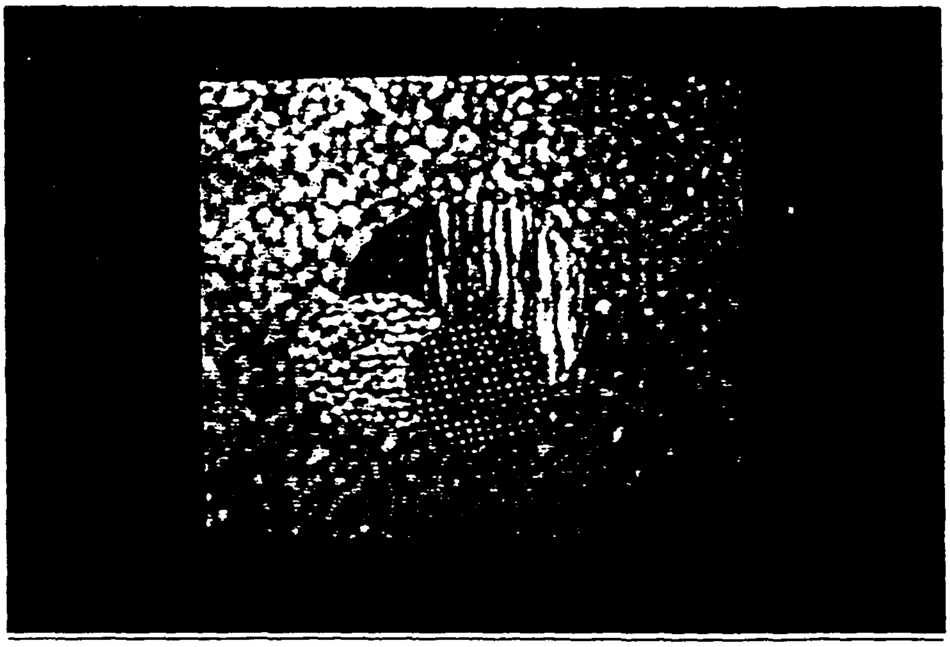


Image 3: Simulated wood-like texture



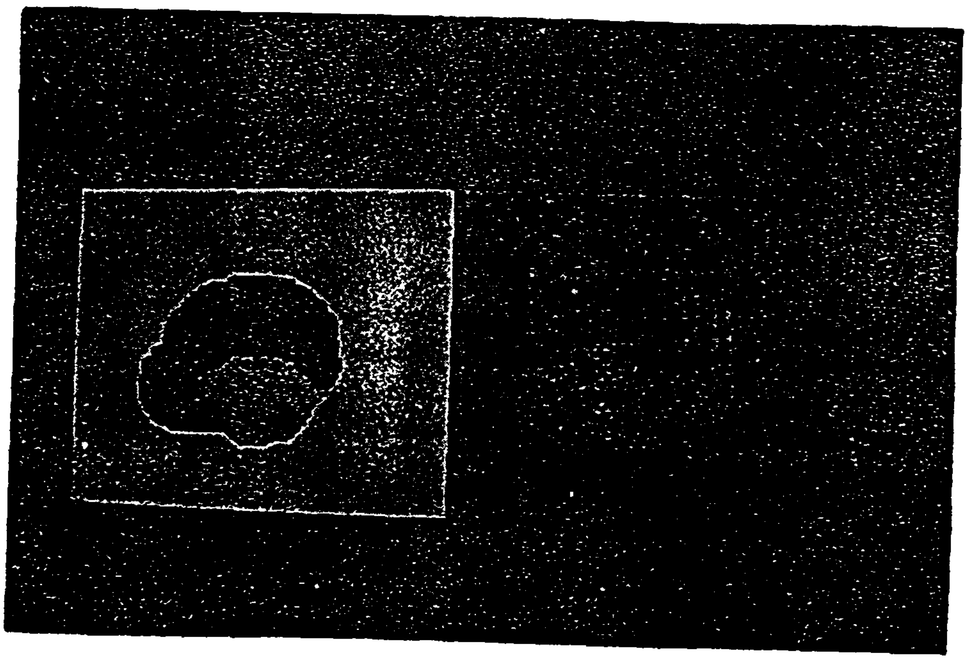


Image 4: Segmentation of four textures

LIST OF PUBLICATIONS

1. "Asymptotics of Maximum Likelihood Estimators for the Curie-Weiss Model" (with F. Comets), Annals of Statistics 19 (1991) 557–578.

2. "Image Analysis and Computer Vision" (with D. Geman), in *Spatial Statistics and Image Processing*, National Research Council, National Academy Press (1991) pp. 1–36.

3. "Parameter Estimation for Gibbs Distributions from Partially Observed Data" (with F. Comets), Annul of Applied Probability 2 (1992) 142–170.

4. "A Two-Stage EM Algorithm with Applications to Emission Tomography" (with M. Hudson), submitted for publication (1991).

5. "A Nonlinear Multi-Grid EM Algorithm for Emission Tomography" *(with M. Hudson), submitted for publication* (1991)

6. "Parameter Estimation for Gibbs Distributions from Fully Observed Data", in *Markov Random Fields: Theory and Applications*, Academic Press (1993) pp. ..., eds.: R. Challappa and A. Jain.

7. "A Variational Method for Estimating the Parameters of MRF from Complete or Incomplete Data" (with M. Almeida) Annals of Applied Probability 3 (1993) ? - ?.

8. "Metropolis - Type Monte Carlo Simulation Algorithms and Simulated Annealing" to appear in *Topics in Contemporary Probability Theory* (1994), eds.: J. L. Snell and P. Doyle.

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4. Jose Torreao, Ph.D. 1990
5. Alejandro Murua, Ph.D. 1993
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