Crossgrid – Development Of Grid Environment For Interactive Applications

Marian Bubak(1,2), **Jesus Marco**(3), **Holger Marten**(4), **Norbert Meyer**(5), **Marian Noga**(2), **Peter A.M. Sloot**(6) **and Micha_ Tura_a**(7,2)

(1) Institute of Computer Science, AGH, al. Mickiewicza 30, 30-059 Kraków, Poland
(2) Academic Computer Centre – CYFRONET – AGH, ul. Nawojki 11, 30-950 Kraków, Poland
(3) Consejo Superrior de Investigaciones Cientificas, Spain
(4) Forschungszentrum Karlsruhe GmbH, Central Information and Communication Technologies Department, Karlsruhe, Germany
(5) Pozna_ Supercomputing and Networking Center, Institute of Bioorganic Chemistry PAS, Pozna_, Poland
(6) Faculty of Science, Universiteit van Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands
(7) The Henryk Niewodnicza_ski Institute of Nuclear Physics, High Energy Physics Department, Kraków, Poland

ABSTRACT: *The CrossGrid project will develop, implement and exploit new Grid components for interactive compute and data intensive applications like simulation and visualisation for surgical procedures, flooding crisis team decision support systems, distributed data analysis in high-energy physics, air pollution combined with weather forecasting. The elaborated methodology, generic application architecture, programming environment, and new Grid services will be validated and tested thoroughly on the CrossGrid testbed, with an emphasis on a user friendly environment. The work will be done in close collaboration with the Grid Forum and the DataGrid project to profit from their results and experience, and to obtain full interoperability. The primary objective of this Project is to further extend the Grid environment to a new category of applications of great practical importance, and into 11 new European countries.*
KEYWORDS: *Grid computing, interactive applications, near real-time, testbed, middleware, ASP, tools, visualization, HPC, HPV*

The work supported in part by the European Union IST Commission, Contract No. IST-2001-32243

Introduction

The essential novelty of this Project consists in extension of the Grid to a completely new and societally important category of applications. The main features of these are the presence of a person in a processing loop, and a requirement for real-time response from the computer system. Moreover, these applications are at the same time compute- and data-intensive. Generic applications were selected: interactive simulation and visualisation for surgical procedures, flooding crisis team decision support systems, distributed data analysis in high-energy physics, and air pollution combined with weather forecasting. A visualisation engine will be developed and optimised for these applications. The components of the CrossGrid Project and their relation to other Grid projects are presented in Fig.1.

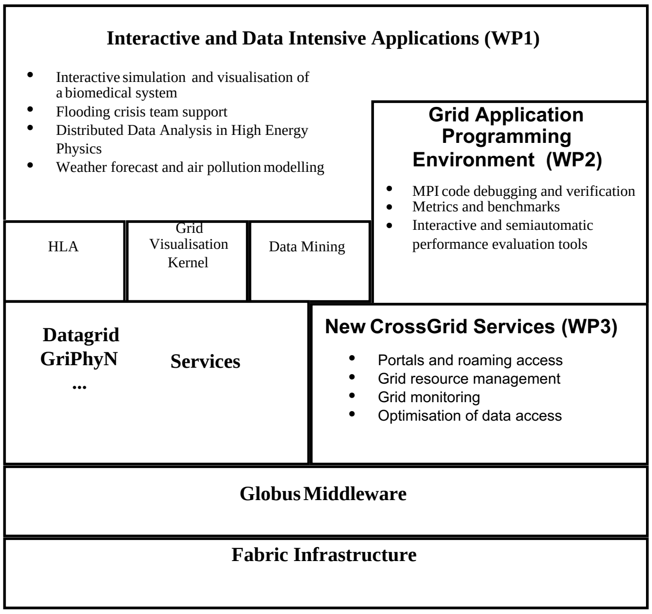


Fig. 1. Basic components of the CrossGrid Project

The new methodology, generic application architecture, programming environment, and new Grid services will be validated and tested thoroughly on the CrossGrid testbeds. This will result in further extension of the Grid across Europe into 11 new countries.

The Project is split into 5 workpackages:

- WP1 CrossGrid Application Development, WP2 Grid Application Programming Environments, WP3 New Grid Services and Tools, which will develop specific well-defined parts of different applications and GRID middleware.
- WP4 International Testbed Organisation will collect all of the developments from the workpackages WP1-3 and integrate them into successive software releases. It will also gather and transmit all feedback from the end-to-end application experiments back to the developers, thereby linking development, testing, and user experience.
- WP5 Project Management will ensure the active dissemination of the project results and its professional management.

Each of the development workpackages will start with a user-requirement gathering phase, followed by an initial development phase before delivering early prototypes to the testbed workpackage. Following the delivery of these prototypes a testing and refinement phase will continue for each component until the end of the Project.

CrossGrid Application Development

The objectives of this workpackage are to provide a representative collection of sample applications from various fields that will drive and exploit the specific (interactive) functionalities to be developed in the CrossGrid project. Firstly, through their need for specific services and their performance characteristics, they will provide a driving force for the technology-oriented workpackages. Secondly, they will serve as a benchmark for the performance of these workpackages, and finally, they will serve as demonstrators, for their respective fields, of the added value provided by the Grid in general, and the technology developed by the CrossGrid project in particular. Each task in this workpackage will focus on the development of one of these applications. Together, they cover a wide range of final user communities, from health care to environment management, and basic research.

Task 1.1 Interactive simulation and visualisation of a biomedical system

In Task 1.1 we develop a Grid-based prototype system for pre-treatment planning in vascular interventional and surgical procedures through real-time interactive simulation of vascular structure and flow. The system will consist of a distributed real-time simulation environment, in which a user interacts in Virtual Reality (VR). A 3D model of the arteries, derived using medical imaging techniques, will serve as input to a real-time simulation environment for blood flow calculations. The results will be presented in a specially designed virtual reality environment. The user will also be allowed to change the structure of the arteries, thus mimicking an interventional or surgical procedure. The effects of this adaptation will be analysed in real time and the results will be presented to the user in the virtual environment (Fig. 2).

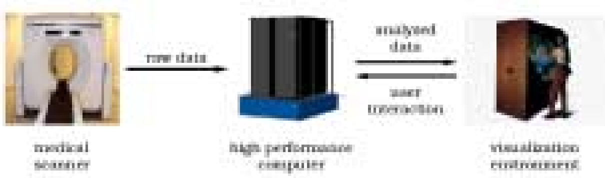


Fig. 2. Experimental set-up of interactive bio-medical simulation and visualisation

Simultaneous visualisation clients may be activated anywhere on the Grid, with the possibility of multiple clients operating on different kinds of output devices. Therefore, the connection between the server application and the visualisation client faces several problems, such as a limited and varying bandwidth, the possibility of communication failures, and the dynamics of the Grid environment itself.

The challenges in this task will be: distribution of source data, distributed simulation and visualisation tasks, near real-time response, virtual time management, simulation/visualisation rollback due to user actions, and VR visualisation. In the area of performance management, use will be made of the results of the Dynamite project [Iskra2001] and of the performance tools developed in WP2. To support the distributed interactive simulations, use will be made of the concepts and techniques provided by the High Level Architecture (HLA) [HLA1999]. The parallel simulation code will internally use MPI. The system will build upon current work at the UvA on interactive visualisation and simulation and on lattice-Boltzmann simulations of vascular blood flow [Belleman2000].

Task 1.2 Flooding crisis team support

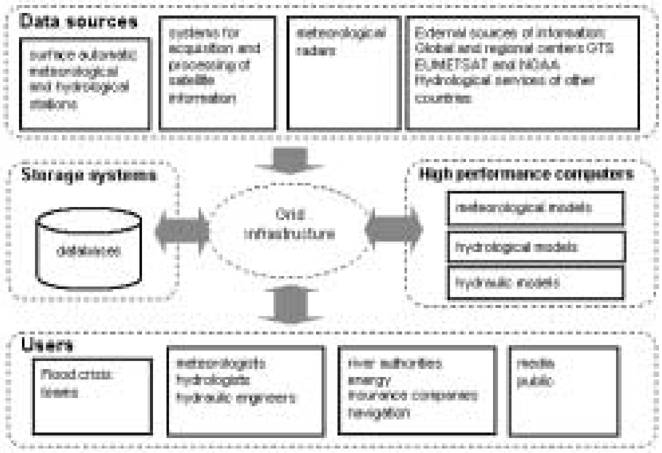
This task will develop a support system for establishment of a Virtual Organisation (VO) associating a set of individuals and institutions involved in flood prevention and protection, and integrating the most advanced techniques in data sampling, data processing, data transfer, data management and Grid technology (Fig. 3). Grid technology will enable co-operation between flood crisis teams on international rivers. The kernel of this task is numerical flood modelling that uses an appropriate physical model and robust numerical schemes for a good representation of reality. Realistic simulations of large problem sizes are computationally challenging but need to be performed on short time-scales in crisis situations [Hluchy2001a, Hluchy2001b, Hluchy2001c]. The system to be developed in this task will employ a Grid technology to seamlessly connect together the experts, data and computing resources needed for quick and correct flood management decisions. The final aim is to be able to work in real-time. This will also require the timely transfer of individual new precipitation events (e.g. evaluated from the meteorological radar monitoring).

Fig. 3. Support system for Virtual Organisation for Flood Prevention and Protection

Task 1.3 Distributed Data Analysis in High Energy Physics

In Task 1.3 we aim to develop final user applications for physics analysis running in a distributed mode in a GRID-aware environment using large distributed databases. They will be used in the high-energy physics field, the main focus being future LHC experiments (ALICE, ATLAS, CMS and LHCb). Next generation experiments in HEP will require unprecedented computing resources for physics analysis [LHCC2001]. Hundreds of physicists around the world will collaborate in the analysis of Peta bytes of data stored in distributed databases. Most of the experiments are adopting a model for distribution of these databases, such as the MONARC model proposed for LHC computing, proposing tiered data and computing centres. The DataGrid project will provide a file-level service, based on replication, for access to these databases, including transparent user access that accommodates distributed simulation and reconstruction requirements. For the final interactive user analysis, however, an object-level service is also required, to optimise the use of the resources.

The task will address several challenging points:



access to large distributed databases in the Grid environment, development of distributed data-mining techniques suited to the HEP field, definition of a layered application structure, flexible enough to adapt to different experimental set-ups, and integration of user-friendly interactive access, including specific portal tools.

Task 1.4 Weather forecast and air pollution modelling

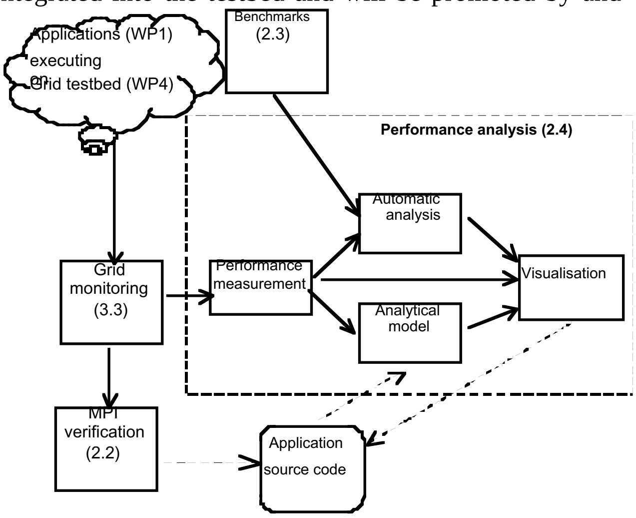
Atmospheric applications require large computational power and fast access to large data sets stored in geographically distributed archives. We plan to develop a data mining system for the analysis of the archive of operational data from a mesoscale model (in volume 32 GB) and meteorological reanalysis DBs which includes homogeneous meteorological information from a single numerical weather prediction model integrated over decades (in the order of Tera bytes). Data mining techniques, including association rules, linear and non-linear correlation methods, and neural nets (Self-Organised Maps SOM), will be developed for extracting interesting patterns (clusters) or trends (spatial and temporal correlations and tele-connections) within the DB.

Air pollution chemistry models need to solve tens to hundreds of gas-phase chemical reactions, coupled to the air pollution transport. Gas-phase chemistry is a heavy task for personal computers and aqueous chemistry and scavenging processes add more complexity to the problem, so parallel systems should be applied for a reasonable response time. We propose to consider the Sulphur Transport Eulerian Model 2 (STEM-II) as a first approach to develop a GRID based code, although we can focus on other models.

Grid Application Programming Environment

The aim of this workpackage is to specify, develop, integrate and test tools that facilitate the development and tuning of parallel distributed high-performance and high-throughput computing applications on Grid infrastructures.

Verifying that user applications comply with the MPI standards will reduce the need for debugging sessions on the Grid environment. This workpackage will develop a debugging and verification tool for MPI programs. Efficiently using the Grid as an environment for large applications requires job performance measurement and analysis [Bubak, 2001]. In this workpackage, an on-line tool will be developed that analyses the performance of Grid applications and graphically presents the results. Besides a pure performance measurement module, the tool will include an automatic analysis component [Fahringer, 2000; Dikaiakos, 1998] that assesses the measured performance according to the performance capabilities of the Grid infrastructure. In addition, the tool will support performance prediction for selected application kernels based on analytical performance models. The workpackage will develop benchmarks that model workloads typical of Grid applications of interest. These benchmarks should capture and isolate performance characteristics of the Grid, with respect to processing power, data throughput, synchronisation, communication and I/O overhead, etc. Benchmarks will allow identification of important factors that affect application performance, and provide application developers with initial performance estimates. In addition, benchmark results are an input to the automatic analysis component in the performance analysis tool, which will help application developers to analyse the system at various granularity levels, from the Grid level down to the process level which finally allows them to tune their applications for optimal Grid performance.The tools developed in this workpackage will interoperate [Wismueller, 2000] and be integrated into the testbed and will be promoted by and tested with the real end-user applications of WP1.



The component structure of the programming environment, as well as its relations to the other workpackages in the project is presented in Fig. 4. Solid arrows denote interactions between software components, dashed ones indicate manual or semiautomatic steps. Numbers in parenthesis identify the workpackage and task related to a component.

Fig. 4. Relations between tasks of WP2 and other WPs of the CrossGrid Project

New Grid Services and Tools

The main objective of this workpackage is to develop Grid services and a software infrastructure required to support the Grid users, applications and tools as defined in the workpackages WP1 and WP2. This workpackage includes a set of tools and services, which will define (also including the results of WP2) the middleware layer of the CrossGrid project. The development in WP3 will use and take into account the current and future state of the art. We will also follow the GRID standards which are the subject of the Global Grid Forum meetings [GGF,GGFU,GGFD]. We are aware of other Grid projects, like DataGrid (concerning especially workpackages developing the Grid middleware) or EuroGrid under the subject access points to applications. Therefore, our goal is also to assure the compatibility with the middleware developed within the aforementioned and other projects.

The subject of Task 3.1 is to establish a user friendly Grid environment by portal access to the Grid independently from the user location [Pitoura, 1997; Bethel, 2000]. This task includes two major subtasks. The first subtask will allow one to access applications via portals, which will support the users directly by simplifying the handling of applications. The second subtask will create a mechanism allowing one to enter the Grid environment at any place and from any hardware (independently of the type of the operating system) with the same previously used user’s environment. This is a new approach, currently not developed in any other project. Task 3.2 addresses the construction of new resource management techniques, namely the design and evaluation of self-adaptive scheduling agents that will be responsible for scheduling parallel applications submitted to a Grid with the goal to achieve a reasonable trade-off between the efficiency of resource usage and application speedup according to the user’s optimisation preferences [Berman, 1998; Casanova, 1999; Heymann, 2001]. In Task 3.3 we propose to develop a prototype infrastructure for the needs of monitoring-related activities for automatic extraction of high level performance properties and for tool support of performance analysis (as described in the workpackage WP2) [Bubak, 2000]. We also propose to build a tool for monitoring network infrastructure. Another aspect of the Grid performance will be solved in Task 3.4. In order to help users in their interaction with large data manipulation, we propose a kind of expert system which will operate as an advisor for the selection of migration/replication policy in a particular environment. Within this task a common middleware for fast tape file access [Slota, 2000] and a system for data access time estimation will also be developed [Nikolow, 2001].

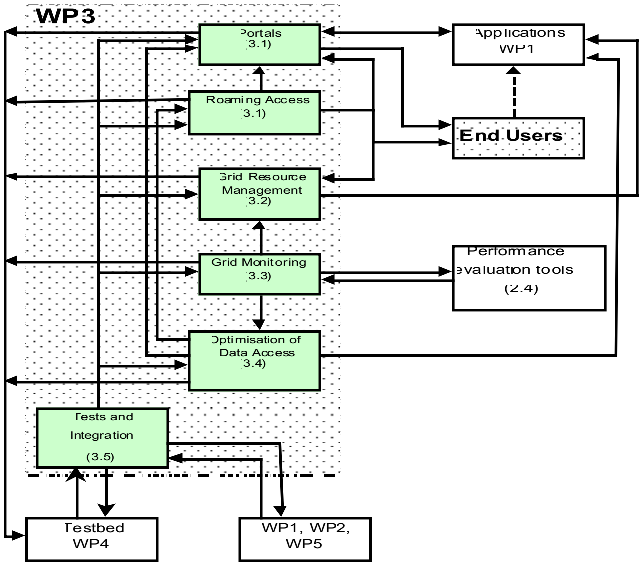


Fig. 5. Relation between WP3 and other WPs of the CrossGrid

International Testbed Organisation

The international testbed is a key component of the CrossGrid Project, as it will provide the framework to run the applications in a realistic GRID environment. In particular, organisational issues and performance and security aspects, including among others the network support, may only be evaluated with the help of a testbed relying on a high-performance network (which will be provided as the result of the Géant project), thereby assuring the participation of an adequate number of computing and data resources distributed across Europe. The main objectives of this workpackage are to:

- provide a distributed resource facility where the different WP developments can be tested on a Grid,
- support the construction of testbed sites across Europe, integrating national facilities provided by the involved partners into the CrossGrid framework,
- monitor the network support required in the testbed set-up, and establish the required links with the corresponding network providers,
- integrate the basic middleware software developed or required in the different WP tasks,
- assure the required level of interoperability with other Grid testbeds, firstly with the DataGrid testbed,
- coordinate in practice the software releases that should provide the appropriate documentation and support for the installation across the distributed sites. In particular, assure that GRID applications from WP1 will run in the corresponding setup.

CrossGrid testbed sites will be placed in 16 different institutions distributed across 9 European countries, expanding the Grid community to these countries.

Project Management

The CrossGrid Project is large taking into account the number of participating institutions and the number of European countries where the Grid will be spread out. An important positive factor is that all CrossGrid Project participants have very good experience of large international research collaborations, so we are sure the Project will have a considerable impact on the research community in Europe. At the same time we are aware of the possible managerial problems.

The Project Management (PM) will consist of:

- a Project Coordinator (PC) accompanied by the Project Secretary (PS) responsible for representation of the Project at the EU Brussels office, efficient long-term and daily administration of the Project, contacts with partners, conflict solving, and reporting,
- a CrossGrid Architecture Team (AT), responsible for technical co-ordination.
- The technical co-ordination will focus on:
- definition of the overall CrossGrid architecture,
- establishing the rules for component transfer from other Grids and integration into CrossGrid,
- selection of appropriate software engineering development methodologies,
- definition of measures necessary for interoperability with other Grids,
- definition of quality assurance criteria and procedures,
- reviewing of the technical progress of the Project.

The above-mentioned actions will be elaborated by the Architecture Team (AT) and then accepted by the Project Steering Group (PSG).

The Consortium

1. CYFRONET Academic Computer Centre of the University of Mining and Metallurgy, Kraków, Poland, is the coordinating partner (leader of the WP5), and contributes to the programming environment (WP2), grid services and tools (WP3) and testbeds (WP4).

2. The Interdisciplinary Centre for Computational and Mathematical Modelling, Warsaw, Poland, coordinates the air pollution applications (WP1) and contributes to the testbed developments (WP4).

3. The Institute of Nuclear Physics, Kraków, Poland, contributes to the HEP applications (WP1) and the testbed developments (WP4).

4. The Institute for Nuclear Studies, Warsaw, Poland, contributes to HEP applications (WP1) and the testbed developments (WP4).

5. The Universiteit van Amsterdam, The Netherlands, is coordinating the workpackage on applications (WP1). It is responsible for the medical applications (WP1).

6. The Institute of Informatics, Bratislava, Slovakia, is responsible for the development of flood prediction applications (WP1).

7. The University of Linz, Austria, is responsible for the development of visualisation software (WP1).

8. Forschungzentrum Karlsruhe, Germany, coordinates the workpackage on the development of programming environment (WP2), and contributes to the

testbed developments (WP4) as well as to the implementation of the HEP application (WP1).

9. HLRS Stuttgart, Germany, contributes to the development of programming environment (WP2).

10. Technische Universität München, Germany, contributes to the development of programming environment (WP2).

11. Pozna_ Supercomputing and Networking Center, coordinates and contributes to the workpackage on grid services and tools (WP3), and contributes to the testbed developments (WP4) as well as deployment of applications (WP1).

12. The University of Cyprus, contributes to the development of programming environment (WP2) and the testbed developments (WP4).

13. DATAMAT, Rome, Italy, contributes to the development of new services and tools (WP3) and to central dissemination (WP5).

14. Trinity College Dublin, Ireland, contributes to the development of new grid services and tools (WP3) and testbed developments (WP4).

15. CSIC Santander, Valencia and Madrid, Spain, coordinates the workpackage on testbeds (WP4). It is responsible for the HEP applications (WP1), and contributes to the programming environment (WP2).

16. The University Autonoma of Barcelona, Spain, contributes to the development of HEP applications (WP1), grid services and tools (WP3), and the testbed development (WP4).

17. The University Santiago de Compostela, Spain, contributes to the air pollution applications (WP1), programming environment (WP2) and testbed developments (WP4).

18. NCRS "DEMOKRITOS", Athens, Greece, contributes to the testbed developments (WP4).

19. The Aristotle University of Tessaloniki, Greece, contributes to the testbed developments (WP4) and the dissemination (WP5).

20. LIP, Lisbon, Portugal, contributes to the testbed developments (WP4).

21. Algosystems S.A., Athens, Greece. It works on dissemination (WP5), and contributes to the development of grid services and tools (WP3)

References

[Belleman2000]
R.G. Belleman and P.M.A. Sloot: The Design of Dynamic Exploration Environments for Computational Steering Simulations, in M. Bubak; J. Moscinski and M. Noga, editors, Proceedings of the SGI Users' Conference 2000, pp. 57-74, Academic Computer Centre CYFRONET AGH, Krakow, Poland, October 2000, ISBN 83-902363-9-7.

[Berge1997]
Berge, E. Transboundary Air Pollution in Europe. MSC-W Status Report 1997. Part 1 and 2 EMEP/MSC-W Report 1/97. The Norwegian Meteorological Institute, Oslo, Norway, 1997. http://www.emep.int.

[Berman, 1998]
F. Berman, R. Wolski, S. Figueira, Jennifer Schopf and G. Shao, "Application-Level Scheduling on Distributed Heterogeneous Networks", Proc. of Supercomputing'96.

[Bethel, 2000]
W.Bethel, B.Tierney,J.Lee, Using High-Speed WANs and Network Data Caches to Enable Remote and Distributed Visualization, SC2000 conference materials, Dallas 2000

[Bubak, 2000]
Bubak, M., Funika, W., _bik, D., van Albada, D., Iskra, K., Sloot, P., Wismueller, R., and Sowa-Pieklo, K.: Performance Measurement, Debugging and Load Balancing for Metacomputing, The 1st European GRID Forum Workshop, Poznan, April 12-13, 2000, Proc. of ISThmus 2000 -- Research and Development for the Information Society, pp. 409-418, Poznan, 2000.

[Bubak, 2001]
Bubak, M., Funika, W., Balis, B., and Wismueller, R.: On-line OCM-based Tool Support for Parallel Applications. In: Yuen Chung Kwong (ed.): Annual Review of Scalable Computing, Vol.3, Chapter 2, pp. 32-62, World Scientific Publishing, Singapore, 2001.

[Carmichael, 1986]
Carmichael, G.R., Peters, L.K., Kitada, T. A second generation model for regional-scale transport/chemistry/deposition. Atmospheric Environment, 20, pp. 173-188, 1986.

[Casanova, 1999]
H. Casanova, M. Kim, J. S. Plank and J. Dongarra, "Adaptive scheduling for task farming with Grid middleware", International Journal of Supercomputer Applications and High-Performance Computing, pp. 231-240, Volume 13, Number 3, Fall 1999.

[CCAFor]
CCA Forum: http://www.acl.lanl.gov/cca/

[Dikaiakos, 1998]
Dikaiakos, M., Rogers, A., and Steiglitz, K.: Performance Modeling through Functional Algorithm Simulation. In: Zobrist, G., Bagchi, K., and Trivedi, K. (eds): Advanced Computer System Design, Chapter 3, pp. 43-62, Gordon & Breach Science Publishers, 1998.

[Fahringer, 2000]
Fahringer, T., Gerndt, M., Riley, G., and Treff, J.L. : Specification of Performance Problems in MPI-Programs with ASL. International Conference on Parallel Processing (ICPP'00), pp 51-58, 2000.

[Gancio2001]
The DataGrid Architecture Version 1, G.Cancio et al., presented in the European DataGrid Conference, Amsterdam, 7 March 2001.

[GGF]
Global Grid Forum http://www.gridforum.org

[GGFD]
Remote Data Access Working Group http://www.sdsc.edu/GridForum/RemoteData/

[GGFU]
Grid Forum User Services Working Group http://dast.nlanr.net/GridForum/UserServ-WG/

[Gropp1994]
William Gropp and Ewing Lusk and Anthony Skjellum. USING MPI Portable Parallel Programming with the Message-Passing Interface.

The MIT Press. Cambridge Massachusetts and London England. 1994.

[Heymann, 2001]
E. Heymann, M. A. Senar, E. Luque and M. Livny, "Self-Adjusting Scheduling of Master-Worker Applications on Distributed Clusters", Proc. of EuroPar Conference, , Manchester, UK, 2001.

[HLA]
HLA: http://hla.dmso.mil/

[HLA1999]
Defense Modeling and Simulation Office, Dept. of Defense (USA), High Level Architecture Run Time Infrastructure, 1999 http://hla.dmso.mil/.

[Hluchy2001a]
L. Hluchy, V.D. Tran, J. Astalos, M. Dobrucky: Parallel numerical solution for flood modeling systems. Parallel Processing and Applied Mathematics PPAM'2001, Naleczow, Poland, September 2001. To appear.

[Hluchy2001b]
L. Hluchy, G. T. Nguyen, L. Halada, V. D. Tran: Parallel Flood Modeling, Parallel Computing PARCO'2001, Naples, Italy, September 2001. To appear.

[Hluchy2001c]
L. Hluchy, V. D. Tran, G. T. Nguyen: Cluster Computation for Flood Simulations. High-Performance Computing and Networking HPCN'2001, pp. pp. 425-434, Amsterdam, The Netherlands, June 2001.Lecture Notes on Computer Sciences 2110, Springer Verlag. ISBN 3-540-42293-5. ISSN 0302-9743.

[IEEE828]
IEEE Standard for Software Configuration Management Plans. IEEE Std 828-1998

[IEEE1058]
IEEE Standard for Software Project Management Plans. IEEE Std 828-1998.

[Iskra2000]
K.A. Iskra; F. van der Linden; Z.W. Hendrikse; B.J. Overeinder; G.D. van Albada and P.M.A. Sloot: The implementation of Dynamite - an environment for migrating PVM tasks, Operating Systems Review, vol. 34, nr 3 pp. 40-55. Association for Computing Machinery, Special Interest Group on Operating Systems, July 2000.

[Kalas1998]
Kalas M., K. Szefler (1998) The test of application of the WAM model for the wind wave forecasting of the Baltic Sea. Bull. Maritime Inst. 25 No 2, 73-82.

[Kalas1999]
Kalas M., B. Jakubiak (1999) Assessment of numerical wind forecasts for the Gdansk Bay area during the POLRODEX'97 experiment. Bull. Maritime Inst. 26 No 1, 13-25.

[LHC2001]
Report of the Steering Group of the LHC Computing Review, CERN/LHCC/2001-004

[Mellor1998]
Mellor, G. L., 1998: User's guide for a three-dimensional, primitive equation, numerical ocean model, 41 pp., Prog. in Atmos. and Ocean. Sci, Princeton University.

[Mouriño2001a]
J. C. Mouriño, D. E. Singh, M. J. Martín, F. F. Rivera, R. Doallo and J. D. Bruguera. The STEM-II Air Quality Model on a Distributed Memory System. Proc. Workshop on High Performance Scientific and Engineering computing with Applications (HPSECA-2001) in conjunction with the International Conference on Parallel Processing (ICPP-2001) . Valencia, Spain. (2001)

[Mouriño2001b]
J.C. Mouriño, D.E. Singh, M.J. Martin, J.M. Eiroa, F.F. Rivera, R. Doallo, J.D. Bruguera, Parallelization of the STEM-II air quality model, pp.543-550 in L.O. Hertzberger; A.G. Hoekstra and R.D. Williams: Proceedings High-Performance Computing and Networking (HPCN Europe 2001), Amsterdam, The Netherlands, in series Lecture Notes in Computer Science, vol. 2110, Springer Verlag, 2001. ISBN 3-540-42293-5.

[Niezgodka1998]
Niezgodka M., B. Jakubiak, 1998: Numerical weather prediction system: Scientific and operational aspects. Proceedings of the III Symposium on Military meteorology, 191-197.

[Nikolow, 2001]
Nikolow, D., Slota, R., Kitowski, J., Benchmarking Tertiary Storage Systems with File Fragmentation, PPAM'2001, Naleczow, Sept. 10-12, 2001.

[Paplinska1999]
Paplinska B., Wave analysis at Lubiatowo and in the Pomeranian Bay based on measurements from 1997/1998 – comparision with modelled data (WAM4 model). Oceanologia, 41(2), 1999. pp. 241-254

[Pitoura, 1997]
E. Pitoura, G. Samaras, Data Management for Mobile Computing, Kluwer International Series on Advances in Database Systems, 10, 1997

[Preussner1981]
Preussner, P.R., Brand, K.P. Application of a semi-implicit Euler method to mass action kinetics. Chem. Engng. Sci, 10, pp. 1633-1641, 1981.

[Singh2000]
D.E. Singh, M.Arenaz, F.F. Rivera, J.D. Bruguera, J. Touriño, R. Doallo, M.R. Mendez, J.A. Souto and J. Casares. Some proposals about the vector and parallel implementations of STEM-II. Proc. 8th Int. Conf. Development and Application of Computer Techniques to Environmental Studies. ENVIROSOFT 2000.Bilbao, Spain. pp. 57-66. (2000).

[Slota, 2000]
Slota, R., Kosch, H., Nikolow, D., Pogoda, M., Breidler, K., Podlipnig, S., MMSRS - Multimedia Storage and Retrieval System for a Distributed Mediacal Information System, in: Bubak, M., Afsarmanesh, H., Williams, R., Hertberger, B., (Eds.), Proc. Int. Conf. High Performance Computing and Networking, Amsterdam, May 8-10, 2000, Lecture Notes in Computer Science 1823, pp. 517-524, Springer, 2000.

[WAMDIGroup1988]
WAMDI Group, 1988, A Third Generation Ocean Wave Prediction Model. J. Phys. Oceanogr. 18, 1775.
[Wismueller, 2000]
Wismueller, R., Ludwig, T.: Interoperable Run-Time Tools for Distributed Systems – A Case Study. The Journal of Supercomputing, 17 (3) pp. 277-289, 2000.