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.
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 (albedo, 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 one unsupervised. The mod-
elling 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 math-
ematical 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 scintilation 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 con-
ceptually 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 math-
ematical problems, one of which is a conceptually new form of the classical
Wiener-Kolmogorou prediction theory.
LIST OF IMAGES

**Image 1**: (a) original image: an egg imaged under uncontrolled illumination (using a desk lamp), (b) reconstruction; a matte surface was assumed; the algorithm estimated height, albedo, and an effective light source direction; (c) and (d) show the reconstructed scene illuminated from the $x-$, $y-$ direction.

**Image 2**: (a) plot of a simulated surface, (b) a 32 - look SAR image, (c) plot of the reconstruction using (b) as the data.

**Image 3**: Simulation of wood-like texture.

**Image 4**: Segmentation of four textures: wood, carpet, cloth, plastic background.
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 3: Simulated wood-like texture
Image 4: Segmentation of four textures
LIST OF PUBLICATIONS


LIST OF PARTICIPANTS

1. Dr. Yali, Amit, Visiting Assistant Professor

2. Dr. Chris Raphael, Visiting Assistant Professor

3. Murilo Almeida, Ph.D. 1990

4. Jose Torreao, Ph.D. 1990

5. Alejandro Murua, Ph.D. 1993

6. Panos Paraskevopoulos, Ph.D. 1993