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Multiprocessor systems: Applications to image and video processing and optimization. SMAPIVO TIC2002-00228

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Abstract

This project deals with the problem of finding efficient solutions for a set of applications requiring intensive computation by using a parallel and/or distributed computing. Applications of this project come from two different research areas where our group has got a great experience. One subset of applications belongs to the image processing field, where new proposal for the 3D reconstruction, segmentation and visualization of 3D scenes, compression, transmission, managing images, etc. problems can only be solved by using multicomputer systems. The second subset of applications is related to the field of Global optimization where many irregular problems arise. They will be treated in two different aspects: a) designing new algorithms with parallel properties and novel accelerating devices, and b) implementing these new algorithms on heterogeneous multicomputer platforms. In this project we also will deal with the set of problems related to progressive image and video transmission.
Keywords: Image processing, Global optimization, image compression, parallel algorithms, load balancing.

1 Project Goals

Globally, the goal of our project consists of searching for efficient and feasible solutions to computationally expensive problems by creating parallel algorithms and experimenting with their implementation on parallel and distributed computers. This project deals with real life applications coming from several fields. All these applications represent a special class of problems characterized by managing *irregular and dynamic* data structures. Efficient parallelizations of these algorithms involve the use of (i) parallel computing on supercomputers or networks of workstations, (ii) sophisticated code optimization techniques, (iii) intelligent use of hierarchical memory systems in the computers and (iv) awareness of communication latencies. From the experience of the design and parallelization of several algorithms, theoretical models for a wide

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set of irregular problems can be designed. This global and general goal can be described by the following specific objectives:

1. **Algorithms for 3D Image Reconstruction and image processing.** This work concerns the analysis of several aspects of 3D Image Reconstruction from Projections problem: (i) We are interested in investigating new iterative algorithms based on the concept of *Blobs* which from a theoretical point of view should produce more accurate results than the traditional *voxel* based methods, and therefore provide visually better reconstructed volumes; (ii) designing a new methodology for testing iterative reconstruction methods and image registration and translational alignment by the use of multidimensional global optimization methods; (iii) developing parallel implementations of these algorithms for 3D image reconstruction from projections which will allow to determine the 3D structure of large volumes in reasonable computation time from the execution on parallel computer architectures. We are interested in finding general parallel strategies which efficiently run on different parallel systems such as a distributed-shared memory multiprocessor or a cluster of processors. In the context of this project, strategies for 2D images have also been analyzed and their parallel version developed and evaluated.

2. **Global Optimization Algorithms.** This part of our project concerns the development of both stochastic and deterministic global optimization algorithms. We study these algorithms from several perspectives: (i) Theoretical, where new techniques are mathematically analyzed; (ii) technical by implementing and evaluating the new algorithms, both sequential and parallel alternatives and (iii) applied by using our methods for solving real life problems.

3. **Matrix Computation and Workload balancing for Parallel Algorithms.** This topic concerns with the study of algorithms which typically work with sparse matrices, so that irregular computations due to the irregularity of the sparse matrices appear. We specifically deal with the eigenvalue-eigenvector problem for huge and sparse matrices from a parallel computing point of view, so proposing new models and strategies for data distribution, studying the workload balance and memory management problems.

4. **Video and Image Compression Transmission.** Our group is interested in developing a modules based software for image and video compression. This software must be able to work as a Lossy and a Lossless compression method, depending on the requirements of the system where it is used. Our interests mainly address to the progressive image transmission based on JPEG 2000 and on the development of new techniques for streaming video over the Internet.

2 Degree of project success

1. **Algorithms for 3D Image Reconstruction and image processing.** We have analyzed the application of blob-based series expansion methods in electron tomography of complex biological specimens, with a special emphasis on the computational perspective. First, we have made use of efficient iterative methods to tackle the problem of image reconstruction. Additionally, high performance computing (HPC) techniques have been

applied to face the high computational demands and take advantage of parallel systems. The new iterative reconstruction methods we have implemented are very efficient, providing least squares solutions in a small number of iterations. In this are, the use of High Performance Computing will allow us to deal with *grand challenge* applications currently unapproachable by uni-processor systems due to the computational resource requirements [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. Parallel implementations of a region growing segmentation algorithm based on the *Split-and-Merge* approach have also been carried out. The region growing problem is representative of a class of irregular problems requiring the use of specific load balancing schemes to achieve efficient parallel implementations. In our parallel approaches we propose and analyze several dynamic load balancing schemes [19].

2. **Global Optimization Algorithms.** Our research deals with two different methods: Deterministic and stochastic global optimization. Our group has been working on both alternatives from four different points of view: (i) mathematical by designing new reliable methods; (ii) technical by implementing and evaluating algorithms; (iii) applied by testing algorithms for real problems and (iv) high performance computing by implementing parallel solutions on multiprocessors. The deterministic global optimization algorithms are based on *Branch and Bound* and *Interval Arithmetic*. Some of our contributions consisted on devising new support functions and selection, subdivision and rejection criteria. The first zero crossing point for a real function and finding the minimal root in a set of multiextremal one-dimensional functions were also studied. Based on our new algorithms, solutions for practical problems such as packing circles in a square, facility location or ray tracing have been analyzed [20, 21, 22, 23, 24, 25]. The stochastic global optimization algorithms we have developed are of a population type. More specifically we have studied and developed new parallel global optimization algorithms and they have been used for solving problems from the field of image processing [26, 27, 28]. Multi-objective meta-heuristics pareto-based algorithms for solving the graph-partitioning problem have also been analyzed [29, 30, 31, 32, 33, 34, 35].

3. **Matrix Computation and Workload balancing for Parallel Algorithms.** We have developed efficient parallel implementations of the eigenproblem of large, symmetric and sparse matrices based on the Lanczos methods for tridiagonalizing matrices. Two different approaches to the eigenproblem have been parallelized: One based on the *Bisection* and the *Inverse Iteration* methods and the other based on the *Divide-and-Conquer* method. Our interest has also been focused on designing data partitions which obtain load balance of both sparse and dense structures, simultaneously. This data distribution problem has been formulated as a Set Partitioning Problem subject to the *uniformity* constraint. Two heuristic strategies for data distribution based on permutations have been proposed: ABO (*Average Based Ordering*) and GPB (*Generalized Pivoting Block*).Both methods include a pre-process stage of low computational cost [36, 37, 38, 39, 40]

4. **Video and Image Compression Transmission.** In this topic of our project, we have introduced a lossless progressive image transmission system (LPIC) based on a specific wavelet transform and the efficient encoding method known as SPIHT for the potential application in telemicroscopy, teleastronomy and telemedicine environments. The performance of the system has been measured by means of a task oriented methodology

that guarantees objective comparisons. In the field of video compression we have studied and tested several methods to improve the scalability features of the compressed data for streaming video systems. [41, 42, 43, 44, 45, 46, 47, 48]

3 Indicators of results

Currently, J.A. Martínez, J.F. Sanjuan, J.A. Álvarez, S. Tabik, R. Baños, M.F. López and J.L. Redondo are working on their PhDs. Most of the results obtained from our research in this project have been published as papers in relevant scientific journals (21 papers) and as chapters of books or proceedings of international conferences (more than 25 articles). Some of our results have been transferred to the industry by a contract for a research project with the firm TEDIAL (Tecnologias Digitales Audiovisuales, S.L.). The objective of this project is to create tools for progressive and lossless image transmission, and decoding DICOM files. In the field of parallelization of 3D image reconstruction from projections we have been working in an international project: *Parallel Computing of 3D Biological Structures and New Methods for Querying Databases* (Convenio de Cooperacion Cientifica y Tecnologica entre España y los Estados Unidos. Ministerio de Asuntos Exteriores). In this project, besides our research group, the CNB (Centro Nacional de Biotecnologia) and the National Center for Microscopy and Imaging Research (university of California) took part. Our group has also been funded by the Ministerio de Asuntos Exteriores for the Hungarian and Spanish cooperation program. The project *Reliable Methods for Global Optimization and its Parallel Implementation* was carried out by our group and the group coordinated by Dr. T. Csendes of the University of Szeged (Hungary). A summary of our cooperation is: **Centro Nacional de Biotecnologia** and **the National Center for Microscopy and Imaging Research** for *parallel computing 3D image reconstruction from projections for biological structures* (see references [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 26, 27, 28, 18]). In the field of Global optimization: **Dept. of Informatics, Univ. of Szeged (Hungary)**, **Univ. della Calabria (Italy)** [20, 21, 22, 23, 24], and **Univ. of Wageningen (The Netherlands)** [45, 46].

References

[1] J.J. Fernández, J.R. Bilbao-Castro, R. Marabini, I. García, and J.M. Carazo. Structure determination of biological specimens by electron microscope tomography and distributed computing. In *Proc. HealthGrid: First European Conference on Grid Computing in Medicine and BioSciences*, pages 66–67, Lyon, France, 2003. poster.

[2] J.J. Fernández, J.R. Bilbao-Castro, R. Marabini, J.M. Carazo, and I. García. Grid computing in structure determination of biological specimens by electron microscope tomography. In *First European Across Grids Conference*, Santiago de Compostela - Spain, 2003. poster.

[3] J.J. Fernández, J.M. Carazo, and I. García. Three-dimensional reconstruction of cellular structures by electron microscope tomography and parallel computing. *Journal of Parallel and Distributed Computing*, 64(2):285–300, In Press.

[4] J.J. Fernández, R. Marabini, J.M. Carazo, and I. García. Biological structure determination by em is well. suited to grid computing. *New Generation Computing (Special Issue on Grid Systems for Life Science)*, 22:187–188, 2004.

[5] J.J. Fernández, J.R. Bilbao-Castro, R. Marabini, J.M. Carazo, and I. García. Grid computing in structure determination of biological specimens by electron microscope tomography. *Lecture Notes in Computer Science (Grid Computing: First European Across Grids Conference)*, 2970:171–181, 2004.

[6] J.J. Fernández, J.R. Bilbao-Castro, R. Marabini, J.M. Carazo, and I. García. On the suitability of biological structure determination by electron microscopy to grid computing. *New Generation Computing*, In press:–, In Press.

[7] J.J. Fernández and S. Li. Anisotropic nonlinear denoising in cryoelectron tomography. In Dirk Van Dyck and Patrick Van Oostveldt, editors, *Proceedings of the thirteenth European Microscopy Congress, EMC 2004*, volume I, pages 423–424, Belgium, 2004.

[8] R. Marabini, C.O.S. Sorzano, S. Matej, J.J. Fernández, J.M. Carazo, and G.T. Herman. 3-D reconstruction of 2-D crystal in real space. *IEEE Transactions on Image Processing*, 13(4):549–561, 2004.

[9] J.R. Bilbao-Castro, J.M. Carazo, J.J. Fernández, and I. García. Parallel and distributed computing for efficient tomographic reconstructions. In *First Joint Meeting RSME-AMS. Session 37, The Mathematics of Electron Microscopic Imaging.*, Sevilla, 2003.

[10] J.R. Bilbao-Castro, J.M. Carazo, I. García, and J.J. Fernández. Phan3D: A 3D design tool for creation of tomographic phantoms. In M.H. Hamsa, editor, *Proceedings of the IASTED International Conference Visualization, Imaging and Image Processing*, volume 1, pages 129–134, Benalmadena (Spain), 2003.

[11] J.R. Bilbao-Castro, J.M. Carazo, I. García, and J.J. Fernández. Parallel iterative reconstruction methods for structure determination of biological specimens by electron microscopy. In *Proceedings of the 2003 IEEE International Conference on Image Processing (ICIP-2003)*, volume 1, pages 565–568, Barcelona (Spain), 2003.

[12] J.R. Bilbao-Castro, J.M. Carazo, J.J. Fernández, and I. García. Performance of parallel 3D iterative reconstruction algorithms. *WSEAS Transactions on Biology and Biomedicine*, 1(1):112–119, 2004.

[13] J.R. Bilbao-Castro, R. Marabini, J.M. Carazo, I. García, and J.J. Fernández. The potential of grid computing in three-dimensional electron microscopy. *Parallel Processing Letters*, 14(2):151–162, 2004.

[14] J.R. Bilbao-Castro, J.M. Carazo, I. García, and J.J. Fernández. Parallelization and comparison of 3D iterative reconstruction algorithms. In *Proceedings of the 12-th Euromicro Conference on Parallel, Distributed and Network based Processing. PDP2004*, pages 96–102, A Coruña, (Spain), 2004. IEEE Press.

[15] J.R. Bilbao-Castro, C.O.S. Sorzano, I. García, and J.J. Fernández. Phan3D: Design of biological phantoms in 3D electron microscopy. *Bioinformatics*, (Accepted June 17, 2004).

[16] J.R. Bilbao-Castro, J.M. Carazo, I. García, and J.J. Fernández. Performance evaluation of parallel 3d reconstruction algorithms from electron microscopy projections. In *Proceeding of the 6th international meeting VECPAR-04, High Performance Computing for Computational Science*, volume III, pages 887–900, Valencia, Spain, 2004.

[17] P.C. Fritzsche, J.J. Fernández, A. Ripoll, I. García, and E. Luque. Performance prediction model for tomographic reconstruction in structural biology. In *Proceeding of the 6th international meeting VECPAR-04, High Performance Computing for Computational Science*, volume I, pages 147–160, Valencia, Spain, 2004.

[18] J.A. Velazquez-Muriel, C.O.S. Sorzano, J.J. Fernández, and J.M. Carazo. A method for estimating the CTF in electron microscopy based on arma models and parameter adjustment. *Ultramicroscopy*, 96(1):17–35, 2003.

[19] M.D. Gil Montoya, C. Gil, and I. García. The load unbalancing problem on the region growing image segmentation algorithms. *Journal of Parallel and Distributed Computing*, 63:387–395, 2003.

[20] L.G. Casado, I. García, J.A. Martínez, and Ya. D. Sergeyev. New interval analysis support functions using gradient information in a global minimization algorithm. *Journal of Global Optimization*, 25(4):345–362, April 2003.

[21] L. G. Casado, I. García, T. Csendes, and V.G. Ruíz. Heuristic rejection in interval global optimization. *Journal of Optimization Theory and Applications (JOTA)*, 118(1):27–43, July 2003.

[22] J. A. Martínez, L. G. Casado, I. García, and B. Tóth. AMIGO: Advanced multidimensional interval analysis global optimization algorithm. In C.A. Floudas and P.M. Pardalos, editors, *Nonconvex Optimization and Applications Series. Frontiers in Global Optimization*, volume 74, pages 313–326. Kluwer Academic Publishers, 2004.

[23] J.A. Martínez, L.G. Casado, I. García, Ya.D. Sergeyev, and B. Tóth. On an efficient use of gradient information for accelerating interval global optimization algorithms. *Numerical Algorithms*, In press:–, 2004.

[24] J.A. Martinez, L.G. Casado, J.A. Alvarez, and I. García. Interval parallel global optimization with Charm++. In Technical University of Denmark, editor, *Proceedings of the Workshop on state of the art in scientific computing. PARA'04*, pages 93–99, 2004.

[25] J.F. Sanjuan-Estrada, L.G. Casado, and I. García. Reliable algorithms for ray intersection in computer graphics based on interval arithmetic. *Proceedings of the XVI Brazilian Symposium on Computer Graphics and Image Processing (SIBGRAPI 2003)*, pages 35–42, Sao Carlos. Brazil, 2003. IEEE Computer Society Press.

[26] J.L. Redondo, P.M. Ortigosa, I. García, and J.J. Fernández. Image registration in electron microscopy. a stochastic optimization approach. *Lecture Notes in Computer Science, Vol. 3212, Proceedings of the International Conference on Image Analysis and Recognition, ICIAR 2004*, 3212(II):141–149, 2004.

[27] J.L. Redondo, J.J. Fernández, I. García, and P.M. Ortigosa. Application of an evolutionary algorithm to image alignment. In Le Thi Hoai An and Pham Dinh Tao, editors, *Modelling, computation and optimization in information systems and management sciences*, pages 661–668, London, 2004. Hermes Science Publishing.

[28] J.L. Redondo, P.M. Ortigosa, I. García, and J.J. Fernández. A global optimization approach to image translational alignment in electron microscopy. *Proceedings of the 2004 IEEE International Conference on Systems, Man and Cybernetics, IEEE SMC 2004*, pages 4485–4490, The Hague (The Netherlands), October 2004.

[29] R. Baños, C. Gil, M.G. Montoya, and J. Ortega. A parallel evolutionary algorithm for circuit partitioning. In *Proceedings of the 11th Euromicro Workshop on Parallel and Distributed Processing.PDP2003*, pages 365–371. IEEE Computer Society Press, 2003.

[30] R. Baños, C. Gil, J. Ortega, and F.G. Montoya. Multilevel heuristic algorithm for graph partitioning. In *3rd European Workshop on Evolutionary Computation in Combinatorial Optimization*, pages 143–153. Lecture Notes in Computer Science, Vol. 2611, 2003.

[31] R. Baños, C. Gil, J. Ortega, and F.G. Montoya. Optimising graphs partitions using parallel evolution. In *Proceedings of the 6th International Conference on Artificial Evolution (EA'03)*, pages 119–130, Marseille, France, 2003.

[32] R. Baños, C. Gil, J. Ortega, and F.G. Montoya. Parallel heuristic search in multilevel graph partitioning. In *Proceedings of the 12th Euromicro Conference on Parallel, Distributed and Network based Processing. PDP2004*, pages 88–95, A Coruña, (Spain), 2004. IEEE Press.

[33] R. Baños, C. Gil, J. Ortega, and F.G. Montoya. A parallel multilevel metaheuristic for graph partitioning. *Journal of Heuristics*, 10:315–336, 2004.

[34] R. Baños, C. Gil, J. Ortega, and F.G. Montoya. Optimising graph partitions using parallel evolution. *Lecture Notes in Computer Science. Artificial Evolution*, 2936:91–102, 2004.

[35] R. Baños, C. Gil, M.G. Montoya, and J. Ortega. A new pareto-based algorithm for multi-objective graph partitioning. *Lecture Notes in Computer Science. Computer and Information Sciences-ISCIS 2004*, 3280, 2004.

[36] E. M. Garzón, S. Tabik, I. García, and A.R. Bretones. Multiprocessing of the time domain analysis of thin-wire antennas and scatterers. In *Proceedings of the 12-th Euromicro Conference on Parallel, Distributed and Network based Processing. PDP2004*, pages 80–87, A Coruña, (Spain), 2004. IEEE Press.

[37] E.M. Garzón and I. García. Solving eigenproblems on multicomputers: Two different approaches. *International Journal of Computers and Applications*, 26(4):213–222, 2004.

[38] E.M. Garzón and I. García. Value based data distributions for sparse matrices on multiprocessor systems: Two approaches based on permutations. *Journal of Supercomputing*, In Press.

[39] E.M. Garzón, S. Tabik, A. R. Bretones, and I. García. Analysis of the interaction of electromagnetic signals with thin-wires structures. multiprocessing issues for an iterative method. In *Proceeding of the 6th international meeting VECPAR-04, High Performance Computing for Computational Science*, volume II, pages 513–524, Valencia, Spain, 2004.

[40] J.A. Alvarez, J. Roca, J.C. Ortega, and I. García. Object cluster computing advantages of object oriented load balancing strategies. In *Proceedings of the IADIS International Conference Applied Computing 2004*, pages 147–150, Lisbon, Portugal, 2004.

[41] J.P. Ortiz, V.G. Ruiz, and I. García. Improving web proxy caching on browsing JPEG2000 remote images with JPIP. *WSEAS Transactions on Information Science and Application*, 1(1):167–172, 2004.

[42] J.P. García-Ortiz, V.G. Ruiz, and I. García. Remote browsing of JPEG 2000 images on the web: Evaluation of existing techniques and a new proposal. In Juan J. Villanueva, editor, *Proceedings of the Fourth IASTED International Conference on Visualization, Imaging, and Image Processing*, pages 854–859. Acta Press, September 2004.

[43] J.P. García-Ortiz, V.G. Ruiz, and I. García. Improving the remote browsing of JPEG 2000 images on the web. In Juan J. Villanueva, editor, *Proceedings of the Fourth IASTED International Conference on Visualization, Imaging, and Image Processing*, pages 890–895. Acta Press, September 2004.

[44] V.G. Ruiz, J.J. Fernández, M.F. López, and I. García. A rigorous evaluation of progressive image transmission methods for telemicroscopy of biological specimens. In M.H. Hamsa, editor, *Proceedings of the IASTED International Conference Visualization, Imaging and Image Processing*, volume 1, pages 281–286, Benalmadena (Spain), 2003.

[45] V.G. Ruiz, M.F. López, I. García, and E.M.T. Hendrix. Improving MPEG-2 through JPEG 2000. In M.H. Hamsa, editor, *Proceedings of the IASTED International Conference Visualization, Imaging and Image Processing*, volume 1, pages 287–290, Benalmadena (Spain), 2003.

[46] V.G. Ruiz, M.F. López, I. García, and E.M.T. Hendrix. JPEG 2000 vs. JPEG in MPEG encoding. In *Proceedings of the First International Workshop on Interactive Rich Media Content Production: Architectures, Technologies, Applications, Tools*, pages 61–67, Lausanne, Switzerland, 2003.

[47] V.G. Ruiz, J.J. Fernández, M.F. López, and I. García. Wavelet-based vs. DCT-based progressive compression of biological specimens images. In *Proceedings of the First International Workshop on Interactive Rich Media Content Production: Architectures, Technologies, Applications, Tools*, pages 89–95, Lausanne, Switzerland, 2003.

[48] V.G. Ruiz, J.P. García-Ortiz, J.J. Fernández, J.M. Carazo, and I. García. Progressive image transmission in telemicroscopy. In Dirk Van Dyck and Patrick Van Oostveldt, editors, *Proceedings of the thirteenth European Microscopy Congress, EMC 2004*, volume I, pages 395–396, Belgium, 2004.