INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team dolphin

Parallel Cooperative Multi-criteria Optimization

Lille - Nord Europe

Theme : Optimization, Learning and Statistical Methods

Activity Report

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2. Overall Objectives

2.1. Presentation

The goal of the DOLPHIN[1] project is the modelization 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.

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

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.

- **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

[2] This framework was initially developed by Geneura TEAM (Spain), INRIA (France), LIACS (Netherlands). http://paradiseo.gforge.inria.fr.

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

- New lower bounds for bin packing problems with conflicts [20].
- One challenge has been to come out with the GPU-based design of the WHOLE hierarchy of parallel models for metaheuristics (speed-up factor up to $\times 40$ for combinatorial problems and up to $\times 2000$ for continuous problems).

3. Scientific Foundations

3.1. Modeling and landscape analysis

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 [72] 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] Graphical User Interface for Multi-Objective Optimization (http://guimoo.gforge.inria.fr).

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 [70], [71].

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 [73]. The DOLPHIN research group has proposed two indicators: the *contribution* and the *entropy* [67]. 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 [66]. 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 [62], [65]. 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'.

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 [69]. 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.

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

- *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 [63].

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 [64], [68].

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, Jérémie Humeau, 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, many works have 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 news are managed via the INRIA's Gforge project. A new version of ParadisEO is available since July 2010. See also the web page of ParadisEO 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

Paradiseo-GPU (Graphics Processings Units) is a new module in development dedicated to the execution of parallel models for metaheuristics on graphics cards. For achieving this, CUDA (Computed Unified Device Architecture) is a parallel computing environment which provides an application programming interface for GPU architectures. The goal of this module is to allow the execution of the main metaheuristics on the GPU in a transparent manner. In other words, the user will not need to know how to manipulate the CUDA programming interface. Nevertheless, the development of a GPU-based module for metaheuristics is not straightforward. Indeed, several technical issues mainly related to the hierarchical memory management have to be faced. The major issues are the efficient distribution of data processing between CPU and GPU, the thread synchronization, the optimization of data transfer between the different memories, the capacity constraints of these memories, the static allocations (no heap and no stack structures on GPU), etc. A conceptual effort has been done to take into account the aspects related to the GPU architecture and to the ParadisEO-MO module. It allows us 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. Currently, since this module is in a conceptual form, the provided features are still limited. The set of classes and templates which are provided only allows the user to execute some local searches on a particular class of problems (without data inputs) with a pre-determined neighborhood. In a couple months, this module will be extended to deal with most of optimization problems.

5.1.4. New technical features

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

- Check compatibility with different operating systems
- Review and check compatibility with new versions of the tools used (Cmake, g++, Visual Studio...)
- Unary 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 documentations:

- 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. Design of the whole hierarchy of local search algorithms on GPU

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

Even if local search (LS) algorithms allow the computational time of the solution search space exploration to be significantly reduced, this latter cost remains exorbitant when very large problem instances are to be solved. Therefore, the use of GPU-based parallel computing is required as a complementary way to speed up the search. The main objective of our research work is to deal with such issues for the re-design of parallel LS models to allow solving of large scale optimization problems on GPU architectures. Our challenge is to come out with the GPU-based design of the whole hierarchy of parallel models. As a main result, we already proposed methodologies for building efficient parallel algorithms on GPUs based on the two major models: 1) the parallel evaluation of the neighborhood ; 2) the multi-start cooperative. Apart from being generic, we proved the effectiveness of our proposed methodologies by making extensive experiments. In particular, we show that they enable to gain very significant factors in terms of acceleration when deploying them for well-known instances in comparison with mono-CPU architectures [25], [41].

6.2. GPU-based island model for evolutionary algorithms

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

In the last decades, evolutionary algorithms (EAs) have been successfully applied to solve optimization problems. Different models have been proposed in the literature for the design and implementation of EAs. The island model for EAs generally delays the global convergence of the evolution process and encourage diversity. However, solving large-size and time-intensive combinatorial problems with the island model requires a large amount of computational resources. GPU computing is recently revealed as a powerful way to harness these resources. In [39], we focused on the parallel island model on GPU. We addressed its re-design, implementation, and associated issues related to the GPU execution context. The preliminary results demonstrate the effectiveness of the proposed approaches and their capabilities to exploit the GPU architecture.

6.3. Interval-based initialization method for permutation-based problems

Participants: Malika Mehdi, Nouredine Melab, El-Ghazali Talbi.

When dealing with exponential search spaces and when no special knowledge is available on global optima, initial populations for population-based meta-heuristics should be uniformly distributed on the search space in order to sample basins of attraction of all local optima. In [44], we propose a new initialization strategy for permutation problems. The new method is based on an original tree representation of the search space. Such representation was previously used for exact methods but never for meta-heuristics. The proposed method has been tested using a parallel Genetic Algorithm implemented in the ParadisEO framework and experimented on the Nationwide Grid5000 experimental grid using the Q3AP (3D QAP) permutation problem.

6.4. Parallel and distributed hybrid optimization models for grids

Participants: Malika Mehdi, Jean-Claude Charr, Nouredine Melab, El-Ghazali Talbi.

Three parallel hybridization schemes combining Genetic Algorithms (GAs) and the Branch-and-bound (B&B) algorithm are proposed in this work: a parallel relay model where the two algorithms are executed in a pipeline mode, a low level hybrid scheme where a given operator of the GA is replaced by a B&B solver, and a cooperative hybrid scheme where the two algorithms cooperate and exchange information about (best-found solution, promising regions to exploit by the B&B and unexplored regions to explore by the GA). The particularity of these schemes is the use of a special coding of the search space, more exactly a coded tree-based representation already used in the B&B algorithm. Indeed, in order to enumerate all the solutions of the search space, the B&B algorithm progressively builds a tree that covers the search space. Recently, a special coding for this tree has been used to facilitate the sharing of the search between several B&B process. Each node in the tree is assigned a unique number and any set of contiguous nodes (successive numbers) could be represented as an interval. The idea in this work is to generalize this representation to metaheuristics for a more efficient hybridization with the B&B algorithm.

The main issue in the implementation of the hybridization schemes previously described is that we use two different frameworks: ParadisEO to implement the GAs and, and the BOB++ framework to develop the B&B algorithm. To facilitate any kind of hybridization schemes between metaheuristics and the B&B algorithm (low level, high level, relay, cooperative), a hybridization framework integrated to ParadisEO is developed. This framework contains template classes that help to encapsulate any tree-based sequential exact algorithm, in a paradisEO algorithm.

6.5. Distributed branch and bound : a new pure peer-to-peer approach

Participants: Bilel Derbel, Mathieu Djamai, Nouredine Melab.

The state-of-the-art large scale approach for solving NP-hard permutation-like problems using parallel Branch-and-Bound (B&B) techniques is based on a Master-Slave model which is known to be limited in terms of scalability. In this work, we have proposed a new Peer-to-Peer (P2P) approach that can handle a huge amount of computational resources in a fully distributed way, that is without the need of any centralized coordinator. In fact, we give simple and efficient fully distributed algorithms dealing with major parallel B&B issues, such as work sharing, dynamic load balancing and termination detection. We argue that our P2P approach has a scalability which is *exponentially* better in theory compared to the Master-Slave technique while having a negligible communication overhead in a worst case-scenario, namely *polylogarithmic*. From the experimentation side, our approach was implemented and deployed on top of the Grid'5000 nation-wide French grid. Through extensive simulations involving up to 150 000 computational entities and 130 physical machines distributed over three geographical sites, we show that, compared to the state-of-the-art Master-Slave technique, our P2P approach enables (i) to improve the parallel efficiency up to a ratio of 7 to 1, (ii) to significantly speed up the B&B search process, namely by up to 7.5 factor in terms of number of solutions explored in the search space and, (iii) to keep the communication overhead relatively low, namely by a factor of at most 10 without penalizing the search process.

6.6. A parallel multiple reference point approach for multi-objective optimization

Participants: Arnaud Liefooghe, El-Ghazali Talbi.

When approximating the efficient set, multiple reference points can be uniformly distributed within a region that covers the Pareto frontier. In [19], a preference-based evolutionary algorithm, based on an achievement scalarizing function, is defined for each reference point, so that all the algorithms can easily be launched in a parallel and distributed environment. Computational experiments are performed on a bi-objective flow-shop scheduling problem. Our results show that the parallelization of evolutionary multi-objective optimization algorithms based on reference point methods gives very promising and statistically significantly better results than comparable non-parallel approaches.

6.7. Metaheuristics for multi-objective bidimensional bin packing problem

Participants: Nadia Dahmani, François Clautiaux, El-Ghazali Talbi.

We propose a multi-objective bidimensional bin packing problem that consists in packing items characterized by two sizes in two independent dimensions: a weight c_i and a volume d_i into an infinite number of identical bins with a weight and a volume capacity C and D respectively. We stated the mathematical formulation of the problem based on linear programming. As a first attempt to validate the bi-objective model, we presented different algorithms based on two methodologies for designing and implementing multiobjective metaheuristics namely population based and single-solution based metaheuristics. These algorithms were implemented using ParadisEO. Regarding the population based metaheuristics, we design three multiobjective evolutionary algorithms. For the single-solution based metaheuristics, we devise an iterated tabu search algorithm and an evolutionary algorithm based on ϵ-Constraint methods. An experimental investigation is performed on various test instances in order to illustrate the effectiveness of the proposed algorithms in solving our bi-objective bidimensional bin packing problem.

6.8. Hybrid approaches for a multi-objective bin packing problem with conflicts

Participants: Ali Khanafer, François Clautiaux, El-Ghazali Talbi.

We considered a bi-objective bin packing problem with conflicts in which we minimize the number of bins used and the number of conflicts violated. This problem is a variation on the bin-packing problem with conflicts, where the resources are limited. We have modeled the problem as a bi-objective integer linear program, and showed that the special structure of its Pareto front allows the problem to be reformulated as a set of mono-objective problems to be solved iteratively. We proposed heuristics and a tabu search to solve this mono-objective problem, and proposed a lower bound based on column-generation and hybrid pricing strategies. From a methodology point of view, we have demonstrated that fast local search methods can reduce the computational effort by a wide range. Computational experiments show that the upper and lower bounds allow to prove the optimality of Pareto solutions in many cases.

6.9. A network flow model for the vehicle routing problem with time windows and multiple routes

Participant: François Clautiaux.

We addressed a variant of the Vehicle Routing Problem, the Multi Vehicle Routing Problem with Time Windows and Multiple Routes. It considers that a same vehicle can be assigned with more than one route per planning period. We proposed a new exact method for this problem. It relies on a pseudo-polynomial network flow model whose nodes represent the time instants, and whose arcs represent feasible vehicle routes. We propose an iterative algorithm that uses our model. We tested our algorithm against a set of benchmark instances from the literature. Our method outperforms the best method of the literature. Our method gives rise to hybrid heuristics and meta-heuristics based on mathematical programming.

6.10. Bi-level formulation of short-distance transport problem and long-distance transport problem

Participants: Moustapha Diaby, Luce Brotcorne, El-Ghazali 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. We are dealing with a bilevel problem at the first level, the carrier (leader) wants to maximize its revenues; at the second level, the client (follower) aims to minimize its expenses. The transport network is defined by the graph $G(K, N, \mathcal{A})$: K represents all the requests, N the nodes and $\mathcal{A}$ the arcs of the graph, the carrier (respectively the company) disposes of P1(respectively P2) trucks characterized by their capacity . We denote respectively by A1 and A2 the respective arcs under the control of the carrier and society. Those controlled by both (Carrier and society) are represented in the graph by parallel arcs. A price is associated with the arcs A1, and are subjected to a constant fixed pricing unit and variable pricing unit imposed by the carrier; arcs A2 are called free and have a fixed cost determined by the competition. There is no loading during the transportation. We assumed also that during a given trip the loading phases of a truck come before unloading phases, the two phases occur at separate times.

6.11. Parallel population-based metaheuristics for solving the dynamic vehicle routing problem

Participants: Mostepha-Redouane Khouadjia, Laetitia Jourdan, El-Ghazali Talbi.

Many combinatorial real-world problems are mostly dynamic. They are dynamic in the sense that the global optimum location and its value change over the time, in contrast to static problems. The task of the optimization algorithm is to track this shifting optimum. Particle Swarm Optimization (PSO) has been previously used to solve continuous dynamic optimization problems, whereas only a few works have been proposed for combinatorial ones. One of the most interesting dynamic problems is the Dynamic Vehicle Routing Problem (DVRP). In [37], we propose a Multi-Adaptive Particle Swarm Optimization (MAPSO) for solving the Vehicle Routing Problem with Dynamic Requests (VRPDR). In this approach the population of particles is split into a set of interacting swarms. Such a multi-swarm allows the population diversity to be maintained and good tracking to be achieved. The effectiveness of this approach is tested on a well-known set of benchmarks, and compared to other metaheuristics from the literature. The experimental results show that our multi-swarm optimizer significantly outperforms single solution and other population based metaheuristics on this problem. Furthermore, we measure the behavior of our algorithms in terms of dynamic performance measures.

6.12. Fitness landscapes: local optima network

Participant: Sébastien Verel.

In [29], we have introduced a network-based model that abstracts many details of the underlying fitness landscape and compresses the landscape information into a weighted, oriented graph, called the *local optima network*. The vertices of this graph are the local optima of the given fitness landscape, while the arcs are transition probabilities between local optima basins. We extend this formalism to neutral fitness landscapes, which are common in difficult combinatorial search spaces. We found some unknown structural features confirmed that neutrality, in landscapes with percolating neutral networks, may enhance heuristic search. We also explore how the network structure and features of a given landscape change, if a first-improvement (greedy-ascent) local search algorithm is used instead for extracting the basins and transition probabilities. The impact of the structural differences in the behavior of search heuristics based on first and best improvement local search is thoroughly discussed. We also conduct a thorough analysis of two types of instances of the Quadratic Assignment Problem (QAP). The local optima networks extracted from the so called uniform and real-like QAP instances, show features clearly distinguishing these two types of instances. Apart from a clear confirmation that the search difficulty increases with the problem dimension, the analysis provides new confirming evidence explaining why the real-like instances are easier to solve exactly using heuristic search, while the uniform instances are easier to solve approximately.

6.13. Landscape analysis for multi-objective combinatorial optimization

Participants: Sébastien Verel, Arnaud Liefooghe, Laetitia Jourdan, Clarisse Dhaenens.

Recently, the property of connectedness has been claimed to give a strong motivation on the design of local search techniques for multiobjective combinatorial optimization. Indeed, when connectedness holds, a basic Pareto local search, initialized with at least one non-dominated solution, allows the efficient set to be identified exhaustively. However, this becomes quickly infeasible in practice as the number of efficient solutions typically grows exponentially with the instance size. We propose biobjective multiple and long path problems to show experimentally that, on the first problem, even if the efficient set is connected, a local search may be outperformed by a simple evolutionary algorithm in the sampling of the efficient set. At the opposite, on the second problem, a local search algorithm may successfully approximate a disconnected efficient set. Then, we argue that connectedness is not the single property to study for the design of multiobjective metaheuristics.

One of the most commonly-used metaphors to describe the process of heuristic search methods in solving combinatorial optimization problems is Fitness Landscape (FiL). However, no definition of FiL establishes an equivalence in the context of multiobjective optimization, where two mains approaches are generally defined: scalar and Pareto-based methods. The efficiency of such strategies depends on the problem properties in general, and in the correlation degree between objective functions in particular. We here define a systematic method to construct multiobjective problems with correlated objective functions, and we extend the well-known multiobjective NK-landscapes. By measuring features on the search space (size of the efficient set, number of supported solutions, connectedness), we show the importance of objective correlation on the design of efficient heuristic approaches. In terms of local optimality, we examine a possible definition where the points represent feasible solutions in the decision space and the "height" represents their vector fitness function. In such a case, the standard definition of local optimum turns into the definition of Pareto local optimum, and the definition of global optimum to the Pareto optimal set. In this context, it is still possible to define the ruggedness of a given landscape. The analysis of such concepts for a given problem is relevant to obtain deep information about its optimization difficulty. Unfortunately, these approaches fail to explain the dynamics of some local search heuristics. In [57], we proposed another possible definition of a multiobjective Fitness Landscape may map each point to a set of feasible solutions. A neighbor is then defined either by i) inserting, ii) removing iii) or mutating one solution of the set. The height can be given in terms of an arbitrary quality indicator (like the hypervolume). This definition follows recent works dealing with set-based search heuristics.

6.14. Landscape analysis for logistic problems

Participants: Marie-Éléonore Marmion, Laetitia Jourdan, Clarisse Dhaenens.

A state-of-the-art on existing statistical indicators of the literature for analyzing the landscape of an optimization problem has been performed. We classify the indicators into three categories according to whether they characterize the search space or the fitness space or the landscape entirely. Thus, we can measure the impact of the neighborhood relation and the fitness function independently or not. These indicators have been applied to two logistic problems : a scheduling problem (FSP) [52] and a routing problem (HFF-AVRP) [43]. The experimentations highlight the advantages of using the information given by statistics on the studied problems about the choice of the representation and the solving methods. Indeed, by comparing the efficiency of several metaheuristics (iterative local search, tabu search with different size of tabu list and genetic algorithm), we explain why some methods give better results and how the representation could guide the search towards the best or a good solution. For the FSP and the HFF-AVRP, we show that the insert operator is better to connect solutions than the swap operator.

7. Contracts and Grants with Industry

7.1. Contracts with industry

+ Vekia (2009-2010): this contract with Vekia company deals with efficient scheduling and timetabling in the distribution of goods. A second contract is in negotiation.

- Intecum (2009-2010): this contract deals with the problem of optimal packing of boxes into containers. The application is related to pharmaceutical companies.
- 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.

7.2. Regional initiatives

- PPF (Bioinformatics) (2006-2009, 2010-2013): This national program within the university of Lille (USTL) deals with solving bioinformatics and computational biology problems using combinatorial optimization techniques.
- 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

7.3. 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 (Université de Grenoble), 2009-2011

7.4. European initiatives

- COST project No.804, dealing with Energy efficiency in large scale distributed systems, 2009-2011
- COADVISE project, 2009-2011

7.5. International initiatives

- 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 CNRS/FCT with the university of Braga (Portugal) on packing problems.
- INRIA Equipes Associées MOMDI with University of Malaga (Spain) (2008-...)
- Collab - SINTEF (Norway) (2009-2011), with the University of Jyväskylä (Finland), CIRRELT (Montreal, Canada), ITMMA (University of Antwerp, Belgium)

7.6. Visits and researcher invitations

The project had visitors during the year 2010:

- C. Gil Montoya (August 2010, 1 month) : Univ. Almeria, Spain
- K. Mellouli (Dec 2010, 1 week) : Univ. Tunis, Tunisia
- A. Lopez Marquez (3 months June - August 2010): Univ. Almeria, Spain
- G. Hasle (SINTEF, Norway)
- Briseida Sarasola: Univ. Malaga, Spain
- Asma Skoudarli (3 months November 2010 - January 2010): Univ. Algers, Algeria

8. Dissemination

8.1. 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.

8.1.1. 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.
- 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).
- 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.

8.1.2. Participation to working groups

- EURO-PAREO (European working group on Parallel Processing in Operations Research).
- 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.

8.1.3. Editions

- Special Issue (Advances on nature bioinspired computing) in the Journal of Mathematical Modelling and Algorithm (JMMA, Springer), volume 9, number 2, 2010
- Book (Advances in multi-objective nature inspired computing) in the series Studies in computational intelligence (Vol. 272, Springer), 2010, with C. A. Coello Coello (México)

8.1.4. Organizations of sessions, workshops and conferences

- Organization of the ACS/IEEE International Conference on Computer Systems and Applications (AICCSA 2010), Hammamet, Tunisia
- Organization of the International Conference on Metaheuristics and Nature Inspired Computing (META 2010), Djerba, Tunisia
- Organization of a session on Metaheuristics and Knowledge discovery (META 2010), with D. Corne (University of Edhimburgh, UK)
- Organization of a session on Metaheuristics for Multi-objective Optimization (META 2010), with L. Paquete (University of Coimbra, Portugal)
- Co-organization of the 5th summer school on Artificial Evolution (EA 2010), Calais, France
- Organization of a session on Multi-objective Mathematical Programming (ROADEF 2010), Toulouse, France

8.1.5. 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)

8.1.6. 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).
- Review of journal papers:
  - Transaction on Evolutionary Computation (IEEE)
  - Evolutionary Computation Journal (MIT)
  - European Journal of Operational Research (Elsevier)
  - Journal of Heuristics (Springer)
  - Journal of Artificial Evolution and Application
  - 4OR: A Quarterly Journal of Operations Research (Springer)
  - International Transactions in Operational Research (Wiley)
  - Knowledge-Based Systems (Elsevier)
  - Journal of Scientific Computing (Springer)

8.1.7. Program committees

- 5th Int. Workshop on Intelligent Informatics in Biology and Medecine (IIBM 2010), Krakow, Poland, Feb 2010
- 2nd Int. Conf. on Engineering Systems Management and Applications (ICESMA 2010), Dubai, Emirates, Mar 2010
- 10th European Conference on Evolutionary Computation in Combinatorial Optimisation (EvoCop 2010), Istanbul, Turkey, April 2010
- 8th European Conference on Evolutionary Computation, Machine Learning and Data Mining in Bioinformatics (EvoBio 2010), Istanbul, Turkey, April 2010
- Multiple Objective and Goal Programming Conference (MOPGP 2010), Sousse, Tunisia, May 2010
- 5th Int. Conf. On Grid and Pervasive Computing (GPC 2010), Hualien, Taiwan, May 2010
- 9th Wuhan Int. Conf. on e-Business (WHICEB 2010), Wuhan, China, May 2010
- Int. Conf. on Machine Learning (ICML 2010), Haifa, June 2010
- Third Int. Workshop on Biomedical and Bioinformatics Challenges to Computer Science (in ICCS 2010), Amsterdam, Netherlands, June 2010
- Int. Conf. on Hybrid Artificial Intelligence Systems (HAIS 2010), San Sebastien, Spain, June 2010
- Int. Genetic and Evolutionary Computation Conference (GECCO 2010), Portland, OR, USA, July 2010
- Workshop on Biological Knowledge Discovery and Data Mining (OPTIM 2010), in HPCS conference, Caen, France, July 2010
- Workshop on Optimization Issues in Energy Efficient distributed systems (BIOKDD 10), in DEXA conference, Bilbao, Spain, Sept 2010
- 7th Int. Conf. on Swarm Intelligence (ANTS 2010), Brussels, Belgium, Sept 2010
- 11th International Conference on Parallel Problem Solving from Nature (PPSN XI), Krakow, Poland, Sept 2010
- ACM Int. Conf. on Management of Emergent Digital EcoSystems (MEDES 2010), Bangkok, Thailand, Oct 2010
- Int. Symposium. on Aware Computing (ISAC 2010), Tainan, Taiwan, Nov 2010.
- Eighth Int. Conf. on Simulated Evolution and Learning (SEAL 2010), Kanpur, India, Dec 2010

8.1.8. Phd and HdR committees

El-Ghazali Talbi was a jury member of the following HdR thesis:

- Luce Brotcorne. "Contributions à la gestion du revenu et à la programmation mathématique à deux niveaux", Université de Valenciennes, France, June 2010. Jury : P. Chrétienne, R. Cominetti, A. Freville, M. Labbé, G. Perakis, A. Quilliot, G. Savard, E-G. Talbi.

El-Ghazali Talbi was a jury member of the following PhD thesis:

- Sergio Nesmachnow. "Parallel evolutionary algorithms for scheduling on heterogeneous computing and grid environments". Universidad de la Republica, Montivideo, Uruguay, April 2010. Jury : E. Alba, H. Cancela, I. Loiseau, A. Pardo, C. Ribeiro, E-G. Talbi, M. Urquhart.
- Inès Hamdi. "Modélisation et simulation spatio-temporelle de la dynamique des réseaux de régulation génétique", ENSI, Université de la Manouba, Tunis, Tunisia, May 2010. Jury : M. Ben Ahmed, M. Elloumi, O. Korbaa, M. Tagina, E-G. Talbi.
- M. Camara Sola. "Parallel programming for dynamic multi-objective optimization", Universidad de Granada, Granada, Spain, June 2010. Jury : E. Alba, J. Ortega, F. De Toro, E-G. Talbi.

- Romain Clair. “Etude de méthodes de production d’art génératif et de leur application pour la conception d’outils de création artistique accessibles”, Université de François Rabelais de Tours, France, December 2010. Jury : G. Assayag, J. Lopez Krahe, E. Lutton, N. Monmarché, E-G. Talbi (president).
- Maroun Barcachi. “Algorithme évolutionnaire à états pour l’optimisation difficile”, Université de Nice-Sophia Antipolis, France, December 2010. Jury : P. Bernhard, M. Clergue, P. Collard, Y. Duthen, E-G. Talbi, S. Verel.
- Antonio Lopez Marquez. “On solving real optimization problems using Pareto-based multi-objective evolutionary algorithms”, University of Almeria, Spain, Decemver 2010. Jury : P. Bouvry, C. Gil, M. D. Montoya, R. B. Navarro, E-G. Talbi.

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

- Abdul Sattar, "Face Analysis by using Single Objective and Hybrid Multiple Objective Optimizations in 2.5D Active Appearance Model". SUPELEC Rennes / University of Rennes 1. Jury: Saida Bouakaz (referee), Gaspard Breton, Clarisse Dhaenens (referee), Mireille Garreau, Luce Morin, Jacques Palicot, Renaud Seguier. Avril 2010.
- Marta Girdea, "New methods for biological sequence alignment", Université de Lille I. Jury : Emmanuel Barillot, Michael Brudno, Clarisse Dhaenens, Grégory Kucherov, Laurent Noé, Eric Rivals, Michal Ziv-Ukelson. December 2010

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

- Mario Cámara Sola. "*Parallel Processing for Dynamic Multi-objective Optimization*". University of Granada Spain, advisors: Dr. Julio Ortega Lopera, Dr. Francisco de Toro.

François Clautiaux was jury member for the following PhD thesis:

- Julien Martin, defended at INRIA Paris Rocquencourt, Université Paris VI. Jury : François Fages, François Clautiaux, Yves Deville, François Fages, Daniel Goossens, Christian Queinnec, Michel Rueher.

8.1.9. Commission

- Presidence of the C2D commission of the Lille INRIA center (Commission Détachement Délégation).
- Presidence of selection committees (positions MCF 0856 and PR 1691 - Polytech’Lille, Université Lille I).
- Participation to a selection committee (position PR 202 - Université Paris Dauphine).
- Participation to a selection committee (position MCF - Université Paris XIII).

8.2. Tutorials

- Meta-heuristiques et bio-informatique (Laetitia Jourdan) in summer school EA 2010.
- Optimisation multi-objectif (El-Ghazali Talbi) in summer school EA 2010.
- Combinatorial optimization in Bioinformatics (Clarisse Dhaenens) in the Pattern Recognition in Bioinformatics conference (PRIB 2010).
- Metaheuristics for bioinformatics (Clarisse Dhaenens) in the 3rd International Conference on Metaheuristics and Nature Inspired Computing (META 2010).
- Fitness Landscapes And Graphs: Multimodularity, Ruggedness And Neutrality (Sebastien Verel) in the IEEE World Congress on Computational Intelligence (WCCI 2010).

- Metaheuristics for multi-objective optimization (E-G. Talbi), invited seminar, 3rd Int. Seminar on New Issues in Artificial Intelligence, Madrid, Spain, February 2010.
- Modeling and solving complex optimization problems (E-G. Talbi), Invited seminar, King Saud University KSU, Riad, Saudi Arabia, February 2010.
- Metaheuristics on graphics processing units (T-V. Luong, E-G. Talbi), Invited seminar, SINTEF, Oslo, Norway, March 2010.
- Metaheuristics for multi-objective optimization (E-G. Talbi), Plenary talk, CIRO'2010, Marrakech, Morocco, May 2010.
- Metaheuristics and multi-objective optimization: Towards a unified view (E-G. Talbi), Plenary talk, Multi-objective Optimization and Goal Programming Conference MOPGP'2010, Sousse, Tunisia, May 2010
- Metaheuristics for multi-objective optimization (E-G. Talbi), Invited tutorial, ALIO/INFORMS Joint Int. Meeting on Operations Research and the Management Sciences, Buenos Aires, Argentina, June 2010.
- Parallel evolutionary algorithms (E-G. Talbi), Invited tutorial, IEEE WCCI World Congress on Computational Intelligence, Barcelona, Spain, July 2010.
- A unified view of parallel metaheuristics (E-G. Talbi), Keynote Speaker, Workshop on Parallel and Cooperative Metaheuristics in PPSN Int. Conf. on Parallel Problem solving from Nature, Krakow, Poland, September 2010.
- Metaheuristics: from design to implementation (E-G. Talbi), Invited tutorial, META'2010 Int. Conf. on Metaheuristics and Nature Inspired Computing, Djerba, Tunisia, October 2010.
- A unified view of metaheuristics (E-G. Talbi), Invited Seminar, IHEC Institut des Hautes Etudes Commerciales, Tunis, Tunisia, November 2010.
- A gentle introduction to metaheuristics (E-G. Talbi), Invited Seminar, University of Almeria, Spain, December 2010.

8.3. Teaching

- Postgraduate (IEEA, Université Lille 1): "Optimization methods" (L. Jourdan).
- Postgraduate (IEEA, Université Lille 1): "GRID computing", (N. Melab, B. Derbel).
- Undergraduate (IEEA, Université Lille 1): "Distributed Systems" (N. Melab, B. Derbel).
- Undergraduate (IEEA, Université Lille 1): "Operations Research" (N. Melab).
- Undergraduate (IEEA, Université Lille 1): "Algorithms for Operations Research" (A. Liefooghe).
- Undergraduate (Polytech'Lille): "Operations Research" (C. Dhaenens).
- Undergraduate (Polytech'Lille): "Graphs and combinatorics" (C. Dhaenens).
- Undergraduate (Polytech'Lille): "Data mining" (E-G. Talbi).
- Undergraduate (Polytech'Lille): "Advanced Optimization" (E-G. Talbi).
- Undergraduate (IUT, Université Lille 1): "Graphs and Modeling" (F. Clautiaux).

9. 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. R. 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.

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[10] 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 [*DOI :* 10.1016/J.FUTURE.2006.09.001].

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] L. JOURDAN. *Métaheuristiques Coopératives : du déterministe au stochastique*, Université des Sciences et Technologie de Lille - Lille I, 2010, Habilitation à Diriger des Recherches, http://hal.inria.fr/tel-00523274.

[12] A. KHANAFER. *Algorithmes pour des problèmes de bin packing mono et multi-objectif*, Université des Sciences et Technologies de Lille, 2010.

Articles in International Peer-Reviewed Journal

[13] 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.

[14] J.-C. BOISSON, L. JOURDAN, E.-G. TALBI, D. HORVATH. *Single- and Multi-Objective Cooperation for the Flexible Docking Problem*, in "Journal of Mathematical Modelling and Algorithms", 2010, vol. 9, p. 195-208, http://hal.inria.fr/inria-00522634.

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Parallel & Distributed Processing Symposium (IPDPS)", Etats-Unis Atlanta, 2010, http://hal.inria.fr/inria-00520465.

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