Presentation of the Associated Team "SHAPES"

The proposed associated team will be a collaboration between the Ariana research group (INRIA/I3S), Sophia Antipolis, led by Dr. Josiane Zerubia, and the Computer Vision group at Florida State University, led by Prof. Anuj Srivastava. The proposed research will use ideas from statistical shape theory to extend the theory, algorithms, and applications of stochastic geometry to the analysis of aerial and high-resolution satellite images. It will also compare the results with another approach to shape description and modeling, namely higher-order active contours. Shape analysis has been developed by the FSU group over the last five years, while the use of stochastic geometry for image analysis has been championed by researchers at Ariana over the last eight years. Higher-order active contours are more recent, with the research on them having begun in Ariana only four years ago. The discussion between our two groups started several years ago, but the collaboration reached a new level after Prof. Srivastava's visit to INRIA Sophia Antipolis for four months in summer 2006 on a Visiting Professor grant from INRIA. The problem of detection and recognition of objects, such as trees, buildings, and roads, requires stochastic models of placements, shapes, and interactions between these objects in observed images. Additionally, in the case of hyperspectral image analysis, where the same scene is observed simultaneously at several frequencies, there is a need to fuse information across different bands, suggesting a need for joint statistical inference. Two specific items will be investigated: (i) the characterization of objects in images using infinite-dimensional shape descriptors, and (ii) the application of ideas from stochastic geometry, including shape analysis, to the analysis of hyperspectral images.
The team from INRIA will include:

1. Dr. Josiane Zerubia, Directrice de Recherche,
2. Dr. Xavier Descombes, Chargé de Recherche,
3. Dr. Ian Jermyn, Chargé de Recherche,
4. Ms. Maria Kulikova, who was a Master intern in Ariana and starts her PhD in October 2006, and
5. X to be hired, who will be a Master intern in Ariana in the spring 2007 and possibly continue as a PhD student if a grant from the PACA region is available.

The team from FSU will include:

1. Prof. Anuj Srivastava, Associate Professor,
2. Prof. Victor Patrangenaru, Associate Professor,
3. Mr. Shantanu Joshi, an advanced Ph.D. student, and
4. Mr. Wei Liu, a beginning Ph.D. student at FSU.

1 Associated Team Coordinator

Anuj Srivastava is an Associate Professor in the Department of Statistics, Florida State University, USA. He obtained M.S. and Ph.D. degrees in electrical engineering from Washington University in St. Louis, in the years 1993 and 1996, both under Prof. M. Miller, and was a visiting research scientist at the Division of Applied Mathematics, Brown University in 1996-97, working with Prof.

U. Grenander. Since 1997, he has been with the Department of Statistics at FSU, first as an Assistant Professor 1997-2003, and then as an Associate Professor.

His research interests are in the area of statistical image understanding with a focus on fundamental issues. His broad approach is to develop representations for objects of interest, by studying their shapes, textures, appearances, and motions. Using probability models on these representations, learned from past data, one can use Bayesian strategies for deriving inferences from given image data. In particular, he has developed, along with his colleagues, techniques from differential geometry and statistics for analyzing shapes of two- and three-dimensional objects in images.

In the year 2005, he was awarded FSUs Developing Scholar Award. He is an Associate Editor of IEEE Transactions on Pattern Analysis and Machine Intelligence and the Journal of Statistical Planning and Inference. In past he has been an Associate Editor of IEEE Transactions on Signal Processing. He is coordinator of the computer vision group at FSU, and his research has been funded by the Army Research Office, the National Science Foundation, the Air Force Office of Scientific Research, and the National Geospatial Agency (formerly National Imagery and Mapping Agency). He has published over 90 journal papers, book chapters, and conference articles.

2 Collaboration History

1. Josiane Zerubia and Anuj Srivastava interacted during ICIP, 2001, that resulted in a short visit by Anuj Srivastava to INRIA, Sophia Antipolis in July 2002 to present a seminar in the Ariana group.

2. Anuj Srivatava received a visiting Professor grant from INRIA (U. R. Sophia Antipolis) to visit INRIA and work with the members of Ariana research group for four months from May to August, 2006.

3. Anuj Srivastava is a *rapporteur* for the Ph.D. thesis of Mr. Guillaume Perrin, a Ph.D. student in Ariana group at INRIA. The thesis defense was held on October 2nd, 2006 at Ecole Centrale de Paris.

4. Anuj Srivastava was co-advising a student Ms. Maria Kulikova of Ariana, who finished her Master's degree (MVA, ENS Cachan) in September 2006. She continues for the Ph.D. degree with a MENSR grant from the Doctoral School of the University of Nice - Sophia Antipolis, starting in October 2006 in Ariana.

3 Impact

The impact of collaboration between the FSU group and the Ariana group will be multi-fold. The two groups have overlapping interests yet different expertise. The FSU group is acknowledged as amongst the leaders in the use of differential geometry, statistics, and computational solutions to problems in image analysis. In particular, it is known for development of statistical shape theory for analyzing infinite-dimensional representations of objects in 2D and 3D images. On the other hand, Ariana group has tremendous expertise in aerial and high-resolution satellite image analysis. In particular, it has developed and advanced techniques from stochastic geometry for use in detecting road networks, buildings and tree configurations.

An ultimate goal in image analysis is to detect, recognize, and perhaps track (in case a time series of images will be available) objects of interest from images of an observed scene. The most natural approach seems to be to model objects, or rather their appearances in images, as Marked (interacting) Point Process with features such as shapes, motions, classes, etc, associated with each object. The objects will interact not only in terms of their locations, but also in terms of shapes, motions and labels. Therefore, one needs to represent and analyze not only the geometries of the full scenes but also the geometries of individual objects present in these scenes. An emerging approach to analysis of shapes of objects, such as trees, buildings, roads, and lakes, is to utilize tools from infinite-dimensional differential geometry of shape manifolds formed by the boundaries of these objects. With the availability of such tools, interactions between shapes of neighboring objects can simply be treated as Markov random fields on these shape manifolds. Dynamic objects, changing both their locations and shapes in time, can be modeled as stochastic processes on the joint shape and location manifolds. The combination of tools from studies of scene geometry and shape geometry opens up possibilities for tackling more general problems, involving arbitrary objects in arbitrary configurations. To the best of our knowledge, such tools for analyzing configurations of shapes do not exist in the literature, except perhaps in the *General Pattern Theory* invented by Prof. U. Grenander of Brown University over the last three decades. The proposed collaboration can also be seen as a realization of the profound framework suggested by Prof. Grenander.

In addition to development of framework, this collaboration will provide immediate and significant impact on practical systems. The two teams will together develop algorithms to study aerial and satellite high resolution data that is both presently available and will become available in the near future. Examples of existing data includes data collected by satellites SPOT 5, Cartosat 1, IKONOS, QUICKBIRD, EROS A and B, and Ryesurs-DK1, that are currently in orbit. Future satellites that will provide high-resolution image data include Cartosat2, Orbview 5, Worldview, and PLEIADES. Many of these satellite already provide (or will provide) multispectral data involving four spectral bands. For the hyperspectal data, many current experiments have been conducted using airborne cameras, e.g. Farmstar by Astrium/EADS. A dataset of rural farm areas collected by Dr. D. Landgrebe of Purdue University has been made available to the US team members and aerial images of forest as well as of urban areas have been made available to the French team members by IFN and IGN.

4 Overview of Research Groups

1. **ARIANA Research Group**:

   Ariana is a joint research group created by INRIA, CNRS, and UNSA (University of Nice-Sophia Antipolis) in 1998 and located at INRIA Sophia Antipolis. The Ariana research group develops mathematical tools such as Markovian modeling, variational approaches, and MCMC methods, and applies them to the solution of inverse problems derived from concrete applications in Earth observation and cartography. Past applications include parameter estimation for the restoration of aerial and satellite images (with the French Space Agency (CNES), Alcatel Alenia Space, and Astrium), and road and building detection in aerial images (with the French Mapping Institute (IGN) and the French Defense Agency (DGA)).

2. **FSU Group**:

   The Department of Statistics at FSU has identified *Computer Vision & Image Analysis* as one of its two main focus areas for growth in the coming decade. The vision group in the dept. has two Associate Professors Anuj Srivastava and Vic Patrangenaru, and several PhD students. Their main areas of research are: statistical shape analysis, statistical modeling of natural images, biological growth models, and statistics on nonlinear spaces with applications in computer vision. This group has published articles in leading computer vision and statistics journals and international conferences, and has an ongoing collaboration with the Northrop-Grumman company on industrial applications of shape analysis.

5 Research Program

We are interested in developing statistical descriptors for configurations of objects in an image, where the objects are characterized by the shapes of their boundary contours. As a motivation, consider the problem of analyzing a city terrain [29, 11], building footprint [16], or a forest region using a satellite or an aerial image [30]. We anticipate objects of interest, such as roads, buildings, trees, and lakes, to occur more often in certain configurations. It is reasonable to expect similar objects to occur together, in certain positions and orientations that are more probable than others. For instance, a collection of similar buildings may form a residential complex, or a collection of similar trees may denote a part of a plantation. An aerial image of a large airport will show airplane contours that are similar in shapes and aligned in orientations and placements.

5.1 Stochastic Geometry with a Focus on Shape Analysis

We argue that a convenient approach is to extend ideas from classical stochastic geometry where one studies placements and interactions of simple objects as points, lines, and circles. In our approach, the placement of objects can be modeled using spatial point processes, more specifically area-interaction point processes such as the Strauss model, and the labels (classes) of objects can be modeled using Marked versions of these point processes [5, 17]. We are interested in situations where, in addition to having a discrete label such as a tree or a building, we associate more elaborate "features", such as a shape, an orientation, and a scale, to each object. Furthermore, the model we seek shall allow interaction of these features, in addition to the locations, of neighboring objects.

Imaged objects can be characterized in several ways, using their colors, textures, shapes, movements, and locations. The past decade has seen large efforts in modeling and analysis of pixel statistics in images to attain these goals albeit with limited success. An emerging opinion is that global features such as shapes be taken into account. Characterization of complex objects using their global shapes is fast becoming a major tool in computer vision and image understanding. Analysis of shapes, especially those of complex objects, is a challenging task and requires sophisticated mathematical tools. Srivastava, Patrangenaru and their colleagues have developed a theory for analyzing shapes of planar curves that uses ideas from differential geometry of infinite-dimensional spaces to compare and analyze shapes in two dimensions [10, 28, 7, 27, 13] and three-dimensions [4, 8, 9, 26]. The basic idea is to identify a set of closed curves, form a quotient space by removing all the shape-preserving transformations, and to study differential geometry of the resulting space. Statistics of nonlinear spaces, including shape spaces, has been studied in Patrangenaru and colleagues in [12, 2, 3, 1].

5.1.1 Higher-Order Active Contours with a Focus on Shape Analysing

The proposed effort will also compare this shape analysis with alternative approaches. Higher-order active contours (HOACs) represent an alternative approach to the modeling of shapes, or more generally, regions in the image domain [24]. The boundary of the region is again taken as its representation, but rather than place explicit probability distributions on a shape space with implicit long-range interactions between boundary points, an energy functional of the boundary is constructed that includes explicit long-range interactions between boundary points, while implicitly defining a probability distribution on the space of boundaries. The resulting models bear some resemblance in their information content to the combination of stochastic geometry and shape space models proposed as the main thrust of this proposal, in that an arbitrary number of interacting 'objects' can be described, each one of them having a shape that, like the inter-object interactions, is controled by the nature of the long-range interactions. Current models include an energy that favours network shapes consisting of arms with roughly parallel sides joining together at junctions, another, the 'gas of circles' model, that describes regions consisting of an arbitrary number of circles with a given radius. These models have been applied to the extraction of road networks [21, 22, 25] and tree crowns [6] from satellite and aerial images. A reformulation of HOACs in terms of 'phase fields', offers the possibility for multiscale versions of the models and the algorithms, and the use of random field techniques in their analysis and solution [23]. The role of HOACs in the proposal will be as a point of comparison, in order to understand the advantages and disadvantages of the two approaches.

5.2 Detection and Recognition of Objects Using Hyperspectral Imagery

Late 1960s and early 1970s saw development of airborne and satellite imaging platforms that can image scenes in three to eight spectral bands simultaneously; this process was termed multi-spectral imaging. Later, the advent of hyperspectral imaging increased the number of bands to hundreds. Currently, hyperspectral images can be gathered via many types and sizes of cameras. There are even portable hand-held cameras that can photograph a scene in more than 20 spectral bands. In this research we will concentrate on aerial images of geographical regions, or terrains, taken from a high altitude via aircraft or satellite. Typically, a hyperspectral image is collected in wavelengths ranging from 0.3 micrometers (μm) to 14.0 μm, where 0.3-0.4 μm is the ultraviolet region, 0.4-0.7 μm is the visible region and 0.7-14 μm is the infrared region. The choice of wavelengths used in a particular study depends on the equipment and the experiment. Both groups have extensive experience in working with hyperspectral data and in developing algorithms for analyzing such data. This analysis has included: classification using texture models [20, 19], Gaussian Markov random field models [18], and heavy-tailed (non-Gaussian) generalized Laplacian field models [14, 15].

Detection and recognition of objects using data from hundreds of frequency bands is very challenging. Consider the following simple example. An object present in an imaged scene renders a distinct signature in each frequency band of the hyperspectral data. In case of shape-based characterization of objects, the shape associated with the object may be different in different frequencies. One would like to use this ensemble of shapes to jointly characterize the original object. The tools from statistical theory of shapes help us define and analyze statistics such as means, covariances, moments and stochastic processes on shape spaces, and therefore can be used in analyzing hyperspectral ensemble of shapes. Consider the problem of detecting lakes using aerial images collecting in multiple frequencies. It is possible that the boundaries of lakes may be hard to detect and classify in visible images, but are easier to analyze in thermal images, especially when the ground is at a higher temperature compared to the lake water. Thermal imagery is very useful in identifying bodies of water, roads, plantations, etc due to differences in their thermal profiles from the surroundings.

6 Budget

6.1 Co-funding

We seek the following budget from INRIA and a similar budget from US sources. The money to support US team's efforts in this project will come from already existing grants to Prof. A.

Srivastava from the US Army Research Office, the US Air Force Office of Scientic Research, and the Northrup Grumman Company. No other source of funding is available apart from the PhD grants already allocated in France and in the USA. We hope to get a Master internship via a COLORS funding by INRIA Sophia Antipolis in 2007.

The following is a summary of budget for an expected four-year period:

Year	**French Team** (From INRIA)	**US Team** (From US Sources)
1^{st} Year	20KE	20KUSD
2^{nd} Year	20KE	20KUSD
3^{rd} Year	10KE	10KUSD
4^{th} Year	4KE	4KUSD
Total	**54KE**	**54KUSD**

The detailed budget for the first year (2007) is as follows:

- French team :

	Number	**Salary**	**Visits**	**Conferences**	**Total**
Permanent researchers	3	INRIA	2 in USA=5 KE 3 in Lille=2,55KE	1 in Minneapolis=2,7KE 1 in Poznan=2,5KE	12,75 KE
PhD students	1	MENSR	1 in USA=2,5KE 1 in Lille=1,72K Euros	1 in Poznan=2,5KE	6,42KE
Master Interns	1	COLORS	1 in Lille=0,85KE	-	0,85KE
Total	5		12,62KE	7,40KE	20,02KE

- US team:

	Number	**Salary**	**Visits**	**Conferences**	**Total**
Permanent researchers	2	FSU	3 to Sophia = 6 KUSD	1 to Minneap.=1.5K USD 1 to Hubei=2.5 KUSD	10 KUSD
PhD students	2	FSU	2 to Sophia = 6 K USD	1 to Minneap. 1.5 KUSD 1 to Hubei =2.5 KUSD	10 KUSD
Total					20KUSD

6.2 Exchanges

The detailed exchanges for the first year (2007) are as followed:

6.2.1 French team:

- 2 weeks in January in the Dept. of Statistics at FSU of Maria Kulikova (PhD student) to work with the US team (trip=1KE+stay=1,5 KE)= 2,5 KE
- 2 weeks in March in the Dept. of Statistics at FSU of Dr. Ian Jermyn (senior researcher) to work with the US team (trip=1 KE+stay=1,5 KE)=2,5 KE
- 2 weeks in April in the Dept of Statistics at FSU of Dr Xavier Descombes (senior researcher) to work with the US team (trip=1 KE+stay=1,5 KE)=2,5 KE

- 2 weeks in August at the University of Lille of Maria Kulikova (PhD student) to work with the Prof. Anuj Srivastava, who will be on sabbatical in this University from May to December 2007 (trip=700 Euros+stay=570 Euros)=1,27 KE
- 4 short trips of 2 or 3 days to Lille of the Master student, Ian Jermyn, Xavier Descombes and Josiane Zerubia to meet Prof. Srivastava btw May and December 2007 (trip=700 Euros+stay=150 Euros)=4x850 Euros=3,4 KE.

These exchanges are necessary in order to continue to develop a new theory and to test the algorithms on various aerial and satellite data sets. Furthermore, we will attend conferences to present joint papers:

- 1 trip of Xavier Descombes (senior researcher) to attend the CVPR'07 conference in Minneapolis, USA, in June 2007 to present a joint paper (trip=1KE+registration fees=700 Euros+stay=1 KE)=2,7 KE
- 2 trips of Josiane Zerubia (senior researcher) and Maria Kulikova (PhD student) in Poznan, Poland, in September 2007 to present another joint paper (2 trips=1,5 KE, (1 student registration=500 Euros, 1 full registration=700 Euros, 2 stays=2KE)=4,7 KE.

6.2.2 US team:

We envision three trips by the senior researchers to Sophia-antipolis to work with Ariana group members. Two of these trips will be made by Anuj Srivastava during his sabbatical stay in Lille, France, during July and December 2007. The remaining trip will be made by Vic Patrangenaru from Tallahassee, Florida. We have also planned for two trips by students to present their research to Ariana members. One of the student, Shantanu Joshi, will spend two weeks in Sophia Antipolis in summer 2007 helping transfer his algorithms on shape analysis to Ariana researchers. In terms of conferences, we expect one professor and one student each to attend CVPR conference in Minneapolis, USA, and the EMMCVPR conference in Hubei, China.

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