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Project-Team DOLPHIN

Parallel Cooperative Multi-criteria Optimization

IN COLLABORATION WITH: Laboratoire d'informatique fondamentale de Lille (LIFL)

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Project-Team DOLPHIN

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2. Overall Objectives

2.1. Presentation

The goal of the DOLPHIN[1] project is the modeling and resolution of large multi-criteria combinatorial problems using parallel and distributed hybrid techniques. We are interested in algorithms using Pareto approaches, which generate the whole Pareto set of a given Multi-Objective Problem (MOP). For this purpose, the research actions can be summarized as follows:

- **Modeling and Analysis of MOPs:** Solving Multi-Objective Problems requires an important analysis phase to find the best suitable method to solve it. This analysis deals with the modeling of the problem and the analysis of its structure.

  To propose efficient models for a Multi-Objective Optimization problem, an important aspect is to integrate all the constraints of the problem. Therefore an interesting preliminary approach is to develop efficient models for the problem in its mono-objective forms in order to be able to develop methods that are taking the characteristics of the studied problem into account.

  While studying the problem in its multi-objective form, the analysis of the structure is another interesting approach. The analysis of the structure of the Pareto front by means of different approaches (statistical indicators, meta-modeling, etc.) allows the design of efficient and robust hybrid optimization techniques. In general, the current theory does not allow the complete analysis of optimization algorithms. Several questions are unanswered: i) why is a given method efficient? ii) why are certain instances difficult to solve? Some work is needed to guide the user in the design of efficient methods.

  The NFL (No Free Lunch) theorem shows that two optimization methods have the same global performance on the whole set of uniform optimization problems. Then, it is crucial to make some hypotheses on the studied problem. This may be done in two steps:

  - analyzing the target problem to identify its landscape properties,
  - including this knowledge in the proposed optimization method.

  Our interest in this project is to answer these questions and remarks for the multi-objective case. Another point considered is the performance evaluation of multi-objective optimization methods. We are also working on approximation algorithms with performance guarantee and the convergence properties of stochastic algorithms.

- **Cooperation of optimization methods (metaheuristics and/or exact methods):**

  The hybridization of optimization methods allows the cooperation of complementary different methods. For instance, the cooperation between a metaheuristic and an exact method allows us to take advantage of the intensification process of an exact method in finding the best(s) solution(s) in a sub-space, and the diversification process of the metaheuristic in reducing the search space to explore.

  In this context, different types of cooperation may be proposed. These approaches are under study in the project and we are applying them to different generic MOPs (flow-shop scheduling problem, vehicle routing problem, covering tour problem, access network design, and the association rule problem in data mining).

- **Parallel optimization methods:** Parallel and distributed computing may be considered as a tool to speedup the search to solve large MOPs and/or to improve the robustness of a given method. Following this objective, we design and implement parallel metaheuristics (evolutionary algorithms, Tabu search approach) and parallel exact methods (branch and bound algorithm, branch and cut algorithm) for solving different large MOPs. Moreover, the joint use of parallelism and cooperation allows the improvement of the quality of the obtained solutions.

[1] Discrete multi-objective Optimization for Large scale Problems with Hybrid dIstributed techNiques.

- **Framework for parallel and distributed hybrid metaheuristics:** Our team contributes to the development of an open source framework for metaheuristics, named ParadisEO (PARAllel and DIStributed Evolving Objects). Our contribution in this project is the extension of the EO (Evolving Objects) framework [2], which consists in: i) the generalization of the framework to single solution metaheuristics such as local search, tabu search and simulated annealing; ii) the design of metaheuristics for multi-objective optimization; iii) the design of hybrid methods; iv) the development of parallel and distributed models.

  In this project, our goal is the efficient design and implementation of this framework on different types of parallel and distributed hardware platforms: cluster of workstations (COW), networks of workstations (NOW) and GRID computing platforms, using the different suited programming environments (MPI, Condor, Globus, PThreads). The coupling with well-known frameworks for exact methods (such as COIN) will also be considered. The exact methods for MOPs developed in this project will be integrated in those software frameworks.

  The experimentation of this framework by different users and applications outside the DOLPHIN project is considered. This is done in order to validate the design and the implementation issues of ParadisEO.

- **Validation:** the designed approaches are validated on generic and real-life MOPs, such as:
  - Scheduling problems: Flow-shop scheduling problem;
  - Routing problems: Vehicle routing problem (VRP), covering tour problem (CTP), etc;
  - mobile telecommunications: Design of mobile telecommunications networks (contract with France Telecom R&D) and design of access networks (contract with Mobinets);
  - Genomics: Association rule discovery (data mining task) for mining genomic data, protein identification, docking and conformational sampling of molecules.
  - Engineering design problems: Design of polymers.

  Some benchmarks and their associated optimal Pareto fronts or best known Pareto fronts have been defined and made available on the Web. We are also developing an open source software, named GUIMOO[3], which integrates different performance evaluation metrics and 2D/3D visualization tools of Pareto fronts.

2.2. Highlights

- Best award paper in the conference GECCO'2011: Malika Mehdi, Jean-Claude Charr, Nouredine Melab, El-Ghazali Talbi, Pascal Bouvry: A cooperative tree-based hybrid GA-B&B approach for solving challenging permutation-based problems. GECCO'2011, Dublin, Ireland, July 2011.

BEST PAPERS AWARDS :
[39] **GECCO - Genetic and Evolutionary Computing Conference**. M. MEHDI, J.-C. CHARR, N. MELAB, E.-G. TALBI, P. BOUVRY.
[33] **11th European Conference on Evolutionary Computation in Combinatorial Optimisation - EvoCOP 2011**. A. LIEFOOGHE, L. PAQUETE, M. SIMOES, J. FIGUEIRA.

3. Scientific Foundations

3.1. Modeling and landscape analysis

[2] This framework was initially developed by Geneura TEAM (Spain), INRIA (France), LIACS (Netherlands). http://paradiseo.gforge.inria.fr.
[3] Graphical User Interface for Multi-Objective Optimization (http://guimoo.gforge.inria.fr).

The modeling of problems, the analysis of structures (landscapes) of MOPs and the performance assessment of resolution methods are significant topics in the design of optimization methods. The effectiveness of metaheuristics depends on the properties of the problem and its landscape (roughness, convexity, etc). The notion of landscape has been first described in [64] by the way of the study of species evolution. Then, this notion has been used to analyze combinatorial optimization problems.

3.1.1. Modeling of problems

Generally there are several ways of modeling a given problem. First, one has to find the most suitable model for the type of resolution he or she plans to use. The choice can be made after a theoretical analysis of the model, or after computational experiments. The choice of the model depends on the type of method used. For example, a major issue in the design of exact methods is to find tight relaxations for the problem considered.

Let us note that many combinatorial optimization problems of the literature have been studied in their mono-objective form even if a lot of them are naturally of a multi-objective nature.

Therefore, in the DOLPHIN project, we address the modeling of MOPs in two phases. The first one consists in studying the mono-objective version of the problem, where all objectives but one are considered as constraints. In the second phase, we propose methods to adapt the mono-objective models or to create hand-tailored models for the multi-objective case. The models used may come from the first phase, or from the literature.

3.1.2. Analysis of the structure of a problem

The landscape is defined by a neighborhood operator and can be represented by a graph $G = (V, E)$. The vertices represent the solutions of the problem and an edge (e_1, e_2) exists if the solution e_2 can be obtained by an application of the neighborhood operator on the solution e_1. Then, considering this graph as the ground floor, we elevate each solution to an altitude equals to its cost. We obtain a surface, or landscape, made of peaks, valleys, plateaus, cliffs, etc. The problem lies in the difficulty to have a realistic view of this landscape.

Like others, we believe that the main point of interest in the domain of combinatorial optimization is not the design of the best algorithm for a large number of problems but the search for the most adapted method to an instance or a set of instances of a given problem. Therefore, we are convinced that no ideal metaheuristic, designed as a black-box, may exist.

Indeed, the first studies realized in our research group on the analysis of landscapes of different mono-objective combinatorial optimization problems (traveling salesman problem, quadratic assignment problem) have shown that not only different problems correspond to different structures but also that different instances of the same problem correspond to different structures.

For instance, we have realized a statistical study of the landscapes of the quadratic assignment problem. Some indicators that characterize the landscape of an instance have been proposed and a taxonomy of the instances including three classes has been deduced. Hence it is not enough to adapt the method to the problem under study but it is necessary to specialize it according to the type of the treated instance.

So in its studies of mono-objective problems, the DOLPHIN research group has introduced into the resolution methods some information about the problem to be solved. The landscapes of some combinatorial problems have been studied in order to investigate the intrinsic natures of their instances. The resulting information has been inserted into an optimization strategy and has allowed the design of efficient and robust hybrid methods. The extension of these studies to multi-objective problems is a part of the DOLPHIN project [62], [63].

3.1.3. Performance assessment

The DOLPHIN project is also interested in the performance assessment of multi-objective optimization methods. Nowadays, statistical techniques developed for mono-objective problems can be adapted to the multi-objective case. Nevertheless, specific tools are necessary in many situations: for example, the comparison of two different algorithms is relatively easy in the mono-objective case - we compare the quality of the best solution obtained in a fixed time, or the time needed to obtain a solution of a certain quality. The same idea cannot be immediately transposed to the case where the output of the algorithms is a set of solutions having several quality measures, and not a single solution.

Various indicators have been proposed in the literature for evaluating the performance of multi-objective optimization methods but no indicator seems to outperform the others [65]. The DOLPHIN research group has proposed two indicators: the *contribution* and the *entropy* [59]. The contribution evaluates the supply in term of Pareto-optimal solutions of a front compared to another one. The entropy gives an idea of the diversity of the solutions found. These two metrics are used to compare the different metaheuristics in the research group, for example in the resolution of the bi-objective flow-shop problem, and also to show the contribution of the various mechanisms introduced in these metaheuristics.

3.1.4. Goals

One of the main issues in the DOLPHIN project is the study of the landscape of multi-objective problems and the performance assessment of multi-objective optimization methods to design efficient and robust resolution methods:

- *Landscape study:* The goal here is to extend the study of landscapes of the mono-objective combinatorial optimization problems to multi-objective problems in order to determine the structure of the Pareto frontier and to integrate this knowledge about the problem structure in the design of resolution methods.

  This study has been initiated for the bi-objective flow-shop problem. We have studied the convexity of the frontiers obtained in order to show the interest of our Pareto approach compared to an aggregation approach, which only allows one to obtain the Pareto solutions situated on the convex hull of the Pareto front (supported solutions).

  Our preliminary study of the landscape of the bi-objective flow-shop problem shows that the supported solutions are very closed to each other. This remark leads us to improve an exact method initially proposed for bi-objective problems. Furthermore, a new exact method able to deal with any number of objectives has been designed.
- *Performance assessment:* The goal here is to extend GUIMOO in order to provide efficient visual and metric tools for evaluating the assessment of multi-objective resolution methods.

3.2. Hybrid multi-objective optimization methods

The success of metaheuristics is based on their ability to find efficient solutions in a reasonable time [58]. But with very large problems and/or multi-objective problems, efficiency of metaheuristics may be compromised. Hence, in this context it is necessary to integrate metaheuristics in more general schemes in order to develop even more efficient methods. For instance, this can be done by different strategies such as cooperation and parallelization.

The DOLPHIN project deals with *"a posteriori"* multi-objective optimization where the set of Pareto solutions (solutions of best compromise) have to be generated in order to give the decision maker the opportunity to choose the solution that interests him/her.

Population-based methods, such as evolutionary algorithms, are well fitted for multi-objective problems, as they work with a set of solutions [54], [57]. To be convinced one may refer to the list of references on Evolutionary Multi-objective Optimization maintained by Carlos A. Coello Coello[4], which contains more than 5500 references. One of the objectives of the project is to propose advanced search mechanisms for intensification and diversification. These mechanisms have been designed in an adaptive manner, since their effectiveness is related to the landscape of the MOP and to the instance solved.

In order to assess the performances of the proposed mechanisms, we always proceed in two steps: first, we carry out experiments on academic problems, for which some best known results exist; second, we use real industrial problems to cope with large and complex MOPs. The lack of references in terms of optimal or best known Pareto set is a major problem. Therefore, the obtained results in this project and the test data sets will be available at the URL http://dolphin.lille.inria.fr/ at 'benchmark'.

[4] http://www.lania.mx/~ccoello/EMOO/EMOObib.html

3.2.1. Cooperation of metaheuristics

In order to benefit from the various advantages of the different metaheuristics, an interesting idea is to combine them. Indeed, the hybridization of metaheuristics allows the cooperation of methods having complementary behaviors. The efficiency and the robustness of such methods depend on the balance between the exploration of the whole search space and the exploitation of interesting areas.

Hybrid metaheuristics have received considerable interest these last years in the field of combinatorial optimization. A wide variety of hybrid approaches have been proposed in the literature and give very good results on numerous single objective optimization problems, which are either academic (traveling salesman problem, quadratic assignment problem, scheduling problem, etc) or real-world problems. This efficiency is generally due to the combinations of single-solution based methods (iterative local search, simulated annealing, tabu search, etc) with population-based methods (genetic algorithms, ants search, scatter search, etc). A taxonomy of hybridization mechanisms may be found in [61]. It proposes to decompose these mechanisms into four classes:

- *LRH class - Low-level Relay Hybrid*: This class contains algorithms in which a given metaheuristic is embedded into a single-solution metaheuristic. Few examples from the literature belong to this class.
- *LTH class - Low-level Teamwork Hybrid*: In this class, a metaheuristic is embedded into a population-based metaheuristic in order to exploit strengths of single-solution and population-based metaheuristics.
- *HRH class - High-level Relay Hybrid*: Here, self contained metaheuristics are executed in a sequence. For instance, a population-based metaheuristic is executed to locate interesting regions and then a local search is performed to exploit these regions.
- *HTH class - High-level Teamwork Hybrid*: This scheme involves several self-contained algorithms performing a search in parallel and cooperating. An example will be the island model, based on GAs, where the population is partitioned into small subpopulations and a GA is executed per subpopulation. Some individuals can migrate between subpopulations.

Let us notice, that if hybrid methods have been studied in the mono-criterion case, their application in the multi-objective context is not yet widely spread. The objective of the DOLPHIN project is to integrate specificities of multi-objective optimization into the definition of hybrid models.

3.2.2. Cooperation between metaheuristics and exact methods

Until now only few exact methods have been proposed to solve multi-objective problems. They are based either on a Branch-and-bound approach, on the algorithm $A^{\star}$, or on dynamic programming. However, these methods are limited to two objectives and, most of the time, cannot be used on a complete large scale problem. Therefore, sub search spaces have to be defined in order to use exact methods. Hence, in the same manner as hybridization of metaheuristics, the cooperation of metaheuristics and exact methods is also a main issue in this project. Indeed, it allows us to use the exploration capacity of metaheuristics, as well as the intensification ability of exact methods, which are able to find optimal solutions in a restricted search space. Sub search spaces have to be defined along the search. Such strategies can be found in the literature, but they are only applied to mono-objective academic problems.

We have extended the previous taxonomy for hybrid metaheuristics to the cooperation between exact methods and metaheuristics. Using this taxonomy, we are investigating cooperative multi-objective methods. In this context, several types of cooperations may be considered, according to the way the metaheuristic and the exact method cooperate. For instance, a metaheuristic can use an exact method for intensification or an exact method can use a metaheuristic to reduce the search space.

Moreover, a part of the DOLPHIN project deals with studying exact methods in the multi-objective context in order: i) to be able to solve small size problems and to validate proposed heuristic approaches; ii) to have more efficient/dedicated exact methods that can be hybridized with metaheuristics. In this context, the use of parallelism will push back limits of exact methods, which will be able to explore larger size search spaces [55].

3.2.3. Goals

Based on the previous works on multi-objective optimization, it appears that to improve metaheuristics, it becomes essential to integrate knowledge about the problem structure. This knowledge can be gained during the search. This would allow us to adapt operators which may be specific for multi-objective optimization or not. The goal here is to design auto-adaptive methods that are able to react to the problem structure. Moreover, regarding the hybridization and the cooperation aspects, the objectives of the DOLPHIN project are to deepen these studies as follows:

- *Design of metaheuristics for the multi-objective optimization:* To improve metaheuristics, it becomes essential to integrate knowledge about the problem structure, which we may get during the execution. This would allow us to adapt operators that may be specific for multi-objective optimization or not. The goal here is to design auto-adaptive methods that are able to react to the problem structure.
- *Design of cooperative metaheuristics:* Previous studies show the interest of hybridization for a global optimization and the importance of problem structure study for the design of efficient methods. It is now necessary to generalize hybridization of metaheuristics and to propose adaptive hybrid models that may evolve during the search while selecting the appropriate metaheuristic. Multi-objective aspects have to be introduced in order to cope with the specificities of multi-objective optimization.
- *Design of cooperative schemes between exact methods and metaheuristics:* Once the study on possible cooperation schemes is achieved, we will have to test and compare them in the multi-objective context.
- *Design and conception of parallel metaheuristics:* Our previous works on parallel metaheuristics allow us to speed up the resolution of large scale problems. It could be also interesting to study the robustness of the different parallel models (in particular in the multi-objective case) and to propose rules that determine, given a specific problem, which kind of parallelism to use. Of course these goals are not disjoined and it will be interesting to simultaneously use hybrid metaheuristics and exact methods. Moreover, those advanced mechanisms may require the use of parallel and distributed computing in order to easily make cooperating methods evolve simultaneously and to speed up the resolution of large scale problems.
- *Validation:* In order to validate the obtained results we always proceed in two phases: validation on academic problems, for which some best known results exist and use on real problems (industrial) to cope with problem size constraints.

  Moreover, those advanced mechanisms are to be used in order to integrate the distributed multi-objective aspects in the ParadisEO platform (see the paragraph on software platform).

3.3. Parallel multi-objective optimization: models and software frameworks

Parallel and distributed computing may be considered as a tool to speedup the search to solve large MOPs and to improve the robustness of a given method. Moreover, the joint use of parallelism and cooperation allows improvements on the quality of the obtained Pareto sets. Following this objective, we will design and implement parallel models for metaheuristics (evolutionary algorithms, tabu search approach) and exact methods (branch-and-bound algorithm, branch-and-cut algorithm) to solve different large MOPs.

One of the goal of the DOLPHIN project is to integrate the developed parallel models into software frameworks. Several frameworks for parallel distributed metaheuristics have been proposed in the literature. Most of them focus only either on evolutionary algorithms or on local search methods. Only few frameworks are dedicated to the design of both families of methods. On the other hand, existing optimization frameworks either do not provide parallelism at all or just supply at most one parallel model. In this project, a new framework for parallel hybrid metaheuristics is proposed, named *Parallel and Distributed Evolving Objects (ParadisEO)* based on EO. The framework provides in a transparent way the hybridization mechanisms presented in the previous section, and the parallel models described in the next section. Concerning the developed parallel exact methods for MOPs, we will integrate them into well-known frameworks such as COIN.

3.3.1. Parallel models

According to the family of addressed metaheuristics, we may distinguish two categories of parallel models: parallel models that manage a single solution, and parallel models that handle a population of solutions. The major single solution-based parallel models are the following: the *parallel neighborhood exploration model* and the *multi-start model*.

- *The parallel neighborhood exploration model* is basically a "low level" model that splits the neighborhood into partitions that are explored and evaluated in parallel. This model is particularly interesting when the evaluation of each solution is costly and/or when the size of the neighborhood is large. It has been successfully applied to the mobile network design problem (see Application section).
- *The multi-start model* consists in executing in parallel several local searches (that may be heterogeneous), without any information exchange. This model raises particularly the following question: is it equivalent to execute k local searches during a time t than executing a single local search during $k \times t$? To answer this question we tested a multi-start Tabu search on the quadratic assignment problem. The experiments have shown that the answer is often landscape-dependent. For example, the multi-start model may be well-suited for landscapes with multiple basins.

Parallel models that handle a population of solutions are mainly: the *island model*, the *central model* and *the distributed evaluation of a single solution*. Let us notice that the last model may also be used with single-solution metaheuristics.

- In *the island model*, the population is split into several sub-populations distributed among different processors. Each processor is responsible of the evolution of one sub-population. It executes all the steps of the metaheuristic from the selection to the replacement. After a given number of generations (synchronous communication), or when a convergence threshold is reached (asynchronous communication), the migration process is activated. Then, exchanges of solutions between sub-populations are realized, and received solutions are integrated into the local sub-population.
- *The central (Master/Worker) model* allows us to keep the sequentiality of the original algorithm. The master centralizes the population and manages the selection and the replacement steps. It sends sub-populations to the workers that execute the recombination and evaluation steps. The latter returns back newly evaluated solutions to the master. This approach is efficient when the generation and evaluation of new solutions is costly.
- *The distributed evaluation model* consists in a parallel evaluation of each solution. This model has to be used when, for example, the evaluation of a solution requires access to very large databases (data mining applications) that may be distributed over several processors. It may also be useful in a multi-objective context, where several objectives have to be computed simultaneously for a single solution.

As these models have now been identified, our objective is to study them in the multi-objective context in order to use them advisedly. Moreover, these models may be merged to combine different levels of parallelism and to obtain more efficient methods [56], [60].

3.3.2. Goals

Our objectives focus on these issues are the following:

- *Design of parallel models for metaheuristics and exact methods for MOPs*: We will develop parallel cooperative metaheuristics (evolutionary algorithms and local search algorithms such as the Tabu search) for solving different large MOPs. Moreover, we are designing a new exact method, named

PPM (Parallel Partition Method), based on branch and bound and branch and cut algorithms. Finally, some parallel cooperation schemes between metaheuristics and exact algorithms have to be used to solve MOPs in an efficient manner.

- *Integration of the parallel models into software frameworks*: The parallel models for metaheuristics will be integrated in the ParadisEO software framework. The proposed multi-objective exact methods must be first integrated into standard frameworks for exact methods such as COIN and BOB++. A *coupling* with ParadisEO is then needed to provide hybridization between metaheuristics and exact methods.
- *Efficient deployment of the parallel models on different parallel and distributed architecture including GRIDs*: The designed algorithms and frameworks will be efficiently deployed on non-dedicated networks of workstations, dedicated cluster of workstations and SMP (Symmetric Multi-processors) machines. For GRID computing platforms, peer to peer (P2P) middlewares (XtremWeb-Condor) will be used to implement our frameworks. For this purpose, the different optimization algorithms may be re-visited for their efficient deployment.

4. Application Domains

4.1. Academic generic problems

In this project, some well known optimization problems are re-visited in terms of multi-objective modelization and resolution:

- **Workshop optimization problems:**

  Workshop optimization problems deal with optimizing the production. In this project, two specific problems are under study.

  - **Flow-shop scheduling problem:** The flow-shop problem is one of the most well-known scheduling problems. However, most of the works in the literature use a mono-objective model. In general, the minimized objective is the total completion time (makespan). Many other criteria may be used to schedule tasks on different machines: maximum tardiness, total tardiness, mean job flowtime, number of delayed jobs, maximum job flowtime, etc. In the DOLPHIN project, a bi-criteria model, which consists in minimizing the makespan and the total tardiness, is studied. A tri-criteria flow-shop problem, minimizing in addition the maximum tardiness, is also studied. It allows us to develop and test multi-objective (and not only bi-objective) exact methods.
  - **Cutting problems:** Cutting problems occur when pieces of wire, steel, wood, or paper have to be cut from larger pieces. The objective is to minimize the quantity of lost material. Most of these problems derive from the classical one-dimensional cutting-stock problem, which have been studied by many researchers. The problem studied by the DOLPHIN project is a two-dimensional bi-objective problem, where rotating a rectangular piece has an impact on the visual quality of the cutting pattern. First we have to study the structure of the cutting-stock problem when rotation is allowed, then we will develop a method dedicated to the bi-objective version of the problem.

- **Logistics and transportation problems:**

  - **Packing problems:** In logistic and transportation fields, packing problems may be a major issue in the delivery process. They arise when one wants to minimize the size of a warehouse or a cargo, the number of boxes, or the number of vehicles used to deliver a batch of items. These problems have been the subjects of many papers, but only few of them study multi-objective cases, and to our knowledge, never from an exact point of view. Such a case occurs for example when some pairs of items cannot be packed in the same bin. The DOLPHIN project is currently studying the problem in its one-dimensional version. We plan to generalize our approach to two and three dimensional problems, and to more other conflict constraints, with the notion of *distance* between items.

– **Routing problems:** The vehicle routing problem (VRP) is a well-known problem and it has been studied since the end of the 50's. It has a lot of practical applications in many industrial areas (ex. transportation, logistics, etc). Existing studies of the VRP are almost all concerned with the minimization of the total distance only. The model studied in the DOLPHIN project introduces a second objective, whose purpose is to balance the length of the tours. This new criterion is expressed as the minimization of the difference between the length of the longest tour and the length of the shortest tour. As far as we know, this model is one of the pioneer work in the literature.

  The second routing problem is a generalization of the covering tour problem (CTP). In the DOLPHIN project, this problem is solved as a bi-objective problem where a set of constraints are modeled as an objective. The two objectives are: i) minimization of the length of the tour; ii) minimization of the largest distance between a node to be covered and a visited node. As far as we know, this study is among the first works that tackle a classic mono-objective routing problem by relaxing constraints and building a more general MOP.

  The third studied routing problem is the Ring Star Problem (RSP). This problem consists in locating a simple cycle through a subset of nodes of a graph while optimizing two kinds of costs. The first objective is to minimize a ring cost that is related to the length of the cycle. The second one is to minimize an assignment cost from non-visited nodes to visited ones. In spite of its natural bi-criteria formulation, this problem has always been studied in a single-objective form where either both objectives are combined or one objective is treated as a constraint.

  Recently, within a cooperation with SOGEP, the logistic and delivery subsidiary company of REDCATS (PINAULT PRINTEMPS REDOUTE), a new routing problem is under study. Indeed, the COLIVAD project consists in solving a logistic and transportation problem that has been reduced to a vehicle routing problem with additional constraints. First we are designing a method to solve exactly a bi-objective version of the problem in order to evaluate the interest of modifying the current process of delivery. We are also working on the resolution of a single-objective version of this problem to design an operational tool dedicated to the SOGEP problem.

For all studied problems, standard benchmarks have been extended to the multi-objective case. The benchmarks and the obtained results (optimal Pareto front, best known Pareto front) are available on the Web pages associated to the project and from the MCDM (International Society on Multiple Criteria Decision Making) Web site. This is an important issue to encourage comparison experiments in the research community.

4.2. Application to mobile telecommunication networks

With the extraordinary success of mobile telecommunication systems, service providers have been affording huge investments for network design and infrastructure. Mobile network design is of outmost importance, and is thus a major issue in mobile telecommunication systems. In fact, with the continuous and rapid growth of communication traffic, large scale planning becomes more and more difficult. Hence, automatic, interactive and self-adaptive optimization algorithms and tools would be very useful and helpful. Advances in this area will certainly lead to important improvements in terms of quality of service, network management and cost deployment.

In the past, the DOLPHIN team has initiated solid industrial collaborations within the domain of mobile networks. In fact, the problem of network design and frequency assignment was studied in collaboration with France Telecom. In particular, a new formulation/resolution of the problem as a multi-objective constrained combinatorial optimization problem was considered. In collaboration with Mobinets, the DOLPHIN team has also addressed the problem of access network design. The problem consists in minimizing the cost of the access network and maximizing its availability.

More recently, the DOLPHIN team has been interested in new optimization models and algorithms to address new difficult problems raised by new emerging technologies in wireless networks. In fact, wireless communications are evolving from inflexible and monolithic systems to a composite radio environment made of cognitive radio devices and networks of different technologies. Within this context, the challenge is to design new optimization techniques which are not only resource, power, scale, and applications aware, but which are self-adaptive and fully distributed in order to allow the dynamic optimization of radio-devices behaviors depending on the environment constraints e.g., spectrum availability, network traffic, user demand, etc. To achieve this goal, distributed and nature-inspired algorithms, such as ant-colony and bees, will be investigated in order to dynamically and distributively optimize predefined criterion such as throughput, fairness, quality of service to cite a few. It is expected that the techniques developed in this work will lead to the design of new models and algorithms for opportunistic/dynamic spectrum access and cross layer network optimization which are at the core of future generation wireless networks.

4.3. Application to Bioinformatics

Bioinformatic research is a great challenge for our society and numerous research entities of different specialities (biology, medical or information technology) are collaborating on specific thema.

4.3.1. Genomic and post-genomic studies

Previous studies of the DOLPHIN project mainly deal with genomic and postgenomic applications. These have been realized in collaboration with academic and industrial partners (IBL: Biology Institute of Lille; IPL: Pasteur Institute of Lille; IT-Omics firm).

First, genomic studies aim to analyze genetic factors which may explain multi-factorial diseases such as diabetes, obesity or cardiovascular diseases. The scientific goal was to formulate hypotheses describing associations that may have any influence on diseases under study.

Secondly, in the context of post-genomic, a very large amount of data are obtained thanks to advanced technologies and have to be analyzed. Hence, one of the goals of the project was to develop analysis methods in order to discover knowledge in data coming from biological experiments.

These problems can be modeled as classical datamining tasks (Association rules, feature selection). As the combinatoric of such problems is very high and the quality criteria not unique, we proposed to model these problems as multi-objective combinatorial optimization problems. Evolutionary approaches have been adopted in order to cope with large scale problems.

Nowadays the technology is still going fast and the number of data increases rapidly. Within the new collaboration, started in 2010, with Genes Diffusion, specializes in genetics and animal reproduction for bovine, swine, equine and rabbit species, we will study combinations of Single Nucleotide Polymorphisms (SNP) that can explain some phenotypic characteristics.

4.3.2. Docking and conformational sampling

In molecular modelling, conformational sampling and docking procedures provide help for understanding the interaction mechanisms between (macro)molecules involved in physiological processes. The processes to be simulated are of a combinatorial complexity (molecule size, number of degrees of freedom) which represents an important challenge for the currently available computing power. Such a challenge can be expressed by three major objectives: (1) the proposition of mathematical models of maximum simplicity that nevertheless provide a relevant description of molecular behavior, (2) the development of powerful distributed optimization algorithms (evolutionary algorithms, local search methods, hybrid algorithms) for sampling the molecular energy surface for stable, populated conformations, and (3) the deployment of those intrinsic distributed algorithms on computational Grids.

Within the framework of ANR DOCK and Decrypton projects, the focus was to propose multi-objective formulations of the conformational and docking problems. The goal was to take into account different criteria characteristics of the complex docking process. Furthermore, in order to deal with the multimodal nature of the problems it is important to define new hybrid mechanisms allowing us to provide algorithms with both diversification and intensification properties. Finally, to deal with the exponential combinatory of these problems when large proteins are concerned parallel and grid computing is highly required. Using grid computing is not straightforward, so a "gridification" process is necessary. Such process allows us to adapt the proposed algorithms to the characteristics of the grid. The gridification process must be exploited by the user in a transparent way. Therefore, coupling ParadisEO-PEO with a generic grid middleware such as Globus is important to provide robust and efficient algorithms to be exploited transparently.

New contacts with the Servier company show that these questions are really challenging ones for the design of new drug molecules.

4.3.3. Optimization for health care

The new collaboration (PhD thesis started in october 2010) with Alicante company, major actor in the hospital decision making, will deal with knowledge extraction by optimization methods for improving the process of inclusion in clinical trials. Indeed, conducting a clinical trial, allowing for example to measure the effectiveness of a treatment, involves selecting a set of patients likely to participate to this test. Currently existing selection processes are far from optimal, and many potential patients are not considered. The objective of this collaboration consists in helping the practitioner to quickly determine if a patient is interesting for a clinical trial or not. Exploring different data sources (from a hospital information system, patient data...), a set of decision rules have to be generated. For this, approaches from combinatorial optimization will be implemented, requiring extensive work to model the problem, to define criteria optimization and to design specific optimization methods.

5. Software

5.1. ParadisEO

Participants: Karima Boufaras, Laetitia Jourdan, Arnaud Liefooghe, Thé Van Luong, Nouredine Melab, El-Ghazali Talbi [correspondent], Sébastien Verel.

ParadisEO (PARallel and DIStributed Evolving Objects) is a C++ white-box object-oriented framework dedicated to the flexible design of metaheuristics. See web pages http://paradiseo.gforge.inria.fr/. Based on EO, a template-based ANSI-C++ compliant evolutionary computation library, it is composed of four modules:

- Paradiseo-EO provides tools for the development of population-based metaheuristic (evolutionary and genetic algorithm, genetic programming, particle swarm optimization, etc.)
- Paradiseo-MO provides tools for the development of single solution-based metaheuristics (hill-climbing, tabu search, simulated annealing, iterative local search, variable neighborhood search, incremental evaluation, partial neighborhood, etc.)
- Paradiseo-MOEO provides tools for the design of multi-objective metaheuristics (MO fitness assignment, MO diversity preservation, elitism, performance indicators, easy-to-use state-of-the-art algorithms, etc)
- Paradiseo-PEO provides tools for the design of parallel and distributed metaheuristics (parallel evaluation, parallel evaluation function, island model)

Furthermore, Paradiseo also introduces tools for the design of distributed, hybrid and cooperative models:

- High level hybrid metaheuristics: coevolutionary and relay models.
- Low level hybrid metaheuristics: coevolutionary and relay models.

The ParadisEO framework has been especially designed to best suit to the following objectives:

- Maximum design and code reuse: ParadisEO is based on a clear conceptual separation of the solution methods from the problems they are intended to solve. This separation confers to the user a maximum code and design reuse.
- Flexibility and adaptability: The fine-grained nature of the classes provided by the framework allows a higher flexibility compared to other frameworks.
- Utility: ParadisEO allows the user to cover a broad range of metaheuristics, problems, parallel distributed models, hybridization mechanisms, etc.
- Transparent and easy access to performance and robustness: As the optimization applications are often time-consuming the performance issue is crucial. Parallelism and distribution are two important ways to achieve high performance execution. ParadisEO is one of the rare frameworks that provide the most common parallel and distributed models. These models can be exploited in a transparent way, one has just to instantiate their associated provided classes.
- Portability: The implemented models are portable on distributed-memory machines as well as on shared-memory multiprocessors, as they use standard libraries such as MPI and PThreads.

This year, with the aim of reenforcing ParadisEO, much works has been established:

- A new design and implementation of the Paradiseo-MO module.
- The addition of local search algorithms for multiobjective optimization.
- The addition of a new module dedicated to parallel metaheuristics on graphics cards.

All the new features is managed via the INRIA's Gforge project http://paradiseo.gforge.inria.fr.

5.1.1. Paradiseo-MO: a new design and fitness landscape

In the previous version of ParadisEO-MO, each local search algorithm was implemented as a whole, with only a small number of components shared with the others. Moreover, there was no component to trace statistics on local search execution, and no way to implement them easily, in opposition to the ParadisEO philosophy. A new design and implementation of the ParadisEO-MO module has been achieved, allowing one to tackle an optimization problem as a whole, from its analysis to its resolution. In comparison to the previous version of the framework, the modularity has been largely improved, together with an easier reuse of basic components. Another brand new feature of the ParadisEO-MO software framework relates to sampling and statistical tools for fitness landscape analysis.

The new design is based on a clear conceptual separation of the solution methods from the problems they are intended to solve, new concepts are proposed :

- Neighbor : Moves and saves neighbor informations (fitness and more)
- Neighborhood : Describes how to compute all the neighbors
- Evaluation : Can be incremental or full evaluation

Different features are included to improve the set of ParadisEO-MO modular classes combined to develop single solution based metaheuristics:

- General scheme of Local Search algorithms (LS)
- List of Local search algorithms :
  - Hill-climbing (4 different methods)
  - Random Walk (3 different methods)
  - Metropolis Hasting
  - Simulated annealing
  - Tabu search

  - Iterated local search
  - Variable neighborhood search
- New tools to perform fitness landscapes analysis:
  - Density of states
  - Fitness distance correlation
  - Autocorrelation length and function
  - Sampling the local optima by adaptive walks
  - Neutral degree distribution
  - Evolvability of neutral networks by neutral walks
  - Fitness cloud
- New stopping criteria and control method have been added
- Predefined neighborhood operators for standard problem representations

5.1.2. Paradiseo-MOEO and multiobjective local search

This year, we particularly improved the module dedicated to multiobjective optimization in terms of local search metaheuristics. As a first step, we focused on a subclass of pure neighborhood search methods. These algorithms can be seen as a generalization of the most basic local search procedure for the multiobjective case. Generally speaking, they combine the definition of a neighborhood structure with the management of a population (or archive) of potentially efficient solutions according to a dominance relation. This archive is iteratively improved by exploring the neighborhood of its own content until no further improvement is possible, or until a stopping condition is satisfied. We denoted them as *Dominance-based Multiobjective Local Search* (DMLS). We also started to implement scalar (preference-based) solution-based local search approaches that should be incorporated in the next version of the platform.

Additionally, some hybridization approaches based on the relay mode have been proposed to hybridize easily evolutionary algorithms with local search during mutation or checkpointing in a multiobjective context. At last, archiving good-quality solutions during the execution of the algorithm is often a large part of the execution time. Thus it was important to provide advanced techniques to reduce this cost. Several solutions proposed in the literature have been implemented. All theses new components have been tested and documented.

5.1.3. ParadisEO-GPU

We proposed a pioneering framework called ParadisEO-GPU for the reusable design and implementation of parallel local search metaheuristics (S-Metaheuristics) on Graphics Processing Units (GPU). We have first revisited the ParadisEO-MO software framework to allow its utilization on GPU accelerators focusing on the parallel iteration-level model, the major parallel model for S-Metaheuristics. It consists in the parallel exploration of the neighborhood of a problem solution.

The challenge is on the one hand to rethink the design and implementation of this model optimizing the data transfer between the CPU and the GPU. On the other hand, the objective is to make the GPU as transparent as possible for the user minimizing his or her involvement in its management. From a design point of view, we proposed solutions to this challenge as an extension of the ParadisEO framework. Indeed, a conceptual effort has been done to take into account the aspects related to the GPU architecture and to the ParadisEO-MO module. It has allowed to identify the generic components that are transparent to the user: memory allocation/desallocation on GPU, data transfer between the CPU and the GPU, parallel evaluation of the neighborhood on GPU, structures for the neighborhood evaluation on CPU/GPU, etc.

The first release of the new GPU-based ParadisEO framework has been experimented on the permuted perceptron problem and on the quadratic assignement problem. The preliminary results are convincing, both in terms of flexibility and easiness of reuse at implementation, and in terms of efficiency at execution on GPU.

5.1.4. New technical features

Regarding the technical aspects, the compatibility with dependencies taken into account is:

- Checked compatibility with different operating systems
- Reviewed and checked compatibility with new versions of the tools used (Cmake, g++, Visual Studio...)
- Unit test of all additional components, and experiments on classical applications
- A new Website design, with a rearrangement of information based on a set of collected statistics

5.1.5. Contributions and documentations

Many investigations were made in this context in order to help users to manipulate the framework.

New documentation:

- The API documentation is available on the ParadisEO Website
- New tutorials
  - Hill Climbing
  - Neighborhoods (classical and indexed)
  - Simulated Annealing and Checkpointing
  - Tabu Search
  - Iterated Local Search
  - Fitness Landscapes Analysis
  - Hybrid Lesson

Moreover, a set of implementations for classical problems are now provided as contributions, available within the new version of ParadisEO:

- Single-objective problems: oneMax, queen, quadratic assignment problem, royal road, long path, building block royal road, NK landscapes, NKq landscapes, NKp landscapes, MAX-SAT, unconstrained binary quadratic programming problem, and more.
- Multi-objective problems: traveling salesman problem, quadratic assignment problem, multiple and long path problems.

6. New Results

6.1. Generalizing dual-feasible functions to the multi-dimensional case

Participant: F. Clautiaux.

Dual-feasible functions have been used in the past to compute lower bounds and valid inequalities for different combinatorial optimization and integer programming problems. Until now, all the dual-feasible functions proposed in the literature were 1-dimensional functions. We extended the principles of dual-feasible functions to the m-dimensional case by introducing the concept of vector packing dual-feasible function. We explored the theoretical properties of these functions in depth, and we proposed general schemes for generating some instances of these functions. Additionally, we proposed and analyzed different new families of vector packing dual-feasible functions. All the proposed approaches were tested extensively using benchmark instances of the 2-dimensional vector packing problem. Our computational results show that these functions can approximate very efficiently the best known lower bounds for this problem and improve significantly the convergence of branch-and- bound algorithms.

6.2. Aggregation algorithms for network flow mathematical models

Participant: F. Clautiaux.

We designed a general framework for solving very large network flow mathematical models that use a pseudo-polynomial number of variables. It is based on an initial aggregation of the vertices of the model and its iterative refinement using different optimization techniques. This led to large improvements for a special case of vehicle routing problem. Several theoretical questions regarding convergence, worst-case analysis and approximation algorithms are raised by our work and are now under study.

6.3. New Price Setting models in the Energy Field

Participant: L. Brotcorne.

The electricity supply industry is facing in many countries a restructuring process towards deregulation and competition. In that context classical marginal cost based approaches based on estimation of cost production function and demand functions are not well-suited anymore. Indeed, the energy prices have to be defined not only to retrieve the production costs but also in order to take into account the consumer behavior. Consumers make their choice of service, or of energy provider in order to minimize their disutility values. Failing to recognize that may lead to tremendous lack on revenues. In order to capture this hierarchical decision process where a leader (the energy provider) takes explicitly into account the reaction of a follower (the consumers) in his decision process (see for example [1]) the energy pricing problems addressed in this subject have been modeled as bilevel programs.

6.4. Bi-level formulation for a Long-Distance Freight Transportation Problem

Participants: M. Diaby, L. Brotcorne, E.-G. Talbi.

A company wants to convey different types of products from origin i to points of destination j. It can deliver the goods itself or hire a transport company, and subcontract part of the application. The transport company must offer attractive prices while aiming to maximize its profit. The aim of this problem is to determine rates that allow the carrier to maximize its revenues and remain affordable for the customer. The problem is modeled as a bilevel program at the first level, the carrier (leader) wants to maximize its revenues; at the second level, the client (follower) aims to minimize its expenses. A primal dual heuristic has been proposed to solve the problem.

6.5. Advances in Parallel Metaheuristics on GPU

Participants: Thé Van Luong, Nouredine Melab, El-Ghazali Talbi.

Nowadays, GPU computing has recently been revealed effective to deal with time-intensive problems. This new emerging technology is believed to be extremely useful to speed up many complex algorithms. One of the major issues for metaheuristics is to rethink existing parallel models and programming paradigms to allow their deployment on GPU accelerators. Generally speaking, the major issues we have to deal with are: the distribution of data processing between CPU and GPU, the thread synchronization, the optimization of data transfer between the different memories, the memory capacity constraints, etc. The contribution of our work is to deal with such issues for the redesign of parallel models of metaheuristics to allow solving of large scale optimization problems on GPU architectures. Our objective is to rethink the existing parallel models and to enable their deployment on GPUs.

Thereby, the new results involve a new generic guideline for building efficient parallel metaheuristics on GPU (e.g. tabu search, iterated local search, island model for evolutionary algorithms, pareto local search or multi-start algorithms). Our challenge is to come out with the GPU-based design of the whole hierarchy of parallel models. In this purpose, very efficient approaches are proposed for CPU-GPU data transfer optimization, thread control, mapping of solutions to GPU threads or memory management. These approaches have been exhaustively experimented using eleven optimization problems and six GPU configurations. Compared to a CPU-based execution, experiments report up to 80-fold acceleration for large combinatorial problems and up to 2000-fold speed-up for a continuous problem. The different works related to our work have been accepted in a dozen of publications, including the IEEE Transactions on Computers journal.

6.6. Parallel Evolutionary Algorithms for Energy-Aware Scheduling

Participants: Y. Kessaci, M. Mezmaz, N. Melab, E.-G. Talbi, D. Tuyttens.

In the last decades, energy becomes an increasingly important issue in computing and embedded systems. In computing systems, minimizing energy consumption can significantly reduce the amount of energy bills. The demand for computing systems steadily increases and the cost of energy continues to rise. In embedded systems, reducing the use of energy allows to extend the autonomy of these systems. In addition, the reduction of energy decreases greenhouse gas emissions. Therefore, many researches are carried out to develop new methods in order to consume less energy. In this work, we propose an overview of the main methods used to reduce the energy consumption in computing and embedded systems.

As a use case and to give an example of a method, this work describes our new parallel bi-objective hybrid genetic algorithm that takes into account the completion time and the energy consumption. In terms of energy consumption, the obtained results show that our approach outperforms previous scheduling methods by a significant margin. In terms of completion time, the obtained schedules are also shorter than those of other algorithms.

6.7. A Parallel Bi-objective Hybrid Metaheuristic for Energy-Aware Scheduling for Cloud Computing Systems

Participants: M. Mezmaz, N. Melab, Y. Kessaci, Y.C. Lee, E.-G. Talbi, A.Y. Zomaya, D. Tuyttens.

In this work, we investigate the problem of scheduling precedence-constrained parallel applications on heterogeneous computing systems (HCSs) like cloud computing infrastructures. This kind of applications was studied and used in many research works. Most of these works propose algorithms to minimize the completion time (makespan) without paying much attention to energy consumption. We propose a new parallel bi-objective hybrid genetic algorithm that takes into account, not only makespan, but also energy consumption. We particularly focus on the island parallel model and the multi-start parallel model. Our new method is based on dynamic voltage scaling (DVS) to minimize energy consumption. In terms of energy consumption, the obtained results show that our approach outperforms previous scheduling methods by a significant margin. In terms of completion time, the obtained schedules are also shorter than those of other algorithms. Furthermore, our study demonstrates the potential of DVS.

6.8. A Pareto-based GA for Scheduling HPC Applications on Distributed Cloud Infrastructures

Participants: N. Melab, E.-G. Talbi.

Reducing energy consumption is an increasingly important issue in cloud computing, more specifically when dealing with High Performance Computing (HPC). Minimizing energy consumption can significantly reduce the amount of energy bills and then increase the provider's profit. In addition, the reduction of energy decreases greenhouse gas emissions. Therefore, many researches are carried out to develop new methods in order to consume less energy. In this work, we present a multi-objective genetic algorithm (MO-GA) that optimizes the energy consumption, CO_2 emissions and the generated profit of a geographically distributed cloud computing infrastructure. We also propose a greedy heuristic that aims to maximize the number of scheduled applications in order to compare it with the MO-GA. The two approaches have been experimented using realistic workload traces from Feitelson's PWA Parallel Workload Archive. The results show that MO-GA outperforms the greedy heuristic by a significant margin in terms of energy consumption and CO_2 emissions. In addition, MO-GA is also proved to be slightly better in terms of profit while scheduling more applications.

6.9. An Hybrid Multiobjective Method to solve Biclustering of Microarray Data

Participants: L. Jourdan, K. Seridia, E.-G. Talbi.

In this work, we propose an a multi-objective genetic algorithm (NSGA-II) with a heuristic to solve the biclutering problem of micro-array data. Due to the huge size of the datasets, we propose a new representation based on a string of integers and the associated operators. Experimental results on real data set show that our approach can find significant biclusters of high quality.

6.10. Flexibility and dynamic optimization

Participants: L. Jourdan, M. Khouadjia, E.-G. Talbi.

In this work we propose a new method that explicitly searches for routes that are flexible enough to allow easy adaptation after a new order has arrived. For that we propose a measure of flexibility, and show that better solutions can be obtained when the "planning horizon" for all subproblems is modified to take the flexibility of solutions into account.

6.11. Indicator-based Multi-objective Local Search

Participant: A. Liefooghe.

In the last few years, a significant number of multi-objective metaheuristics have been proposed in the litterature in order to address real-world problems. Local search methods play a major role in many of these metaheuristic procedures. We adapt a recent and popular indicator-based selection method in order to define a population-based multi-objective local search. The proposed algorithm is designed in order to be easily adaptable, parameter independent and to have a high convergence rate. The capacity of our algorithm to reach these goals is evaluated on a large bunch of experiments. Three combinatorial optimization problems are investigated: a flow-shop scheduling problem, a ring star problem and a nurse scheduling problem. The experiments show that our algorithm can be applied with success to different types of multi-objective optimization problems and that it outperforms some classical metaheuristics. Furthermore, the parameter sensitivity analysis enables us to provide some useful guidelines about how to set the main parameters.

6.12. Connectedness and Local Search for Bi-objective Knapsack Problems

Participant: A. Liefooghe.

In [33], we report an experimental study on a given structural property of connectedness of the set of Pareto-optimal solutions for two variants of the bi-objective knapsack problem. A local search algorithm that explores this property is then proposed and its performance is compared against exact algorithms in terms of running time and number of optimal solutions found. The experimental results indicate that this simple local search algorithm is able to find a representative set of Pareto-optimal solutions in most of the cases, and in much less time than exact approaches.

6.13. Set-based Multiobjective Fitness Landscapes

Participants: S. Verel, A. Liefooghe, C. Dhaenens.

Fitness landscape analysis aims to understand the geometry of a given optimization problem in order to design more efficient search algorithms. However, there is a very little knowledge on the landscape of multiobjective problems. In [43], we consider multiobjective optimization as a set problem. Then, we give a general definition of set-based multiobjective fitness landscapes. An experimental set-based fitness landscape analysis is conducted on the multiobjective NK-landscapes with objective correlation. The aim is to adapt and to enhance the comprehensive design of set-based multi-objective search approaches, motivated by an a priori analysis of the corresponding set problem properties. Our experimental study shows that tools from single-objective fitness landscapes can directly be extended for analyzing set-based multiobjective search approaches. The relevant features of multimodality and ruggedness has been highlighted for this particular class of problems.

6.14. On the Structure of Multiobjective Combinatorial Search Space: Multiobjective NK-Landscapes with Correlated Objectives

Participants: S. Verel, A. Liefooghe, L. Jourdan, C. Dhaenens.

The structure of the search space explains the behavior of multiobjective search algorithms, and helps to design well-performing approaches. In this work, we analyze the properties of multiobjective combinatorial search spaces, and we pay a particular attention to the correlation between the objective functions. To do so, we extend the multiobjective NK-landscapes in order to take the objective correlation into account. We study the co-influence of the problem dimension, the degree of non-linearity, the number of objectives, and the objective correlation on the structure of the Pareto optimal set, in terms of cardinality and number of supported solutions [45], as well as on the number of Pareto local optima [46]. This work concludes with guidelines for the design of multiobjective local search algorithms, based on the main fitness landscape features. All our results show that no expectation on the performance of multiobjective local search algorithms can be drawn without taking the problem properties into account very precisely. Indeed, it has now become clear that the number of objectives is one of the key issue to explain a problem complexity, but we also pointed out that the objective correlation is at least as important. Multiobjective fitness landscape analysis plays a central role to explain the performance of local search algorithms, and to design more efficient methods, that suit better the problem features.

6.15. On the Neutrality of Combinatorial Optimization Problem to Design an Efficient Neutrality-based Local Search

Participants: M.-E. Marmion, C. Dhaenens, L. Jourdan, A. Liefooghe, S. Verel.

In the context of the permutation flowshop scheduling problem, a deep landscape analysis focused on the neutrality property has been driven [hal-00550356]. This analysis characterizes the neutral networks of the local optima in order to make propositions about the way to exploit it in algorithms. Hence, NILS has been designed in order to exploit the neutrality of local optima [hal-00563459]. As soon as a local optimum is found, the search is allowed to move to equivalent neighbors. Moreover, NILS gets only one parameter that controls the number of solutions allowed to be visited with the same fitness value. NILS has been tested on flowshop and has shown promising results.

6.16. Guiding the Search over Neutral Networks

Participants: M.-E. Marmion, C. Dhaenens, L. Jourdan, A. Liefooghe, S. Verel.

In a context of neutrality, VEGAS was designed to escape from neutral networks based on the evolvability of solutions, and on a multi-armed bandit by selecting the more promising solution from the neutral network [hal-00579990]. Its main feature is to consider the whole evaluated solutions of a neutral network rather than the last accepted solution as classical methods. VEGAS was tested on NKq-landscapes (problems built to present neutral properties) and results show the importance of considering the whole identified solutions from the neutral network and of guiding the search explicitly.

6.17. DAMS: Distributed Adaptive Metaheuristic Selection

Participants: B. Derbel, S. Verel.

In this work, we design a new Distributed Adaptive Metaheuristic Selection (DAMS) scheme. DAMS is dedicated to adaptive optimization in distributed environments. Given a set of metaheuristics, the goal of DAMS is to coordinate their local execution on distributed nodes in order to optimize the global performance of the distributed system. DAMS is based on three-layer architecture allowing nodes to decide distributively what local information to communicate, and what metaheuristic to apply while the optimization process is in progress. Within this context, we specialize DAMS by describing a particular instantiation called Select Best and Mutate (SBM). Its is a simple, yet efficient, adaptive distributed algorithm using an exploitation component allowing nodes to select the metaheuristic with the best locally observed performance, and an exploration component allowing nodes to detect the metaheuristic with the actual best performance. SBM features are analyzed from both a parallel and an adaptive point of view, and its efficiency is demonstrated through experimentations and comparisons with other adaptive strategies (sequential and distributed).

6.18. A Method to Combine Combinatorial Optimization and Statistics to Mine High-Throughput Genotyping Data

Participants: J. Hamon, C. Dhaenens, J. Jacques.

In collaboration with Gènes Diffusion, we are interested in high-throughput genotyping data in order to select a subset of genes explaining a trait of interest. We suggest to study these high-throughput data combining combinatorial optimization and statistical methods. A first method based on an ILS (Iterated Local Search) and using a statistical criterion to calculate the fitness was suggested and compared with classical statistical approaches.

6.19. Recruitment Optimization in Clinical Trials : a Multi-Objective Combinatorial Optimization Problem

Participants: J. Jacques, L. Jourdan, C. Dhaenens.

This work focuses on helping clinical trials investigators to screen more patients. First, we performed an analysis of clinical trial business and medical data available in French hospitals. We carried on several expert interviews. Then we developed a model to this problem as an association rules mining problem. After a statistical study of rule interestingness measures, we proposed an improvement of this model as a multi-objective combinatorial optimization problem.

6.20. Reducing Thread Divergence in GPU-based B&B Applied to the Flow-shop Problem

Participants: I. Chakroun, A. Bendjoudi, N. Melab.

Branch-and-Bound (B&B) algorithms are attractive methods for solving to optimality combinatorial optimization problems. Nevertheless, they are time-intensive when dealing with large problem instances. Therefore, several parallel B&B strategies based on large computer clusters and grids have been proposed in the literature. However, to the best of our knowledge no contribution has been proposed for designing B&B algorithms on GPUs (Graphic Processing Units). Because of their tremendous computing power and remarkable cost efficiency, GPUs have been recently revealed as a powerful way to achieve high performance on long-running scientific applications. In this research work, we propose to revisit the design and implementation of B&B algorithms on GPU. We focus on the parallel evaluation of the bounds since preliminary experiments performed on the Flow-Shop scheduling problem (FSP) have shown that the bounding operation consumes over 98% of the execution time of the B&B algorithm. To deal with thread divergence reduction issue caused by the bounding operation a code refactoring approach have been proposed.

6.21. Fitness Landscapes: Local Optima Network

Participant: S. Vérel.

A new methodology to study the structure of the configuration spaces of hard combinatorial problems. It consists in building the network that has as nodes the locally optimal configurations and as edges the weighted oriented transitions between their basins of attraction. We apply the approach to the detection of communities in the optima networks produced by two different classes of instances of a hard combinatorial optimization problem: the quadratic assignment problem (QAP). We provide evidence indicating that the two problem instance classes give rise to very different configuration spaces. For the so-called real-like class, the networks possess a clear modular structure, while the optima networks belonging to the class of random uniform instances are less well partitionable into clusters.

7. Contracts and Grants with Industry

7.1. Contracts with industry

+ Opalean (2010-2011) : Constrained network-flow optimization
+ EDF (2010-2011): Bilevel mathematical programming and pricing problems.
+ Alicante (2010-2013): PhD of Julie Jacques. Knowledge extraction by optimization methods for improving the process of inclusion in clinical trials.
+ Genes Diffusion (2010-2013): PhD of Julie Hamon. Analysis of data from high throughput genotyping: cooperation between statistics and combinatorial optimization.
+ EDF (2011-2014): Scheduluing outages of nuclear plants.
+ Tasker (2011-2014) : Scheduling of applications in hybrid cloud computing systems.

8. Partnerships and Cooperations

8.1. Regional Initiatives

+ PPF (Bioinformatics): This national program within the university of Lille (USTL) deals with solving bioinformatics and computational biology problems using combinatorial optimization techniques, 2006-2009 ; 2010-2013.
+ PPF “High performance computing”,2010-2013.
+ CIA (Campus Intelligence Ambiante) project from CPER (Contrat Plan Etat Région): Transversal research action: “High performance computing”, 2010-2013.

8.2. National Initiatives

+ GRISBI project (IBISA program) “Grids for bioinformatics”, involving six national bioinformatics platforms: PRABI Lyon, GenOuest Rennes and Roscoff, CBiB Bordeaux, BIPS Strasbourg, CIB Lille, MIGALE Jouy-en-Josas, 2008-2011
+ ANR GAZE & EEG (Programme Blanc NT09_511856). Coordinator: A. Guérin-Dugué (University of Grenoble), 2009-2011.
+ GdR-RO project (CNRS) "Set-based Search for Multiobjective Combinatorial Optimization", involving the University of Angers (France), 2011

8.3. European Initiatives

8.3.1. Collaborations in European Programs, except FP7

Program: COST

Project acronym: IC0804

Project title: Energy efficiency in large scale distributed systems

Duration: Jan 2009 - May 2013

Coordinator: J. M. Pierson

Other partners: More than 20 European countries.

Abstract: The COST Action IC0804 proposes realistic energy-efficient alternate solutions to share IT distributed resources. As large scale distributed systems gather and share more and more computing nodes and Storage resources, their energy consumption is exponentially increasing. While much effort is nowadays put into hardware specific solutions to lower energy consumptions, the need for a complementary approach is necessary at the distributed system level, i.e. middleware, network and applications. The Action characterizes the energy consumption and energy efficiencies of distributed applications.

8.3.2. Major European Organizations with which you have followed Collaborations

University of Luxembourg: CSC, ILIAS (Luxembourg)

Design of parallel and hybrid metaheuristics to solve complex optimization problems

University of Malaga: ETSI Informatica (Spain)

Parallel metaheuristics for dynamic optimization

8.4. International Initiatives

8.4.1. INRIA Associate Teams

8.4.1.1. MOMDI

Title: Dynamic and multi-criteria combinatorial optimization on Grid computing systems

INRIA principal investigator: Talbi El Ghazali

International Partner:

Institution: University of Malaga (Spain)

Laboratory: E.T.S.I Informatica

Duration: 2009 - 2011

See also: http://dolphin.lille.inria.fr/Dolphin/EA-DOLPHIN

8.4.2. International Cooperation

- University of Sydney, Australia
- University of Montreal, Canada
- Ecole Polytechnique of Montreal, Canada

8.4.3. Visits of International Scientists

The project had visitors during the year 2010:

- Prof. Khaled Mellouli, University of Tunis
- Prof. Theodore Crainic, University of Montreal
- Prof. Pascal Bouvry, University of Luxembourg

8.4.4. Participation In International Programs

- INRIA project 3+3 Méditerrannée PERFORM (2006-2012) involving the University of Malaga (Spain), University of Constantine (Algeria), and University of Tunis (Tunisia). This project deals with multi-objective optimization.
- Project FCT MST4IROT: New models and solution techniques for integrated and real-time optimization in the supply chains (Project in Portugal, coordinator Claudio Alves). Participants: Universities of Minho (PT), Valenciennes, Compiègne, Lille and Brunel (UK) : Real-Time Optimization in Supply-Chain.
- INRIA STIC-Algérie 2011-2012.
- INRIA STIC-Tunisie 2011-2012.

9. Dissemination

9.1. Animation of the scientific community

Members from the DOLPHIN project team are involved into the following activities relation to the animation of the scientific community.

9.1.1. Research management

- Co-fondator and chair of the group META (Metaheuristics: Theory and Applications, http://www.lifl.fr/~talbi/META). This group is associated with the ROADEF (French Operations Research Society), and the CNRS research groups GDR ALP and MACS.
- Co-fondator and co-chair of the Euro Working Group en Tarification et Gestion du Revenu. This group is associated with EURO (European Operations Research Society).
- Chair of the group PM2O (Multi-objective Mathematical Programming, http://www.lifl.fr/PM2O). This group is associated with the ROADEF (French Operations Research Society), and the CNRS research group GDR RO (Operations Research).
- International correspondant for ROADEF (French Operations research Society)
- Secretary and Tresorer of EA (National group on evolutionary computation - http://www2.lifl.fr/EA).
- Direction of the CIB (Bioinformatics Center) of the Genopole of Lille.
- Scientific Committee of the Genopole of Lille.
- Steering Committee of the INRIA nation-wide ADT Aladdin-Grid5000.
- Co-leader of an ALADDIN working group on scalability of Grid-enabled algorithms and applications.
- Member of the Scientific Committee of High-Performance Computing of Université Lille1.
- Coordinator of the High Performance Computing collaborative research action at LIFL.
- Leader of the PPF "High Performance Computing" at Université Lille1.
- Member of the committee of the jury to deliver the TSL best paper award (INFORMS: Transportation Section and Logistics).

9.1.2. Participation to working groups

- EURO-PAREO (European working group on Parallel Processing in Operations Research).
- EURO-PRM (European working group on Pricing and Revenue Management).
- EURO-EU/ME (European working group on Metaheuristics).

- EURO-ESICUP (European Working Group on Cutting and Packing).
- EURO–MCDA (European Working Group on Multicriteria Decision Aiding).
- ECCO (European Chapter on Combinatorial Optimization).
- ERCIM (European Research Consortium for Informatics and Mathematics) working group on Soft Computing.
- EA - JET (National Group on Evolutionary Computation).
- KSO (National Group on Cutting and Packing).
- MCDM (International society on multiple criteria decision making)
- META (National Group on Metaheuristics: Theory and Applications).
- PM2O (National Group on Multi-objective Mathematical Programming).

9.1.3. Editions

- Special Issue (Graph and Optimization Meeting 2008) in Networks, volume 58, issue 2, 2011
- Special issue (edited by E-G. Talbi and G. Hasle) in JPDC " Journal of Parallel and Distributed Computing (JPDC)" on "Metaheuristics on GPUs", Vol.71, No.4, 2011.

9.1.4. Organizations of sessions, workshops and conferences

- Organization of the Stream on Pricing and Revenue Management at IFORS 2011 (The International of Operational Research Societies), Melbourne
- Publicity chair of international conference EA 2011 (Angers, France)
- Co-organization of the 6th summer school of EA 2011 (Calais, France)
- Organization of sessions at ROADEF 2011 (St Etienne, France)

9.1.5. Editorial boards

- Editorial board of the International Journal of Intelligent Computing and Cybernetics (IJICC)
- Editorial board of the International Journal of Innovative Computing and Applications (IJICA)
- Editorial board of the International Journal of Pervasive Computing and Communications
- Editorial board of the Book Series in Intelligent Systems Engineering, Nova science Publishers, NY, USA
- Advisory board of the Book Series on Nature Inspired computing, Wiley & Sons, NY, USA
- Honorary Advisory Board of the International Journal on Mathematical Modeling and Numerical Optimization (IJMMNO)
- Editorial board of the Mediterranean Journal of Artificial Intelligence (MJAI)
- Editorial board of the International Journal of Data Mining, Modelling and Management (IJDMM)

9.1.6. Reviews

- Review of research projects:
  - Evaluation of a three-year project for the ANR (Agence Nationale pour la Recherche)
  - Evaluation of an open competition Project Proposal for Netherlands Organization for Scientific Research (NWO).
  - Evaluation of a JEI (Jeune Entreprise Innovante) and evaluation of a proposal for the CIR (Crédit Impôt recherche).
  - Evaluation of PEPS - PEPII for CNRS

  - Evaluation of national project fund by Luxembourg

- Review of journal papers:
  - Journal of Soft Computing
  - Journal of Discrete Applied Mathematics
  - COR: Computers & Operations Research (Elsevier)
  - Transportation Science(Informs)
  - European Journal of Operational Research (Elsevier)
  - Journal of Heuristics (Springer)
  - KNOSYS: Knowledge-Based Systems (Elsevier)
  - Expert Systems: The Journal of Knowledge Engineering (Wiley-Blackwell)
  - GENO: Engineering Optimization (Taylor & Francis)
  - Journal of Parallel Computing
  - Journal of Knowledge and Information Systems
  - Journal of Memetic Computing
  - International Journal of AI Tools
  - Journal of Zhejiang University-SCIENCE B
  - Journal of Parallel and Distributed Computing
  - International Journal of Production Economics

9.1.7. Program committees

- EA 2011
- LION 6
- GECCO 2011
- IFORS 2011, Melbourne, 2011
- CPAIOR 2012, Nantes, 2012
- ROADEF 2011, "douzième congrès de la Société Française de Recherche Opérationnelle et d'Aide 'a la Décision"
- "Journée Polyèdre et Optimisation Combinatoire" (JPOC), Valenciennes, 2011
- ALEA 2011: Artificial Life and Evolutionary Algorithms, as a part of EPIA 2011, Lisbon, Portugal, 2011
- EMO 2011: 6th International Conference on Evolutionary Multi-criterion Optimization, Ouro Preto, Brazil, 2011

El-Ghazali Talbi was member of the program committee of the following conferences

- GECCO'2011, Dublin, Ireland.
- EA'2011, Angers, France.
- EvoCop'2011, Torino, Italy, Avril 2011.
- EvoBio'2011, Torino, Italy, Avril 2011.
- MIC'2011, Udine, Italy, July 2011.
- BIOMA'2011, Bohinj, Slovenia, Oct 2011.
- MCDM'2011, Paris, France, April 2011.
- SLS'2011, Sept 2011, Brussels, Belgium.

- HAIS'2011 6th Int. Conf. on Hybrid Artificial Intelligence Systems", Wroclaw, Poland, May 2011.
- Workshop IEEE PCO'2011, Anchorage, USA, May 2011.
- 6th Int. Workshop on Intelligent Informatics in Biology and Medecine (IIBM'2011), Seoul, Korea, Feb 2011.
- IESM'2011 Int. Conf. on Industrial Engineering and Systems Management, Metz, France, May 2011.
- ISOR'2011 Int. Symposium on Operational Research, Algiers, Algeria, May 2011.
- ICPCA'2011 6th Int. Conf. on Pervasive Computing and Applications, Port Elisabeth, South Africa, Oct 2011.
- ICSI'2011 Int. Conf. On Swarm Intelligence, Cergy, France, June 2011.
- iCAST'2011: 3rd IEEE International Conference on Awareness Science and Technology, Dalian, China, Sept 2011.
- GreenITEC'11 Workshop on "GreenIT Evolutionary Computation" as part of GECCO' 2011, Dublin, Ireland, July 2011.

9.1.8. Phd and HdR committees

El-ghazali Talbi was a jury member of the following Phd thesis:

- Semya Elaoud, "Genetic and exact methods to solve multi-objective optimization problems", University of Mons, Belgium.
- Juan Jose Durillo, "Metaheuristics for multi-objective optimization: design, analysis and applications", University of Malaga, Spain.
- Elisabeth Montero, "Calibration strategies for bio-inspired population-based algorithms that solve combinatorial optimization problems", University of Nice-Sophia Antipolis.

Clarisse Dhaenens was a jury member of the following PhD thesis:

- Saoud Larabi Marie-Sainte, "Bio-inspired algorithms for exploratory projection pursuit", University of Toulouse, juin 2011. Jury: A. Berro, C. Bertelle, C. Dhaenens (referee), A. Gazen, J. Mothe, P. Winker.
- Jérôme Dubois, "Contribution à l'algorithmique et à la programmation efficace des nouvelles architectures parall eles comportant des accélérateurs de calcul dans le domaine de la neutronique et de la radioprotection", Université lille I, octobre 2011. Jury : C. Calvin, M. Daydé, C. Dhaenens (president), A. Drummond, S. Petiton, M. Snir.
- Sami Laroum, "Prédiction de la localisation de protéines membranaires : méthodes méta-heuristiques pour la détermination du potentiel d'insertion des acides aminés", Université d'Angers, novembre 2011. Jury: C. Dhaenens (referee), B. Duval, J-K. Hao, F. Jacquenet, D. Lavenier, D. Tessier.
- Julien Darlay, "Analyse combinatoire de données: Structure et optimisation", Université de Grenoble, décembre 2011. Jury: C. Artigues, N. Brauner, Y. Crama, C. Dhaenens (referee), S. Gravier, J. Moncel.

Laetitia Jourdan was a jury member of the following Phd thesis:

- Mohammed Amir Esseghir, "Metaheuristiques pour le problème de la sélection d'attributs: approches mémétiques, adaptatives et particulaires",

9.1.9. Commission

- Presidence of the C2D commission of the Lille INRIA center (Commission Détachement Délégation).
- Participation to a selection committee (Position McF 484, Université Lille I).
- Participation to a selection committee (Position McF, Université de Valenciennes).
- Participation to a selection committee (Concours de Chargé de Recherche INRIA (CR1-CR2).
- Participation to a selection committe for chaire INRIA-Lille 3 (COS 2011)
- Participation to "Comité de Centre INRIA Lille Nord Europe"

9.2. Teaching

Initiation à la programmation, 54h (L1) Université de Lille 1, France

Programmation orienté objet, 80h (DUT informatique), Université de Lille 1, France

Méthodes mathématiques pour la modélisation, 64h, (DUT informatique), Université de Lille 1, France

Conception orientée objet, 48h (DUT informatique), Université de Lille 1, France

Systèmes d'exploitation, 48h (DUT informatique), Université de Lille 1, France

Algorithmique - 50 H eq TD (L3), Engineering school Polytech'Lille.

Graphs and combinatorics - 55 H eq TD (L3), Engineering school Polytech'Lille.

Operations Research - 70 H eq TD, Engineering school Polytech'Lille.

Fouille de données 25h (M1), L1, Université de Lille 1, France,

Informatique Décisionnelle 35h (M1) , Université de Lille 1, France,

Mise à niveau en informatique décisionnelle et en recherche opérationnelle 25h (M1), Université de Lille 1, France

Algorithmique Avancée, Complexité, calculabilité, 32h (M1), Université de Lille 1, France

Operations Research - 70 H eq TD (M1), Engineering school Polytech'Lille.

Combinatorial Optimization, 35h (M2), Université de Lille 1, France

Grid Computing, 16h (M2), Université de Lille 1, France

Parallel and Distributed Programming, 12h (M1), Université de Lille 1, France

Advanced Object Programming, 52h (M1), Université de Lille 1, France

Design of Distributed Applications, 60h (M1), Université de Lille 1, France

Algorithms and Applications, 28h, Université de Lille 1, France

PhD soutenues :

PhD : Alexandre Huart, Optimisation de ressources en logistique urbaine, Université de Valenciennes, 9/12/2011, L. Brotcorne and F. Semet.

PhD : Mostepha Khouadjia, Solving Dynamic Vehicle Routing Problems: From Single-Solution Based Metaheuristics to Parallel Population Based Metaheuristics, Université de Lille 1, 2/12/2011, L. Jourdan and E-G. Talbi

PhD : The-Van Luong, Parallel metaheuristics on GPU, Université de Lille 1, 01/12/2011, N. Melab and E-G. Talbi

PhD : Malika Mehdi, Parallel hybrid optimization methods for permutation based problems, Nov 2011, E-G. Talbi and N. Melab.

PhD in progress :

- Mathieu Djamai, Contributions in peer-to-peer systems for combinatorial optimization, October 2009, N. Melab and B. Derbel.
- Trong-Tuan Vu, Robust distributed algorithms for large scale problem solving, October 2011, N. Melab and B. Derbel.
- Francois Legillon, Ordonnancement d'applications dans les clouds hybrides, October 2011, E-G. Talbi and N. Melab.
- Yacine Kessaci, Energy-aware scheduling in clouds, October 2009, E-G. Talbi and N. Melab.
- Mustapha Diaby, Yield Management and Supply chain Management, September 2010, L. Brotcorne and E-G. Talbi
- Nadia Dahmani, Multi-objective packing problems, September 2010, F. Clautiaux and E-G. Talbi
- Sezin Afsar, Bilevel approaches for energy pricing problems, October 2011, L. Brotcorne
- Khedidja Seridi, Métaheuristiques multiobjectives pour le biclustering,october 2010 L. Jourdan and E-G. Talbi

10. Bibliography

Major publications by the team in recent years

[1] J.-C. Boisson, L. Jourdan, E.-G. Talbi. *Metaheuristics based de novo protein sequencing: A new approach*, in "Applied Soft Computing", 2010, to appear, http://hal.inria.fr/inria-00522628.

[2] C. Dhaenens, J. Lemesre, E.-G. Talbi. *K-PPM: A new exact method to solve multi-objective combinatorial optimization problems*, in "European Journal of Operational Research", 2010, vol. 200, n^{o} 1, p. 45-53, http://hal.inria.fr/inria-00522771.

[3] J. Figueira, A. Liefooghe, E.-G. Talbi, A. P. Wierzbicki. *A parallel multiple reference point approach for multi-objective optimization*, in "European Journal of Operational Research", 2010, vol. 205, n^{o} 2, p. 390 - 400, http://hal.inria.fr/hal-00522619.

[4] N. Jozefowiez, F. Semet, E.-G. Talbi. *Target Aiming Pareto Search and its application to the vehicle routing problem with route balancing*, in "Journal of Heuristics", 2007, vol. 13, p. 455-469.

[5] A. Khanafer, F. Clautiaux, E.-G. Talbi. *New lower bounds for bin packing problems with conflicts*, in "European Journal of Operational Research", 2010, vol. 2, n^{o} 206, http://hal.inria.fr/inria-00522668.

[6] A. Liefooghe, L. Jourdan, E.-G. Talbi. *A software framework based on a conceptual unified model for evolutionary multiobjective optimization: ParadisEO-MOEO*, in "European Journal of Operational Research", 2010, to appear, http://hal.inria.fr/hal-00522612.

[7] M. Mezmaz, N. Melab, E.-G. Talbi. *An efficient load balancing strategy for grid-based branch and bound algorithm*, in "Parallel Computing", 2007, vol. 33, n^{o} 4-5, p. 302–313.

[8] E.-G. Talbi. *Metaheuristics: From Design to Implementation*, Wiley, 2009.

[9] A.-A. TANTAR, N. MELAB, E.-G. TALBI, B. PARENT, D. HORVATH. *A parallel hybrid genetic algorithm for protein structure prediction on the computational grid*, in "Future Gener. Comput. Syst.", 2007, vol. 23, n^{o} 3, p. 398–409.

[10] L. VERMEULEN-JOURDAN, C. DHAENENS, E.-G. TALBI. *Evolutionary Feature Selection for Bioinformatics*, IEEE CS/Wiley, 2007, p. 117–139.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] T. VAN LUONG. *Métaheuristiques parallèles sur GPU*, Université des Sciences et Technologie de Lille - Lille I, December 2011, This thesis is written in English, http://hal.inria.fr/tel-00638820/en.

Articles in International Peer-Reviewed Journal

[12] M. BASSEUR, A. LIEFOOGHE, L. KHOI, B. EDMUND. *The efficiency of indicator-based local search for multi-objective combinatorial optimisation problems*, in "Journal of Heuristics", 2011, to appear, http://hal.inria.fr/hal-00609252/en.

[13] J.-C. BOISSON, L. JOURDAN, E.-G. TALBI. *Metaheuristics based de novo protein sequencing: A new approach*, in "Appl. Soft Comput.", 2011, vol. 11, n^{o} 2, p. 2271-2278, http://hal.inria.fr/inria-00575764/en.

[14] L. BROTCORNE, F. CIRINEI, P. MARCOTTE, G. SAVARD. *An exact algorithm for the network pricing problem*, in "Discrete Optimization", 2011, vol. 8, n^{o} 2, p. 246-258, http://hal.inria.fr/inria-00638444/en.

[15] R. CHEVRIER, A. LIEFOOGHE, L. JOURDAN, C. DHAENENS. *Solving a Dial-a-Ride Problem with a Hybrid Multi-objective Evolutionary Approach: Application to the Demand Responsive Transport*, in "Applied Soft Computing", 2011, http://hal.inria.fr/inria-00591138/en.

[16] F. CLAUTIAUX, C. ALVES, J. VALÉRIO DE CARVALHO, J. RIETZ. *New ways of deriving dual cuts for the cutting-stock problem*, in "INFORMS Journal on Computing", 2011, vol. 23, n^{o} 4, p. 530-545 [*DOI :* 10.1287/IJOC.1100.0415], http://hal.inria.fr/inria-00522669/en.

[17] F. CLAUTIAUX, J. ANTOINE, A. MOUKRIM. *A new graph-theoretical model for k-dimensional guillotine-cutting problems*, in "INFORMS Journal on Computing", 2011 [*DOI :* 10.1287/IJOC.1110.0478], http://hal.inria.fr/hal-00616363/en.

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[21] A. LIEFOOGHE, L. JOURDAN, E.-G. TALBI. *A software framework based on a conceptual unified model for evolutionary multiobjective optimization: ParadisEO-MOEO*, in "European Journal of Operational Research", 2011, vol. 209, n° 2, p. 104-112 [*DOI :* 10.1016/J.EJOR.2010.07.023], http://hal.inria.fr/hal-00522612/en.

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[24] T. V. LUONG, N. MELAB, E.-G. TALBI. *GPU Computing for Parallel Local Search Metaheuristics*, in "IEEE Transactions on Computers", 2012, http://hal.inria.fr/inria-00638805/en.

[25] R. MACEDO, C. ALVES, J. M. VALÉRIO DE CARVALHO, F. CLAUTIAUX, S. HANAFI. *Solving exactly the vehicle routing problem with time windows and multiple routes using a pseudo-polynomial model*, in "European Journal of Operational Research", 2011, to appear, http://hal.inria.fr/hal-00616366/en.

[26] M. MEZMAZ, N. MELAB, Y. KESSACI, Y. C. LEE, E.-G. TALBI, A. Y. ZOMAYA, D. TUYTTENS. *A Parallel Bi-objective Hybrid Metaheuristic for Energy-aware Scheduling for Cloud Computing Systems*, in "Journal of Parallel and Distributed Computing", April 2011, http://hal.inria.fr/hal-00639966/en.

[27] L. VANNESCHI, Y. PIROLA, G. MAURI, P. COLLARD, S. VEREL. *A Study of Neutrality of Boolean Function Landscapes in Genetic Programming*, in "Journal of Theoretical Computer Science", July 2011, p. 50 – 68, http://hal.inria.fr/hal-00563462/en.

Invited Conferences

[28] M. DIABY, L. BROTCORNE, E.-G. TALBI. *Approche à Deux niveaux pour un Problème de Transport Longue Distance*, in "ROADEF", Saint-Etienne, France, March 2011, http://hal.inria.fr/hal-00640434/en.

International Conferences with Proceedings

[29] I. CHAKROUN, A. BENDJOUDI, N. MELAB. *Reducing Thread Divergence in GPU-based B&B Applied to the Flow-shop problem*, in "9th International Conference on Parallel Processing and Applied Mathematics (PPAM)", Torun, Poland, September 2011, http://hal.inria.fr/hal-00640805/en.

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[32] Y. KESSACI, N. MELAB, E.-G. TALBI. *A Pareto-based GA for Scheduling HPC Applications on Distributed Cloud Infrastructures*, in "HPCS", Istanbul, Turkey, July 2011, http://hal.inria.fr/inria-00637752/en.

[33] *Best Paper*
A. LIEFOOGHE, L. PAQUETE, M. SIMOES, J. FIGUEIRA. *Connectedness and Local Search for Bicriteria Knapsack Problems*, in "11th European Conference on Evolutionary Computation in Combinatorial Optimisation - EvoCOP 2011", Torino, Italy, Lecture Notes in Computer Science, Springer Verlag, 2011, vol. 6622, p. 48-59, Best paper award [*DOI :* 10.1007/978-3-642-20364-0_5], http://hal.inria.fr/hal-00575922/en.

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[37] M.-E. MARMION, C. DHAENENS, L. JOURDAN, A. LIEFOOGHE, S. VEREL. *The Road to VEGAS: Guiding the Search over Neutral Networks*, in "Genetic And Evolutionary Computation Conference", Dublin, Ireland, ACM, July 2011, p. 1979–1986 [*DOI :* 10.1145/2001576.2001842], http://hal.inria.fr/hal-00579990/en.

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