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FOREWORD

ProTeM Evaluation Workshop

The ProTeM-CC programme - the Thematic Multi-institutional Programme in Computer Science - was created in the end of 1990 aiming at collaborative research and development in computer science. The ProTeM-CC programme has gone through three stages, and is now starting its fourth stage. At the third stage, that is still ongoing, the programme supports 21 projects, reaching a total funding figure of US$ 7.7 million. Besides the budget resources of CNPq, the programme also counts with the support of the United Nations Development Programme (UNDP). ProTeM-CC currently gathers 29 Brazilian Universities, 4 Research Centers, and 12 industrial partners. The programme is strongly based on a partnership philosophy,

At the dawn of its fourth stage, it is important to evaluate the ProTeM-CC programme in order to establish priorities and goals for the future. Therefore, the fourth stage of the Programme begins with the ProTeM Evaluation Workshop, that is an effort to review the results and the projects funded in the second stage of ProTeM-CC. For the Workshop, we invited eight distinguished researchers and consultants to review the 21 projects of the second stage. These proceedings contain a summary of the results obtained by the projects. Going through the papers of the Proceedings, one can learn what was achieved by the ProTeM-CC Second Stage in terms of publications, theses, dissertations and technology generated by the projects.

We hope the findings of the ProTeM-CC Evaluation Workshop will a valuable resource for researchers as well as for the ProTeM-CC Programme administration in their quest to achieve research goals that are relevant and important for the Brazilian society.

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AnlMoMat Project: Image Analysis Using Mathematical Morphology Tools

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Abstract

An overview of the AnIMoMat Project results is presented. The theoretical results are on characterization, representation, decomposition, and automatic design of operators between lattices. The software product, called MMach, consists of several versions of a toolbox for digital image analysis. The tools include the automatic image operator design. The application results cover the areas of Art, Astronomy, Biology, Cartography, Industrial Inspection, Material Science, Medicine, Remote Sensing, and Vision.

Keywords: image processing, image analysis, mathematical morphology, segmentation.

1. Introduction

Mathematical Morphology is a non-linear approach to image processing and analysis. It was invented in the sixties at Paris School of Mines and is based on the algebraic structure of lattice.

In Brazil, the study of Mathematical Morphology began in 1984 at the Image Processing Department of INPE, the National Institute for Space Research. In 1989 a first application to remote sensing image filtering was published in the Photogrammetria journal.

From 1992 to 1995 this research area was sponsored by FAPESP through a Thematic Project on Remote Sensing Image Processing. It was at that time that the Brazilian research group began to spread over other academic institutions in São Paulo State.

From February 2, 1995 to November 23, 1997, CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) sponsored through ProTeM-CC (Programa Temático Multi-institucional em Ciência da Computação) the AnIMomat Project (Proc. n° 680067/94-9) on Image Analysis using Mathematical Morphology Tools.

The AnIMoMat project major objective was the morphological tool design and its application to digital image analysis. In this paper, we give an overview of the work that has been done by 33 participants from seven institutions in four Brazilian states during the three-year project.
In the first part, we present a global result evaluation and in the second part, we link the work done with the originally defined tasks. Finally, in the end note, we give an exhaustive list of the pieces of work supported by the project.

2. Global result evaluation

During the three-year project, the major activities consisted of theoretical research, computational tool implementation and image analysis applications. These activities resulted in a lot of publications in journals and conference proceedings. Furthermore, nine theses were presented.

The list of these publications is given in the Reference section and is summarized in Table 1.

Table 1 - Publication distribution over 1995, 1996 and 1997.

	Published 1st year	published 2nd year	Published 3rd year	submitted 3rd year	total
Masters Thesis		4	4		8
Ph.D. Thesis			1		1
Book		1			1
Proceedings		2	1		3
Journal Paper		1	2	3	6
Paper in Book		2		4	6
Chapter in Book				2	2
Paper in National Conference	1	6	5		12
Paper in International Conference	4	3	2		9
Communication in Workshop	3	20	9		32
Report	2	2	1		5
Manual			2		2
Web Publication	4	8	2		14
TOTAL	14	49	29	9	101

As shown in Table 1, one third of the publications are communications in workshops. Actually, CNPq sponsored three workshops, one per year. These workshops gathered the project participants, people from the scientific Brazilian community and invited researchers from abroad. Two of the three proceedings appearing in Table 1 contain the material of the 96 and 97 Workshops. Both of these proceedings have been posted on the Web.

Furthermore, among the 101 pieces of work of Table 1, 77 have been deposited in a Digital Library (named URLib) which collection is posted on the Web. The complete material of these publications can be accessed from any of the sites having an URLib local collection by clicking the "Search" word and filling in the form with the name (for example: <dpi.inpe.br/banon/1995/09.19.09.44>) of the repository containing the work of interest.

Two important publications are, a Masters Thesis on character recognition [Tomita:1996:PAM] which has been awarded by the Brazilian Computing Society (SBC) and a Ph.D. Thesis [Candeias:1997:AMM] on remote sensing image analysis. Besides, one book dedicated to Mathematical Morphology has been published in Portuguese [Facon:1996:MMT].

The major theoretical contributions have been in the area of characterization of the elementary operators (erosions, dilations, erosions, anti-dilations and anti-erosions) and in the area of automatic operator design.

In the first area, three equivalent characterizations have been introduced for translation invariant operators defined on gray-scale images [Banon:1995:CTI, Banon:1995:CTE].

In the second area, the operator design was done from pairs of images. Figure 1 gives an example of a pair of images.

Figure 1 - A pair of images (source: Oliveira:1997:UAG).

In Figure 1, the right image is a filtered copy of the left noisy image. By using automatic operator design techniques on this pair of images, we are able to obtain an operator that can act as a filter. Applying this operator to the left image of Figure 2, we get, for example, the right image.

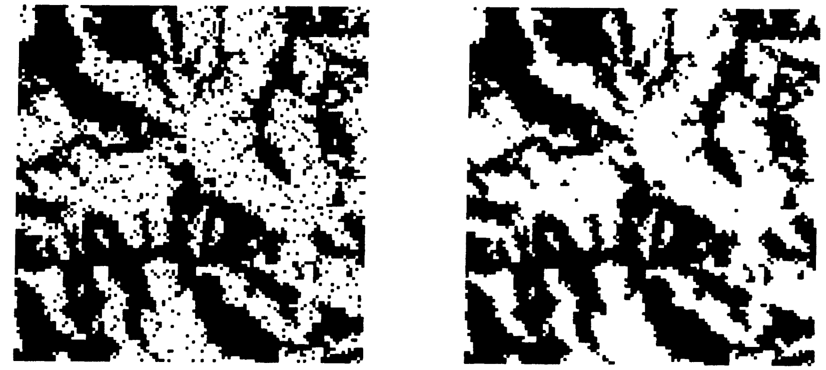

Figure 2 - An input/output pair of a designed filter (source: Oliveira:1997:UAG).

A first approach to automatic operator design consists of establishing a statistical optimization model in the operator space [BarreraDoug::RGW, BarreraDougHira:1998:ADO, TomitaBarr:1996:PAM, BarreraTeraSilvTomi:1996:APM, BarreraTomiCorrTera:1995:APB, CorreaBarrTera:1996:SCL, DoughertyBarr:1996:MPL, DoughertyBarr:1998:NLFB, DoughertyBarr:1998:BOF, DoughertyBarr:1998:NLFG, DoughertyBarr::PID].

Another approach consists of using genetic algorithms [Oliveira:1997:UAG]. Actually, the filtered image of Figure 2 is the output of an operator obtained by using this second approach.

Close to the problem of operator design is the problem of transforming a serial representation of an operator into its parallel representation. Important contributions based on an interval algebra have been made to solve this problem and can be found in [Salas:1996:OCI, BarreraFerrHash::AGS, BarreraHash::CRW, BarreraSala:1995:SOC, BarreraSala:1996:SOC, BarreraSalaHash:1996:SOC].

With respect to software development, new versions of a toolbox for the design and application of mathematical morphology operators have been implemented. The software, named MMach for Mathematical **Machine**, was developed by the groups of Professor Barrera from USP and Professor Lotufo from UNICAMP and has been very well accepted by the international scientific community. Nowadays, the MMach has users all over the world, in universities as well as in research centers

[BarreraBanoLotu:1995:MMT, BarreraBanoLotuHira::MMM, LotufoBarrBano:1995:M12, LotufoZampHiraBarr::MFM, BarreraHira:1997:FAC].

In one of the MMach version [Zampirolli:1997:TMM], the elementary operators have been constructed to transform images represented as a set of connected components. Figure 3 illustrates the effect of a dilation.

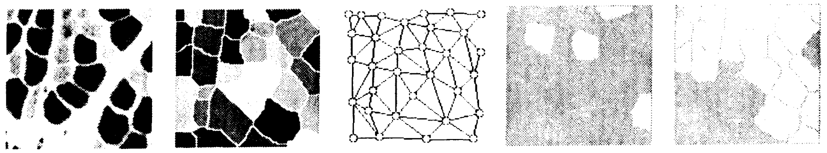

Figure 3 - Dilation on graph (source: Zampirolli:1997:TMM).

The color image of this figure is the result of the gray-scale image segmentation. The middle image shows a graph for the color image. The last two images are, respectively, the input and output of a dilation based on this graph.

One of the most interesting applications using MMach automatic programming has been in the synthesis of an Optical Character Recognition (OCR) prototype that transforms a text image obtained from a scanner into a RTF (Rich Text Format) formatted file [BarreraSalaHash:1996:SOC]. This application is a good illustration of image segmentation and pattern recognition.

The MMach tools have been used extensively to develop morphological applications to image analysis. Some of the major applications have been compiled and have resulted in an hypertext posted on the Web [Banon:1997:MMA]. In this document we can find application examples in the areas of Art, Astronomy, Biology, Cartography, Industrial Inspection, Material Science, Medicine, Remote Sensing, and Vision.

Two indirect results of the AnIMoMat project have been first, the increasing interest for Mathematical Morphology in Brazil, as can be seen in Table 2, and second, the creation of a collection of Web sites dedicated to scientific contributions in the area.

Table 2 shows Brazil at the fifth place just after France where Mathematical Morphology began in the sixties.

The bibliographic references spread over several Web sites have been automatically compiled to form a so-called Bibliographical Mirror deposited in the URLib repository: <dpi.inpe.br/banon/1995/12.08.18.02>. At the present time, almost 900

entries can be found in the Mirror and they can be searched through keywords.

Ultimately, contacts have been made between France and Brazil to organize a common bibliographic database in Mathematical Morphology in order to enrich the current database.

Table 2 - NedStat statistics for the "Mathematical Morphology Digest"
Page-views according to origin.
Statistics from December 21, 1996 to September 17, 1997.
Total number of page-views: 1735.
(Dutch language).

1.	VS Onderwijs	192	11.07 %	31.	Zuid-Afrika	6	0.35 %
2.	Nederland	183	10.55 %	32.	Tsjechië	6	0.35 %
3.	VS Commercieel	154	8.88 %	33.	Groot Britannië	6	0.35 %
4.	Frankrijk	112	6.46 %	34.	Finland	5	0.29 %
5.	Brazilië	110	6.34 %	35.	Hongarije	5	0.29 %
6.	Hong Kong	77	4.44 %	36.	Ierland	5	0.29 %
7.	Duitsland	75	4.32 %	37.	Taiwan	4	0.23 %
8.	Australië	70	4.03 %	38.	Denemarken	4	0.23 %
9.	Netwerk	66	3.8 %	39.	India	4	0.23 %
10.	Japan	61	3.52 %	40.	Indonesië	4	0.23 %
11.	Spanje	59	3.4 %	41.	Verenigde Staten	3	0.17 %
12.	Verenigd Koninkrijk	46	2.65 %	42.	Egypte	2	0.12 %
13.	Russische Federatie	34	1.96 %	43.	Nieuw Zeeland	2	0.12 %
14.	Canada	33	1.9 %	44.	Turkije	2	0.12 %
15.	Zweden	26	1.5 %	45.	Oostenrijk	2	0.12 %
16.	België	24	1.38 %	46.	Costa Rica	1	0.06 %
17.	Mexico	24	1.38 %	47.	Colombia	1	0.06 %
18.	Zuid-Korea	22	1.27 %	48.	Maleisië	1	0.06 %
19.	VS Overheid	21	1.21 %	49.	Estland	1	0.06 %
20.	Italië	19	1.1 %	50.	Argentinië	1	0.06 %
21.	Portugal	18	1.04 %	51.	Zwitserland	1	0.06 %
22.	Polen	14	0.81 %	52.	Puerto Rico	1	0.06 %
24.	Singapore	13	0.75 %	54.	Roemenië	1	0.06 %

25.	Joegoslavië	11	0.63 %	55.	Voormalige USSR	1	0.06 %
26.	Griekenland	10	0.58 %	56.	Thailand	1	0.06 %
27.	VS Militair	10	0.58 %	57.	Koeweit	1	0.06 %
28.	Israel	10	0.58 %	58.	Venezuela	1	0.06 %
29.	Noorwegen	8	0.46 %		Onbekend	139	8.01 %
30.	China	8	0.46 %				

3. Task evaluation

To achieve the project objective, a set of tasks were carried out. Table 3 shows some of them and their resulting work references. The task number is the one defined at project submission time. Numbers beginning with 1 refer to theoretical task, 2 to implementation task, and 3 to application task.

Table 3 - Task versus work reference.

Task	Reference
1.1 Operator Characterization, Representation and Decomposition	Banon:1995:CDF Banon:1995:CTE Banon:1995:CTI Banon:1996:SFO BarreraDoug::RGW BarreraHash::CRW
1.2 Automatic Operator Design	BarreraDougHira:1998:ADO BarreraDougTomi:1997:APB BarreraDoug::RGW CorreaBarrTera:1996:SCL DoughertyBarr:1996:MPL DoughertyBarr:1998:BOF DoughertyBarr:1998:NLFB DoughertyBarr:1998:NLFG DoughertyBarr::PID Oliveira:1997:UAG TomitaBarr:1996:PAM
2.1 MMach 1.2 Implementation	BarreraBanoLotu:1995:MMT LotufoBarrBano:1995:M12
2.2 MMach 2.0 Implementation	LotufoTret:1996:HSM
2.3 MMach 2.1 Implementation	Hirata:1996:FAC
2.5 Granulometry	LotufoTret:1996:III LotufoTret:1996:ISI
2.6 Segmentation	Hirata:1997:SIM HirataBarrLotu:1997:TIS Lotufo:1997:MMK
2.7 MMach 2.2 Implementation	BarreraBanoLotuHira::MMM BarreraHira:1997:FAC BarreraZampLotu:1997:MOC Lotufo:1996:CDM LotufoZampHiraBarr::MFM SantosSant:1996:CBK TaquemasaLotu:1996:ADT
2.8 Operator Design Implementation	Barrera:1997:APM BarreraFerrHash::AGS BarreraHash::CRW BarreraSala:1995:SOC BarreraSala:1996:SOC BarreraSalaHash:1996:SOC BarreraTeraSilvTomi:1996:APM BarreraTomiCorrTera:1995:APB Salas:1996:OCI
3.1 Drainage Segmentation	Candeias:1996:DNE
3.2 Cloud Segmentation	Candeias:1997:AMM
3.3 Control Point Identification	BanonFari:1997:MAT Faria:1997:AMC
3.6 Malignant Non-Hodgkins Lymphomas Analysis	Weber:1997:APC WeberFaco:1997:CMA
3.11 People Segmentation	MoreiraViei:1996:ISP MoreiraViei:1996:UFM
3.12 Character Recognition	BarreraSalaHash:1996:SOC BarreraSilvZampTomiHiraTera:1997:OM O Tomita:1996:LPC
3.13 PCB Inspection	Jamur:1996:PSP JamurFaco:1997:WSP TatibanaLotu:1997:NAP
3.14 Porous Media 3D Analysis	Braga_NetoLotu:1995:MMT
3.16 Left Ventricle Contour Detection	GarconBartFaco:1996:CDF
3.17 Hyphae Segmentation and Measurement	MucheroniReis:1995:MCF MucheroniReis:1996:EMH

Next, we make comments about some of the tasks listed in Table 3.

Task 2.1 is a MMach implementation for KHOROS 2.0. Tasks 2.2 and 2.3 are, respectively, a MMach extended implementation for KHOROS 1.5 and KHOROS 2.0. These implementations were used for a short course during the 95 Brazilian Workshop at UNICAMP and the 96 Brazilian Workshop at USP.

Task 2.6 consisted of a Tutorial on Image Segmentation with KHOROS at the 97 Khoros Conference.

Task 2.7 is the last implementation of the MMach: version 2.2 (for KHOROS 2.0). A manual was written and a short course on Mathematical Morphology with KHOROS 2.1 and MMachLib was given during the 97 Brazilian Workshop at INPE. This task ended with the publication of a paper in the Journal of Electronic Imaging.

Task 3.1 and 3.2 on drainage and cloud segmentation is part of the Ph.D. Thesis by Ana Lúcia Bezerra Candeias.

Task 3.13, on PCB inspection, was carried out by UNICAMP and CEFET. The work by UNICAMP made use of connectivity and influence zone concepts.

Task 3.14 on porous media made use of 3D watershed and is pioneering in Brazil.

The work by Nelson Delfino A. Mascarenhas on Material Science [AylaMasc:1997:SIC, MascarenhasSouzJorg:1996:AMS, MascarenhasSouzJorg:1996:EAT] does not appear in Table 3 because Dr. Mascarenhas joined the project after its submission.

4. Conclusion

The AnIMoMat project results show that Brazil has made a good investment in the direction of image analysis. They place Brazil among the countries that have contributed the most in the area of Mathematical Morphology and that has made the country a candidate for hosting one of the next International Symposium on Mathematical Morphology (ISMM).

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