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論 文 審 査 委 員	主　査　　教授　井上　克巳 教授　宇野　毅明 教授　山田　誠二 准教授　沖本　天太　神戸大学 招聘研究員　佐藤　泰介 産業技術総合研究所

(別紙様式 2)
(Separate Form 2)

論文の要旨

Summary (Abstract) of doctoral thesis contents

For many decades, the field of optimization has progressed both in the way it represents real-life problems and how it solves these problems. There now exists a large variety of techniques to tackle problems of different complexities and with various requirements (limited time, distributed system, ...). However, most of the focus have been towards problems with a single objective to optimize whereas almost all real-life problems involve multiple objectives. For example, a sensor network where each sensor can sense a certain area in a territory might consider (i) data management, (ii) quality and (iii) quantity of observation data, and (iv) electrical consumption. Such multi-objective problems are usually more complex than their mono-objective counterparts. Indeed, instead of being able to define a clear optimal solution, there might now exists numerous solutions offering various trade-offs of the objectives. Ideally, before the solution of a multi-objective problem can be obtained, the set of trade-offs should first be computed. Only then can a solution be selected and implemented.

In this thesis, we study the solving of multi-objective problems that we propose to view as two successive steps. The first step consists in finding the Pareto front of the given problem, i.e., the set of solutions offering optimal trade-offs of the objectives. As the size of this Pareto front can increase exponentially with the size of the problem, efficient algorithms are required to find the Pareto front or at least a good approximation. This first step is thus mostly about algorithms and searching for solutions. This is well studied in centralized optimization but is lacking efficient algorithms in distributed systems. The second step then consists in using the previously found Pareto front to extract a single solution that can be implemented. It can be assumed that this second step is performed by a decision maker. However, selecting a solution from the Pareto front is rarely trivial for a human as the set of alternatives can be very large. Additionally, many problems require quick decisions, in which case interacting with a decision maker can be impossible. This second step is more about decision making and defining additional criteria to extract solutions from the Pareto front.

In the first chapter of this thesis, we present the background of the main fields of research to which our thesis contributes. These fields are Optimization, Constraint Programming and Distributed Problem Solving.

In the second chapter, we introduce the preliminary notions required for the understanding of our contribution. We present the frameworks used to represent multi-objective problems both for centralized and distributed systems. For the distributed case, we also present the different assumptions and considerations made about the agents of the system. We also present the framework to represent dynamic

environments where the problem changes over time. In addition, we present some of the representative applications considered during this thesis, namely Timetabling and Multi-Objective graph coloring.

In the third chapter, we study the first step of multi-objective problem solving and propose two new algorithms for finding the Pareto front of multi-objective optimization problems in distributed systems. The first algorithm is the Multi-Objective Distributed Pseudo-tree Optimization, an exact algorithm based on dynamic programming techniques to find the complete Pareto front. The second algorithm is the Distributed Pareto Local Search, an algorithm based on local search techniques that provides an approximation of the Pareto front.

In the fourth chapter, we study the second step of multi-objective problem solving and propose three multi-objective decision making methods to isolate subsets of Pareto fronts that can be deemed more interesting. The first selection method we propose assumes a weighted preference over the objectives and finds the corresponding subset of the Pareto front. In our second method, we isolate solutions from the Pareto front that can satisfy some resilient properties. In our third method, we consider the cost of implementing solutions and isolate the ones that can comply with a given limit.

In the fifth chapter, we describe other works related to this thesis and compare them with our approach. Our algorithms are compared to the state-of-the-art and their inspirations are presented. Similarly, we discuss other existing decision methods and their differences with the one we propose.

In the final chapter, we conclude this thesis by summing up our contribution and discussing the potential future works related to this thesis.

(別紙様式 3)
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博士論文審査結果の要旨

Summary of the results of the doctoral thesis screening

The Examination of the PhD thesis of the applicant, CLEMENT Maxime, was held as an open defense on the 13th of July 2017, with attendance of all five members of the Examination Committee.　Mr. CLEMENT firstly gave oral presentation of the contents of the thesis for 45 minutes, then the examiners and other attendees asked questions and gave comments for 15 minutes.

The PhD thesis is concerned with Mr. CLEMENT's work on Multi-Objective Distributed Constraint Optimization Problems (MO-DCOPs), and is written in English, consisting of six chapters.

Chapter 1 describes the motivation and the background of the main research fields to which the thesis contributes, including constraint optimization (COP) and distributed problem solving, and introduces a general two-step architecture that involves multiple objective optimization.

Chapter 2 describes all preliminary notions that are required for an understanding of contribution. Such background knowledge includes MO-DCOP and dynamic environments where the problem changes over time, and some representative applications are also illustrated.

Chapters 3 and 4 are the main contributions of the thesis.　Chapter 3 studies the first step of multi-objective problem solving, and proposes two new algorithms for finding the Pareto front of MO-DCOPs.　The first algorithm is the multi-objective distributed pseudo-tree optimization, called MO-DPOP, which is an exact algorithm based on dynamic programming techniques (Section 3.1).　MO-DPOP is a complete algorithm to find the Pareto front of an MO-DCOP, but its incomplete variant is also presented to limit the number of Pareto-optimal solutions.　The second algorithm is the distributed Pareto local search, called DPLS, which is based on local search techniques that provides an approximation of the Pareto front (Section 3.2).　DPLS cannot guarantee Pareto optimal solutions but offers the best scalability.

Chapter 4 studies the second step of multi-objective problem solving, and proposes three decision making methods to isolate subsets of Pareto fronts of MO-DCOPs toward selection of final solutions.　The first selection method uses a preference-based criterion, e.g., weighted-sum (Section 4.1), while the second and third selection methods use criteria specific to dynamic problems, e.g., resilient properties (Section 4.2) and transition costs (Section 4.3).

Chapter 5 summarizes comparison with previously proposed DCOP and MO-DCOP algorithms as well as selection methods in decision making.　Chapter 6 concludes the thesis by summing up the contributions and discussing the potential future works related to the thesis.

At the oral presentation, Mr. CLEMENT stated the features of these developed algorithms in the order of chapters in the thesis. Mr. CLEMENT has made significant improvement on the suggestions by the Committee members at the Preliminary Examination, and in particular the clarification of original contributions of the work has become clearer, so that the presentation was well-organized. As for questions by the Committee members, decision-making and solution selection methods as well as evaluation of them in real problems were mainly discussed, which could involve many future directions including the use of machine learning and relation to the techniques for recommendation systems. Mr. CLEMENT answered these questions appropriately.

As for the publication related to the contents of the thesis, DPLS (Section 3.2) has been evaluated on multi-objective graph-coloring instances and the results have been accepted as a peer-reviewed paper for the *IEICE Transactions on Information and Systems*. On the selection methods to select solutions from Pareto fronts, the weighted-sum approach (Section 4.1) was evaluated on timetabling instances and the results were published as a refereed paper in *Proceedings of the 11th International Conference on the Practice and Theory of Automated Timetabling* (PATAT 2016). The resilience-based approach (Section 4.2) was evaluated on proactive dynamic problems and the results were published as a refereed paper in *Proceedings of the 7th International Conference on Agents and Artificial Intelligence* (ICAART 2015). Other materials in Sections 3.1 and 4.3 are planned to be published in the future.

The Evaluation Committee expressed their satisfaction with the quality of the PhD work, and recognized that the submitted thesis fulfilled the requirements for a PhD thesis. In conclusion, the Evaluation Committee judged a pass for Mr. CLEMENT on his Doctor degree.