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TRACER: Advanced Optimization Techniques for Complex Problems TIC2002-04498-C05

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Abstract

This project (TRACER) is intended to provide new efficient optimization tools, develop theoretical results, and apply the designed techniques to real world problems. The techniques dealt with inside the project come both from the exact and (especially) metaheuristic fields of research; the problems are mainly drawn from the combinatorial optimization domain, with a clear stress put on hard instances and possible applications in telecommunications, parallelism and bioinformatics. Besides providing more efficient algorithms, TRACER is targeted to give new cutting-edge results in as many problems as possible from the mentioned fields. Additionally, a great amount of ready-to-use software solutions will be publicly available for the community, as well as many technical information will be disseminated during the three years of live. It is planned to initiate still new research lines in grid computing, multiobjective optimization, and network-related issues in the third year, in a kind of natural synergy with the ongoing work. Much emphasis is put on the collaboration with foreign groups and the industry, and also on the dissemination of results; all this ensures a third year of promising research and a final success of the overall project.

Keywords: complex problems, optimization, telecommunications, parallelism, efficient new techniques

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1 Objectives and Project Management

The coordinated project TRACER aims at extending and improving the existing background on advanced optimization techniques as well as at solving complex problems in academia and industry. The main goal of this project is to achieve an efficient resolution of complex problems by developing innovative optimization procedures that can help in present and future applications.

The team is made up of five groups in a joint effort to arrive at a successful end:

- **TRACER::UMA**: University of Málaga.
- **TRACER::UPC**: Politechnique University of Catalunya.
- **TRACER::ULL**: University of La Laguna.
- **TRACER::UNEX**: University of Extremadura.
- **TRACER::UC3M**: University Carlos III of Madrid.

The general statement of goals is further detailed in subsequent sections by separately discussing on technical goals, chronogram, and means to achieve a successful project.

1.1 Technical Goals

To arrive to the mentioned objectives we propose the design, implementation and evaluation of sophisticated (parallel, hybrid, self-guided) variations of evolutionary algorithms, and, in general, of heuristic and exact solving tools. The target domains for these problems are traditional combinatorial optimization, telecommunications, bioinformatics, and FPGA's, among others.

As an added-value result, the project will offer two software systems. The first one is a client/server Internet system endowing researchers with the ability to submit their problems to be solved by the optimization techniques developed in this project. The second software package is builded as a large repository of problems including theoretical data, software, numerical results, and related links. In addition, much on the achieved studies and technical stuff will be publicly provided through the Internet in the form of thematic web sites, algorithms in C++ and Java, and working reports.

In order to get such goals we have planned to join forces among five groups having experience in the many fields considered in the project. By using local and combined remote computational results one important research line spins around exact and heuristics algorithms, what should serve as the workforce to address complex problems later. As outlined before, the scientific fields of competence are in metaheuristics (genetic algorithms, genetic programming, simulated annealing, scatter search, tabu search, etc.) and exact methods (branch and bound, dynamic programming, divide and conquer, etc.). In addition, a special interest exists in hybridizing algorithms to get efficient new techniques.

By exchanging and sharing information on the applications the project is intended to create and spread knowledge to the scientific community. The project promotes work on similar problems in all the groups and especially focuses on defining and solving new and harder instances of interesting problems. One important global contribution of TRACER will be that of providing more efficient solutions, both from a numerical and real time point of view, to open problems in research. The list of problems can be consulted at `http://tracer.lcc.uma.es/problems`, and it includes academic problems like knapsack, TSP, VRP, graph problems (max clique, coloring), cutting and FPGAs/circuits design. In addition, real world problems are also solved in TRACER in the fields of task scheduling in parallel systems, software project planning, computer cryptography, mobile network design, image processing, ad-hoc networks, tide level prediction, adversarial games, genomics, and multi-objective applications.

1.2 Chronogram

We here briefly discuss the steps and planning of TRACER. The steps to be followed in the project are outlined in Table 1.

In the first year, the groups in TRACER are intended to create a computational infrastructure of computers, networks and other locally needed hardware (such as FPGAs or multicomputers) to address complex problems. Also, this year is devoted to defining and implementing a first prototype of the remote optimization service (ROS). Of capital importance is the analysis of literature to end in a state-of-the-art study of the algorithms and problems selected for the project. This task is very influent to know in advance which are the techniques to beat and the problems deserving a deeper attention during the next two years.

In the second year, after one year of coordinated discussions on the problems (enhanced by its formal description published in the web sites) all the groups will propose new techniques to improve on the best known results in literature. One goal of TRACER is to advance as much as possible the scientific and practical knowledge on the involved techniques and problems, and therefore it is important to compare results against the best performing solutions to the moment and try to make it better during the second and third year. This means numerical and wall clock time improvements, since we plan to provide efficient algorithms from these two perspectives. In the second year all the groups will coordinately add into ROS their algorithms and problems to get ready for the very last deliverable (third year). The evaluation of new trends in parallel computing (MPI-G, Java RMI/IDL, Globus), network security and difficult problem solving is a target goal of this year.

Finally, in its third year, TRACER is intended to present a cooperative and large set of results in hard instances of combinatorial problems and real world instances of problems of interest for the industry. The ROS service will be released publicly to run on a single machine, LAN or Internet, and it will exist a great amount of written documents in the web sites of TRACER dealing with applications, and thematic web sites full of meaningful information. During the third year of the project it is expected to engage in national and international new collaborations with academic groups, as well as trying to setting up some projects within the national, EU, and the rest of the international arena. Last but not least we will also try to create liaisons with the industry for technology transfers, a goal that is also healthy for getting real world problems, one of our goals. Dealing with new technologies in distributed software and networks will be of importance to address problems in telecommunications and bioinformatics in this last year.

Dissemination of results in conferences, journals and books will be a goal for the three years, as well as performing coordinated actions. The third year will be important to crystalize all this because research will be mature enough to allow intense dissemination and interaction.

YEAR	SCIENTIFIC TASKS
2003	1. **Problems:** documentation and study of selected instances 2. **Algorithms:** design of solving techniques (exact, heuristic and hybrid) 3. **Opt. Service:** definition and implementation of an open web optimization service (ROS) 4. **Technology:** gathering information on new trends and standards (XML related, telecoms) 5. **Infrastructure:** set up web sites and computational resources (e.g. LANs and desktop computers)
2004	1. **Problems:** definition of real world problems (combinatorial optimization, telecoms, bioinformatics) 2. **Algorithms:** evaluation of the first year initial techniques plus extended algorithms 3. **Opt. Service:** extensions to the ROS by each group (adding new problems and algorithms) 4. **Technology:** study of parallelism within the techniques (LAN, WAN, grid computing) 5. **Infrastructure:** web site homogeneity and completeness, interconnection of internal networks
2005	1. **Problems:** Reproduction and improvement of best-so-far results 2. **Algorithms:** generation of theoretical results, beat current performances 3. **Opt. Service:** Public release of the ROS system, full of algorithms and applications 4. **Technology:** evaluation on state-of-the art hardware (computers, FPGA) and software (Globus, XML) 5. **Infrastructure:** completion of web sites with thematic contents, problems, and references

Table 1: Scientific chronogram: tasks in TRACER by year.

1.3 Means for Success

The means to achieve our goals are based, first, in a powerful task force of researchers. Table 2 shows the details on the staff involved in TRACER:

It can be seen that having 5 groups into a project is an advantage over other configurations in terms of computational and human resources. By cooperating between all our groups we expect a deep interaction among people that will hopefully lead to results of high quality published in conferences and journals of international impact. In addition, it is expected to

	UMA	UPC	ULL	UNEX	UC3M	TOTAL
EDP	**5**	**3.83**	**6**	**4.5**	**5**	**24.33**
Total Researchers	**6**	**8**	**7**	**5**	**7**	**33**
Doctorate Researchers	**5**	**7**	**4**	**3**	**5**	**24**

Table 2: Human resources involved in TRACER.

organize a considerable set of activities such as editing specialized journal issues, organizing workshops at international conferences, and collaborate with groups and institutions outside TRACER that will ensure a high dissemination of the work developed inside the project.

It comes as no surprise that such a large set of researchers dispersed in Spain is difficult to coordinate. We have developed a plan for plenary semi-annual meetings (celebrated at Málaga, Barcelona, and Madrid, for the time being, with two more meetings planned), with also sparse discussions between people of two or more sites made during international events. Since communications are readily fluent among all the researchers, email open discussions and telephone calls results of great help. Of course, we are forced to develop reports continuously to circulate information (in)formally inside the project.

Finally, a means to end in a beneficial project is external and internal collaborations in a multilateral way. This is a task not easy to quantify, but that can be appreciated taking a look to the success indicators of this report. Concretely, working in the same algorithms and problems is leading to improve on the number and quality of scientific papers, since background knowledge is daily accessible from one or more groups in the project by query to the project specialists, and also through Internet access to our sites. We plan especial measures to work in exactly the same problems during the second and third year, what will lead to several joint publications. In addition, bilateral collaborations are fostered continuously, and this has lead to some joint works: ROS improvements (UMA and UC3M), parallel software algorithms (UPC, UMA, ULL) and sharing techniques (like genetic programming between UNEX, ULL, UC3M). Several published papers and book chapter will be delivered during the third year and later.

2 Degree of the Achievements of the Project

In this section we address a unified view of the technical achievements of TRACER. We are organizing this section into subsections accounting for problems, algorithms, optimization service, technology, and infrastructure.

2.1 Problems

From the point of view of the problems solved in TRACER several types exist at different stages of analysis. We outline in Table 3 both, problems addressed from the beginning of the project (half upper part), and problems with a shorter history in TRACER but with an appealing future attending to our recent results.

PROBLEM	STAGE OF THE RESEARCH AT PRESENT
Vehicle Routing	150 problem instances solved, 10 new best-so-far results computed by cellular GAs
MultiDim Knapsack	OR-library instances solved to optimality by parallel exact algorithms (BB, DC)
Graph Problems	Bisection, maximum clique, Steiner problems, coloring, theory on planar graphs
Natural Language Tagging	Assigning lexicographical functions to words by parallel GAs, CHC, and SA
Circuits and FPGA Design	Designing on board circuits and FPGA configurations with GAs and GP
Medical Classification	Training neural networks with hybrid EAs for medical applications
Multiobjective Benchmarks	Constrained and unconstrained problems solved in grid (Condor and Globus)
Error Correcting Codes	Optimal set of codewords for telecoms and the similar Thomsom problem
Dynamic Optimization	Creating structured instances with problem generators solved with GAs
Advanced Algorithms	Multi-objective cellular GA and scatter search, theoretical background in EAs
Time Series	Prediction of tides by using system identification and evolutionary algorithms
Cryptanalysis	IDEA on FPGAs (16 times faster than software) and GAs for TEA/XTEA
Theory	Convergence of distributed EAs, bloat in GP, algorithms for graphs, etc.
Bioinformatics	Microarray data, phylogenetic inference and DNA fragment assembly problems
Ad-hoc Networks	Optimize the broadcasting protocol in ad-hoc networks by a multi-objective EAs
2D Cutting	Dressing patterns and glass cutting problems by specialized operators
Scheduling	Software tasks, software projects and production systems in the metal industry
Interaction and Games	Adversarial models, two players 3D games and interactive design with EAs
Earthquake	Forecasting the needed help after a earthquake
New Applications	Searching new applications of EP, GRASP, Particle Swarm and Ant Colony Systems
Advanced Applications	Robot navigation, spam filtering by supervised training, network failures, etc.

Table 3: Degree of advance in different problems inside TRACER: (up) completed (down) in progress.

2.2 Algorithms

In terms of the algorithms we are developing in the project, we are utilizing several technologies to improve the numerical as well as the real time performance over existing techniques. The main source of inspiration for the innovative algorithms designed in TRACER are the following ones:

- **Multi-objective approaches**: new genetic algorithms and scatter search algorithms are being devised to account for Pareto dominance and compute optimal Pareto fronts.
- **Grid computing**: new algorithms for computing exact Pareto Fronts, executing metaheuristics and solving difficult problems.
- **Memetic algorithms**: structured hybridization of algorithms for bioinformatics and telecommunications.
- **FPGA**: platform for execution of algorithms for high speed, and optimal design of FPGAs through metaheuristics.
- **Theory**: new results for graphs, pseudo-random number generation and convergence of distributed EAs.
- **Parallelism**: collaboration and competition in a network for faster algorithms.
- **New technologies**: research on the advantages of including XML, SOAP, .NET, and Globus in our research.
- **New algorithms**: investigating how well new algorithms appeared in literature can improve our own applications: scatter search, memetic algorithms, mathematical issues to reduce the space search (e.g. constraint satisfaction).

2.3 Optimization Service and Internet

Powerful and robust algorithms are being developed in close connection with Internet in TRACER. In all our research we pay great attention to the efficiency and to the software design aspects of the algorithms. We plan to release a public Internet service to help researchers with the task of solving complex problems by feeding them (written in Java, C++, and other languages) into a client/server system, and then selecting one solver from an assorted set of algorithms to obtain a solution with a short round-trip time and low effort.

A first prototype has been developed and called *remote optimization service* (ROS). In this system the groups in TRACER will add during the project's life algorithms and problems to create a later release for external users. The means for extending ROS is to create wrappers in Java to interface developed algorithms to interact with the whole system. A great deal of software is then planned to put into such system, both with specialized and generic optimization tools. The system is ready for execution in a single station, as well as in a LAN or through Internet. The exchange of information is made by SOAP and/or *webstream*, being this last a substitute to SOAP for those organizations with strict firewall restrictions. Information itself is encoded in XML (easy legibility, extensibility and compatibility), and the whole system is multi-platform (Windows, Linus and Solaris versions running at present). See the system architecture of ROS in the following Figure 1.

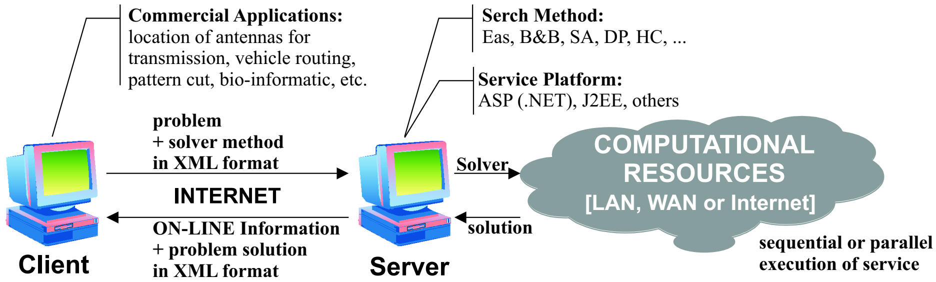

Figure 1: Architecture of the remote optimization service (ROS) developed in TRACER.

Although it means a high effort, this it not the primary goal of TRACER nor the only one. Many interactive software for optimization has been developed in TRACER:

- **MINLA**: minimum linear arrangement of graphs at the web site of the UPC node of TRACER.
- **TIDE**: prediction of tides included in ROS by the UC3M and UMA nodes.
- **MALLBA**: large amount of algorithms in the MALLBA library available through ROS at UMA.
- **CRIPTO, SIRVA and BLOAT-GP**: Internet applications for cryptology, vision and genetic programming at UNEX.
- **MOSET**: time series identification problem based on parameterized mathematical models.
- **Software**: JGDS, Jcell, problem generators, extensions to lil-gp and many auxiliary software tools.

Finally, an additional set of results are available in the problem sites of each group, as well as many thematic web sites with references, articles, definitions, applications and useful information have been created. Some of them are devoted to cellular genetic algorithms, vehicle routing kind of problems, new algorithms with extensive documentation and some others that are now under development.

2.4 Technology

We have addressed some initial studies on how important new technologies could be for our goals. The aim is to profit from recent tools in fields related to TRACER. First, we have analyzed the utilization of Condor and Globus as management tools for developing algorithms to be run in a grid of a large number of computers. We have set up a grid in Málaga of more than 110 computers for computing the exact Pareto front of multi-objective problems that are otherwise very difficult to generate. This result is having a deep impact in this field and many researchers are using our fronts themselves and the related software. In addition, we are enlarging the grid with novel computing facilities at Málaga by using the TRACER budget, and plan to connect it to foreign similar grids, and to other local grids being developed inside the project (especially in La Laguna).

The utilization of XML is quite important in many software tools of TRACER to configure algorithms and problems in a flexible and readable way. Also, SOAP is a means to connect algorithms in Internet in a lighter form compared to the constructed .NET algorithms, that have shown to be so complex to manage and so unnecessarily slow that have been abandoned after some tries during the first year of project.

New network issues like specialized networks such as Myrinet or large multicomputers are being analyzed. Also, technologies of growing interest like InfiniBAND are probably being tested for new performance in TRACER. This is the reason to have not only new ofimatic equipment like laptops, printers or desktop computers, but also new computing facilities such as processors of latest generation and new network cards and switches in the present domains of research. Software issues concerning Java, MPI, OpenMP, Handle-C and related programming tools will be also under analysis for developing advanced techniques in the project along all its life.

Finally, during the third year of the project it is expected to test the interest for the project of new domains of research for optimization tools like designing UMTS networks, mobile infrastructure, ad hoc/sensor networks and related fields. This could complete a wide spectrum of applications that could be the best exponent of the success of the developed algorithms.

2.5 Infrastructure

The different nodes in TRACER have spent part of the budget in updating and creating software and specially hardware devices to ease the daily work. We include here laptops, printers, personal computers and similar stuff. But also, the kind of problems tackled in the project usually suggests using parallel algorithms on LANs or some class of clusters of computers.

Besides setting up the infrastructure for computing, all the nodes have created local web sites with up to date information on the ongoing research, full of information for researchers.

Also, it is planned to create a large pool of machines to solve still harder problems or present problems at higher speeds; the foreseen impact in the applications would be high, and the groups will have an excellent excuse to study Condor pools integrated by a grid tool like Globus. In addition, new timid incursions in ad hoc and sensor networks can prove the extensibility and knowledge transfer of the present project to other domains.

3 Success Indicators

In this section we include several indicators allowing the evaluation of the impact that TRACER is having after two years of work of all the groups. We are arranging the presentation in several sections focusing on different indicators.

3.1 Scientific Papers

Let us begin this section by summarizing the impact of the project through the usual means of presenting the scientific publications of the groups in TRACER. We begin by outlining the progress of each group in the first and two years of the project. It follows a set of five tables with such results, one for each group.

Group	Year	Journals	Book Chapters	Intl. Conferences	Natl. Conferences
UMA	2003	6	2	9	3
UMA	2004	14	4	16	7
UPC	2003	1	-	4	-
UPC	2004	13	-	16	1
ULL	2003	1	-	6	4
ULL	2004	5	-	3	4
UNEX	2003	1	-	5	6
UNEX	2004	4	1	8	8
UC3M	2003	2	-	5	-
UC3M	2004	4	-	4	-
TOTAL		**51**	**7**	**76**	**33**

Table 4: Summary of the scientific production in TRACER by subgroup.

3.2 National and International Collaborations

As suggested in this report, we pay a great attention and importance to establishing international collaborations. The work headed to create funded projects is discussed in the next section. We now give the list of collaborations set up since TRACER began:

1. USA group of Colorado State University (Manuel Laguna) and San José State (Sami Khuri).
2. Luxemburgean group at the University of Luxemburgo (Pascal Bouvry).
3. Swiss group at the University of Lausanne (Marco Tomassini).

4. French group at the University of Lille (El-Ghazali Talbi).
5. Mexican group at CINVESTAV (Carlos Coello).
6. Important Spanish-Argentinian collaboration with many universities.
7. Uruguay group at Republic University (Héctor Cancela).
8. German group at the University of Leipzig (Martin Middendorf).
9. Australian groups at Sidney (Albert Zomaya) and Newcastle (Pablo Moscato).
10. English group at Queens University (Alan Stewart) and EPCC (Mario Antonioletti).
11. Belgian group from the European Metaheuristics Network at IRIDIA (Christian Blum and Marco Dorigo).
12. Other collaborations at USA (Sandia, California), Italy (E.U.R.C. Ispra), Cuba (ICIMAF), Mexico (CINVESTAV, CICESE) and Canada (CNRT, Alberta).

Some other nationally funded activities that are being successfully being carried out by the groups in TRACER are these:

- Participation in the Andalusian network on algorithms: RADI-AEB.
- Participation in the national network on metaheuristics: META.

3.3 Participation in European and Other International Projects

The different groups in TRACER are applying for different international funded projects and collaborations:

- European initiatives for grid computing and applications (coreGRID).
- European project for data mining in medical applications (SURPRISE).
- European funding for computational infrastructures (ULL supercomputer).
- European integrated actions (Spain-France, Spain-Germany, Spain-UK).
- Integration in the European consortium for Informatics and Mathematics (ERCIM).

By means of our integration in ERCIM as part of the Spanish Consortium SpaRCIM we have developed two special actions for diffusion of the work in TRACER in Europe. ERCIM has a news journal (ISSN 0926-4981) with technical details about ongoing projects, usually in the form of special issues (`http://www.ercim.org/publication/Ercim_News"`). Two efforts of dissemination have been achieved coordinated by the node of Málaga:

- E. Alba, *Solving Complex Problems with Advanced Techniques*, ERCIM News, n. 56, pp. 45-46, January 2004
- E. Alba, A.J. Nebro *Solving Optimization Problems with Grid-Enabled Technologies*, ERCIM News, n. 59, pp., September 2004

In addition, a presentation of TRACER will be included in the workshop **PAREO 2005** in January of next year, in order to find (funded) synergies with other international groups, since this is the main goal of such a workshop.

3.4 Training and Human Resources

In Table 5 we summarize the outcomings of TRACER in terms of human resources and training activities. We include values in an $a + b$ format, where a means work finished and b means work in progress. Thus, if a DEA (Advanced Studies Diploma) has a value of $2 + 1$ it indicates that 2 persons got the diploma while 1 person is working (or ready) to have it. One single value means work finished. The included information shows that the training activities are also an important feature of this project, since many researchers are progressing as a result of the project's development.

GROUP	PhD Thesis	DEA	Master Thesis	Degree Projects	Grants & Contracts
UMA	1 + 4	4	6	7	2
UPC	0 + 2	-	7	-	1
ULL	2 + 4	1	1	2	2
UNEX	1 + 6	1 + 2	-	6	1
UC3M	2 + 2	2	1	-	2
TOTAL	**6 + 18**	**8 + 2**	**15**	**15**	**8**

Table 5: Training and other human resources information at TRACER (2003 and 2004).

3.5 Technological Transfer to the Industry

Technological transfer to the industry is being addressed from inside TRACER. Some companies are already in formal collaboration with TRACER, and some others are have shown interest in our work; it follows a list of all of them:

- Tartessos Technologies Inc. (Málaga): handover and mobile cells arrangement by using genetic algorithms.
- Optimi (Atlanta): optimal frequency assignment to base station transmitters.
- SEAT (Barcelona): definition of problems related to minimizing noise inside cars.
- Regional Dress Company (La Laguna): optimal 2D cut of regional dresses at Canary Islands.
- European Research Center at Ispra (Italy): optimum allocation of resources for help after an earthquake.
- Lawrence Livermore National Lab (California): applications of evolutionary algorithms.

3.6 Other Indicators

We have detected some references to TRACER papers in the literature made by other national and foreign researchers, but it is still too early to evaluate this indicator. Some of the software tools are also being used by foreign groups, like it occurs with the extended MALLBA library, and with the contents of publications made in special sessions and journal issues (such as in the *Journal of Heuristics* and other international journals). At this moment, we can also ensure that many of the results in the project will be used and described in the new book edited by E. Alba entitled **Parallel Metaheuristics**, to be published by Wiley during 2005.

The approved European funding for a huge computer awarded to the group in La Laguna (650.000 euros), the excellent and numerous workshops and conferences organization from the groups of Málaga (NIDISC'04, NIDISC'05, MAEB'03, MAEB'04, FD'04) and Carlos III (CEC'03, CEC'04, GECCO'04), the high European vocation of the group in UPC (grid project and UK strong collaborations) and the quality of the applications of UNEX (vision, time series, FPGAs) are also indicators of the high success of this project.

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