

# **A SOCIAL- AND KNOWLEDGE-BASED COALITION FORMATION USING MODIFIED COMBINATORIAL PARTICLE SWARM OPTIMIZATION**

by

**AZLEENA BINTI MOHD KASSIM**

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## LIST OF ABBREVIATIONS

ACO	Ant Colonization Optimization
ANOVA	Analysis of Variance
ATB	Attitude towards Behavior
BDE	Binary Differential Evolution
BIU	Behavior of Intention to Use
BPSO	Binary Particle Swarm Optimization
CCD	Computational Cultural Dynamics
CPlanT	Multi-Agent and Knowledge-based Coalition Formation System
CPSO	Combinatorial Particle Swarm Optimization
CPSO-CGA	Combinatorial Particle Swarm Optimization with Crossover Operator
CPSOII	Dynamic Clustering using Combinatorial Particle Swarm Optimization
CPSO-SAGA	Combinatorial Particle Swarm Optimization with Crossover and Simulated Annealing-based Mutation Operator
CSG	Coalitional Skill Games
CSGP	Coalition Structure Generation Problem
CSP	Constraint Satisfaction Problem
CST131	Computer Organization Course
DE	Differential Evolution
DPSC	Discrete Particle Swarm Clustering
EA	Evolutionary Algorithms
EPM	Educational Process Mining
EPSO	Enhanced PSO
FOAF	Friend-of-a-Friend

GA	Genetic Algorithm
GQM	Goal-Question-Metric
ICA	Independent Component Analysis
IPIP	International Personality Item Pool
JBI	Joint Battlespace Infosphere
LSL	Learning Societies Lab research group
MAS	Multi-Agent Systems
MBTI	Myers–Briggs Personality Traits
NIQGA	Improved Quantum Genetic Algorithm
NMPC	Nonlinear Model Predictive Control
OWL	Ontology Web Language
PACT	Progressive, Anytime, Convergent, and Time-efficient algorithm
PCA	Principal Component Analysis
PEU	Perceived Ease of Use
PGHA	PSO-GA-based hybrid algorithm
PJSSP	Periodic Job Shop Scheduling Problem
PKTR2013	Program Kepimpinan Tun Razak 2013
PR	Perceived Usefulness for Performance
PSO	Particle Swarm Optimization
PU	Perceived Usefulness
QGA	Quantum Genetic Algorithm
QPSO	Quantum-behaved Particle Swarm Optimization
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
SA	Simulated Annealing
SAT	Satisfaction
SD	Standard Deviation

SKCF	Social- and Knowledge-based Coalition Formation
SKCO	Social-and Knowledge-based Coalition Ontology
SLP	Semantic Learner Profile
SSE	Sum of Squared Error
TACF	Task Allocation Coalition Formation
TAM	Technology Acceptance Model
TCS	Theoretical Computer Science
TS	Tabu Search
TSH	Thyroid-Stimulating Hormone
VM	Virtual Machine
VPGA	Population-Size Genetic Algorithm
VRC	Variance Criterion
XML	Extended Markup Language
XSL	Extensible Style Language



**PEMBENTUKAN PAKATAN BERASASKAN FAKTOR SOSIAL DAN  
PENGETAHUAN MENGGUNAKAN PENGOPTIMUMAN KERUMUNAN  
PARTIKEL GABUNGAN TERUBAHSUAI**

**ABSTRAK**

Pembentukan pakatan adalah suatu pendekatan untuk mencapai agihan kumpulan secara optima untuk menjalankan sesuatu tugas. Dalam pembentukan pakatan melibatkan manusia, kebanyakan penyelidik memberikan fokus kepada keupayaan individu yang berkaitan dengan sesuatu tugas, namun aspek sosial tidak diterajui secara meluas. Gabungan antara pendekatan berkoperasi dan agen berkepentingan juga tidak diterajui secara meluas dalam pembentukan pakatan melibatkan manusia. Selain itu, pembentukan pakatan sering dikendalikan sebagai proses sekali sahaja dan tidak disimpan. Kaedah optimasi sedia ada seperti Pengoptimuman Kerumunan Partikel Gabungan (CPSO) adalah didapati sesuai untuk pengoptimuman pakatan dan penggugusan, namun kelemahannya dalam carian tempatan. Oleh itu, objektif utama tesis ini ialah untuk membangunkan rangkakerja baharu untuk pembentukan pakatan berasaskan faktor sosial dan pengetahuan (SKCF). Sub-objektif yang berkaitan ialah: 1) untuk menakrifkan faktor pakatan dan sosial untuk membentuk model pembentukan pakatan, 2) untuk membangunkan skema perwakilan pengetahuan untuk menyimpan pengetahuan tentang pakatan yang telah dibentuk, dan 3) untuk membangunkan algoritma yang berkesan untuk mengoptimumkan suatu pakatan yang juga boleh dianggap sebagai masalah pengelompokan. Untuk mencapai objektif-objektif tersebut, faktor - faktor pakatan dikompilasikan daripada penyelidikan dalam pembentukan pakatan sedia ada, manakala faktor sosial dipilih untuk menepati ganjaran kepada pakatan, bagi menggunakan pendekatan agen berkepentingan. Ontologi digunakan sebagai

repositori pengetahuan. Skema perwakilan ontologi dibangun untuk menyimpan dan menguruskan faktor sosial dan pakatan, dan juga menyimpan pengetahuan daripada pakatan yang berjaya dihasilkan. Untuk pengoptimuman, algoritma CPSO telah dipertingkatkan dengan menjalankan hibridisasi dengan algoritma meta-heuristik lain, bagi mengatasi kelemahan CPSO, di mana dua tahap penambahbaikan telah dilakukan. Yang pertama, CPSO dengan Operator Persilangan (CPSO-CGA) dan yang keduanya CPSO-CGA dengan Operasi Mutasi Berasaskan Penyepuhlindapan Simulasi (CPSO-SAGA). Eksperimen telah dijalankan ke atas lima set data penanda-  
aras pengelompokan untuk membandingkan prestasi algoritma dengan CPSO asal. CPSO-SAGA menunjukkan keputusan yang terbaik. CPSO-SAGA juga diuji bersama CPSO dan kaedah rawak menggunakan set data yang dikumpul daripada eksperimen kes sebenar. Keputusan menunjukkan bahawa CPSO-SAGA menghasilkan pengoptimuman yang lebih baik berdasarkan kualiti penyelesaian. Analisis penerimaan pengguna juga dijalankan ke atas salah satu eksperimen kes sebenar dan keputusan menunjukkan bahawa kepuasan dan tahap penilaian prestasi adalah lebih tinggi berbanding agihan kumpulan secara rawak.

**A SOCIAL- AND KNOWLEDGE-BASED COALITION FORMATION  
USING MODIFIED COMBINATORIAL PARTICLE SWARM  
OPTIMIZATION**

**ABSTRACT**

Coalition formation is an approach for accomplishing optimal groups to perform certain set of tasks. In human-based coalition formation, researchers mostly focus on individual capability related to the task, however social aspects are not widely explored. The combination of cooperative and selfish agent approaches are also not widely explored for human-based coalition formation. Furthermore, coalition formation is often treated as a one-off process where formed coalitions are not stored. Existing optimization such as Combinatorial Particle Swarm Optimization (CPSO) is found to be suitable for coalition optimization and clustering, however its weakness in local search needs to be addressed. Therefore, the thesis main objective is to develop a new framework for social- and knowledge-based coalition formation (SKCF). The related sub-objectives are: 1) to define coalition and social factors to form a coalition formation model, 2) to develop a knowledge representation scheme to store knowledge of formed coalitions, and 3) to develop an effective algorithm to optimize the coalition which can also be treated as a clustering problem. In order to realize these objectives, the coalition factors are compiled from existing coalition formation work, whereas social factors are chosen to satisfy the coalition's payoff to address the selfish agent approach. The ontology is utilized as the knowledge repository. The representation schema of the ontology is developed to store and manage the social and coalition factors, and also to store knowledge of successfully formed coalitions. For the optimization, the CPSO algorithm is enhanced by hybridizing it with other meta-heuristic algorithms to overcome the CPSO's weakness, resulting in two levels of

enhancements. Firstly, the CPSO with Crossover Operator (CPSO-CGA) and secondly, CPSO-CGA with Simulated Annealing-based Mutation Operator (CPSO-SAGA). Experiments were conducted on five clustering benchmark datasets to compare the algorithms' performance with the original CPSO. CPSO-SAGA showed best result. The CPSO-SAGA was also tested against CPSO and random method on two datasets collected from real case experiments. Results showed that CPSO-SAGA had better optimization based on the quality of solution. User acceptance analysis was also conducted on one of the real case experiments and results showed that the satisfaction and performance evaluation level is higher compared to random grouping.

# CHAPTER 1

## INTRODUCTION

### 1.1 Overview

Coalition formation is an approach motivated to attain optimal groups in equilibrium, set to perform a certain set of tasks. The role of coalition formation is mainly significant in a scenario where a goal is better accomplished in a group setting rather than by an individual. Neumann and Morgenstern (1953) presented one of the earliest theories of coalition formation from game theory, where it is used to explore the economic behavior and benefits of forming coalitions. Ever since then, researchers have studied and worked on coalition formation approaches several different angles and applied them in many different domain and areas.

In the computing field, coalition formation is seen as a dynamic process; where the payoffs are generated as the coalitions form, split up and regroup (Ray and Vohra, 2014). From this concept, it is believed that a computing system that handles coalition formation should be able to intelligently form a group, disintegrate the group when required and regroup under certain circumstances.

There are many different approaches to coalition formation. Different entities and different resources may be available but the essential part of a coalition formation is forming a group. In the area of computer systems, coalition formation is often adapted to solve problems of assigning resources in equilibrium, where the resources

are used to solve various types of computing issues, such as those concerning virtual machine, network configuration and multi-agent systems.

In a coalition formation, the performance of the agents or individuals can be improved by combining their efforts and resources to efficiently perform the tasks at hand (Elkind, 2013). From the review on coalition formation systems carried out by Elkind (2013), agents can be categorized into two types: 1) Cooperative agents who share common goals, and 2) Selfish agents who are only concerned about their own payoffs. In research that focus on cooperative agents, the focus lies on finding the optimal collaboration achieving common goals to complete a task, and the best way to distribute agents into groups. However, for selfish agents, the focus is on how the gains can be distributed since payoff is important for the agents in order to take part in a coalition. The multi-agent systems that use a coalition formation approach usually take one of the directions, and the combination of both is not explored widely.

Most of the multi-agent systems that used the coalition formation approach focus on the tasks that need to be completed by the coalition. In coalition formation that involves human as agents in a system, most of the proposed methods focus on the computational and structural aspects (Aziz et al., 2013). Many multi-agent systems in coalition formation use the approach from cooperative game theory which is often too abstract to be beneficial in modeling real-world cooperative scenarios (Sless, 2014).

In a broader context, Computational Cultural Dynamics (CCD) is an interdisciplinary research field that combines human behavioral and social factors with technological aspects which includes computer science, computational linguistics, game theory, and operations research (Nau and Wilkenfeld, 2008). One of the primary issues in this area is determining how to model various cultural characteristics. There

are limitations in behavioral and social sciences, especially in data gathering where it can be a rather time consuming and labor-intensive process. Therefore, integration with computational methods can reform these areas by offering methods and tools for activities such as data gathering.

For a CCD-inspired coalition formation, the attributes that are related to humans are derived from the anthropology and sociology aspects of social sciences. These variables are computationally represented and manipulated to perform a certain task or solve some problems.

Throughout this thesis, the term coalition formation will be used extensively. Used interchangeably with coalition formation, the terms group, grouping and group formation are also used to describe the state of a coalition or coalition formation.

## **1.2 Problem Statement**

Current coalition formation approaches mainly focus on individualistic attributes but not so much on the cohesiveness of a coalition as a whole (Ray and Vohra, 2014; Gabora, 2008; Aziz et al., 2013). Focusing on individualistic attributes is indeed very helpful in identifying whether a particular person can be suitable to perform a certain task. Most coalition formation efforts use this approach, choosing individuals that best suit to the group task. However, the contribution of relationship among individuals to achieve an optimal group needs to be further investigated.

Sless (2014) addressed this issue of cohesiveness of a coalition by focusing on the relationship of people. This is represented as a weighted graph of a social network. The work defined the relationship of people by the connection that they have among

each other. However other factor such as their skills to carry on a certain task is not considered. The relationship is based on the acquaintance that the people have without taking the quality of the relationship into consideration thus the overall cohesiveness of a group can be questioned.

Elkind (2013) stated that works on coalition formation systems takes the approach of cooperative agents or selfish agents separately. In coalition formation especially that involves people as agents, the combination of both approaches can be further explored. The cooperative agents approach focuses on how a group can be formed. Similarly in coalition formation involving humans, the cohesiveness to achieve the same goal is an important factor to determine an effective group. The selfish agent approach focuses on how the payoff can benefit each individual. In coalition formation involving people to be grouped together, the question lies on which approach one should take. Focusing on one approach makes the overall coalition lose the benefit of the other approach. Goradia and Vidal (2007) used a combination of both approaches in their work using a negotiation algorithm. Their work is based on a simulation of agents and did not define the type of payoff that is used, but used a generated number to represent the coalition values. Hence, a framework that includes a representation of people with realistic human-based factors has not been explored in coalition formation. Aside from coalition factors that determine a coalition to be cohesive such as the task related factors, and skills or knowledge, the social factors involving people required to form a coalition need to be further addressed.

After a coalition is formed, the knowledge that is created is often disregarded as it is treated as a one-time process. Knowledge such as the groups or coalitions that have been formed and the evaluation of a coalition can be stored and reused in future



coalitions. Thus, the appropriate method to store this knowledge is crucial in ensuring that the knowledge is easily assessable and reusable for future coalitions.

From the cooperative agent approach, it is essential for the coalition formation to find an optimal collaboration pattern. In terms of the mechanism of the coalition, there are different techniques used by different researchers to solve the coalition formation approach. The issue is to identify a suitable method for the coalition formation for grouping people based on social and behavioral factors.

Cho (2013) presented a survey on available works on multi-objective optimization formulation and solution in coalition formation. It is shown that there are different approaches that can be taken to address a multi-objective problem, such as coalition weighted sum, constraint-based, evolutionary algorithms and game theory approach. It shows that there are already several methods to solve coalition formation problems but it depends on each research's requirements and constraints. From the existing methods, one of the issues that needs to be further explored is on improving the optimization of the coalition methods.

Ouimet and Cortés (2011) presented a distributed algorithm where agents cluster into groups to attain good network configurations, and the solution is distributed optimally over the environment. This algorithm lets the agents to independently form coalitions of a desired size, cluster together within a fixed time, and finally reach an optimal distribution. This work shows that a clustering approach can be applied to coalition formation especially when the coalition is concerned about the size of the groups. However, Ouimet and Cortés (2011) stated that further work is to investigate the policy of optimizing the coalition formation. From the different approaches available, the issue that arises is which approach would be suitable for the

coalition formation in this research. Thus, for a coalition formation using the clustering approach, the issue is on how to incorporate the optimization technique, needs to be addressed. In order to identify the appropriate method, further investigation is carried out on related works in optimization and clustering, and will be presented in Chapter 2 of the thesis.

Another concern is on the knowledge created when a coalition formation takes place. This knowledge is typically disregarded and not stored after a coalition formation has been successfully formed. Pechoucek et al. (2002) had presented a architecture for a knowledge-based coalition formation for humanitarian and peace-keeping missions known as the CPlanT. The knowledge that was stored in CPlanT was used as an input for a coalition, but the coalitions that were formed were not stored as knowledge. This is seen as one of the common problem in coalition formation systems, thus an efficient way of knowledge storage of the successful coalitions need to be explored.

### **1.3 Research Question**

From the problem statements, the following questions can be raised to further scrutinize the problems so as to strategize on finding the appropriate solutions.

- i. What are the social and coalition factors that will be used in order to manipulate the individuals with the motivation of forming a group?
- ii. How to store and organize the social and coalition factors as knowledge for a coalition formation model?
- iii. What method or technique is to be used in forming coalitions?

## **1.4 Research Objectives**

The main objective of this research is to develop a coalition formation model to form groups of people to perform certain tasks. The key idea of the thesis is to define a model for the proposed coalition formation by studying and adapting relevant factors such as coalition and social factors. Therefore, a new framework for coalition formation to be known as Social- and Knowledge-based Coalition Formation (SKCF) is developed.

In order to achieve the main objective, the sub-objectives are as follows:

- i. To define the social and coalition factors to form a CCD-inspired coalition formation model.
- ii. To develop a suitable knowledge representation schema by investigating the suitability of using ontology representation and social network environment.
- iii. To define an effective mechanism to optimize coalition formation.

## **1.5 Scope and Limitations of the Research**

The reason for adopting a CCD approach is because the research focuses on grouping humans. The proposed CCD inspired coalition formation approach investigates existing works that intertwines group behavior and sociology, in order to tackle and capture variables on behavioral and social factors. Using the coalition formation theory and approach, this research works on defining a model for coalition formation of humans, and to form groups of people that are in equilibrium to carry out desired or required tasks. Groups in equilibrium here refers to groups that have equal

number of people in each group or cluster. Thus, to reach the equilibrium, besides the number of people, the groups are distributed equally based on certain factors. Since CCD is a basis for this research, social factors are adapted alongside coalition factors to form the basis of the proposed research model.

The social factors are focused to satisfy the approach of coalition formation in terms of gaining coalitions that are cohesive in an optimal distribution (as cooperative agents) as well as taking into consideration the factor that can contribute as the payoff of a coalition (as selfish agents). Aside from the existing social and coalition factors, a new factor which is ‘group’ factor is introduced to be adopted into the coalition formation model, in order to store the knowledge of successfully formed groups or coalitions.

Having identified social networks as the backbone for knowledge representation purposes, the development of the social networks comprising different individuals is done using an ontology.

There are many approaches and techniques than can be utilized to perform a coalition formation. Clustering method being one of them is being investigated thoroughly in this thesis. There are works by researchers that combine the coalition formation approach with clustering (Farinelli et al., 2017; Asfar, 2015; Ouimet and Cortés 2011). The coalition formation solution in this thesis has been developed with the help of the clustering method, as the coalition formation framework requires a known number of coalitions, which can also be referred to as clusters. The clustering method has to be able to cluster and at the same time optimize for a better solution. Therefore, several hybridized evolutionary algorithms have been studied for this work.

As a result, the Particle Swarm Optimization (PSO) method is adopted, and an existing hybrid approach known as the Combinatorial Particle Swarm Optimization (CPSO) is chosen to be the basis for the proposed work, based on its capability to explore the search space for solutions and its label-based encoding which is suitable as the solution representation for coalition formation. The CPSO is further improved to improve the weakness of the algorithm where it tends to get stuck in local optima. Here, the proposed work is not to improve the algorithm in terms of time efficiency but more on finding out if it can provide better quality solution.

## **1.6 Assumptions with Justifications**

Since the proposed work involves social factors, another important direction is to use social networks with the ontology model. The assumption is that the use of social network can be suitable for a coalition formation. Since the SKCF takes the CCD approach of combining social and behavioral factors with computer technology, use of ontology in social network environment is proposed.

The main constraint comes from the participants in the coalition itself because it involves each and everyone's contribution to the coalition, both before and after formation of the coalition. Each individual has its own personal traits. In the process of constructing a coalition, these criteria will influence the decision of the group distribution. Theoretically, as the assumptions, these criteria are supposed to influence the performance of a group as well as to control the quality of the task's outcome that will be produced by the group. However, human factors, especially involving emotions and perceptions, are very hard to be predicted or controlled. Against the odds, the SKCF is motivated to use these factors to determine the decision of forming a

coalition. This is because, human factors can be used to enrich the coalition formation and also, the research is motivated to investigate the outcome of this integration.

The impetus of the research is to find an appropriate method (algorithm) that is able to manipulate these factors. At the same time, with the help of existing literature on group dynamics, the suitable factors are adapted, and a calculation method is proposed together with modifications of the chosen algorithm. The result of this coalition formation is analyzed based on a standard deviation approach. The assumption is that the standard deviation calculation can be used as the objective function of coalition formation. As the justification, the objective function used for partitional clustering problem for similarity measures is based on Euclidean measure where it measures the error distance between the instances. The standard deviation is also a part of Euclidean measures and the error distance derived from the standard deviation can be used to measure error between the clusters or groups to determine how the groups are balanced. Thus, this can be used to ensure that the groups are distributed in equilibrium.

The objective function for the coalition formation is developed to maximize the coalition's payoff, based on the team satisfaction and performance. The assumption made was that the coalition formed based on this objective function will optimally group the individuals into groups that have been balanced in terms of the factors that maximize the satisfaction and performance. Therefore, to justify the use of the factors and in order to evaluate the user acceptance towards the coalition formation, a case study analysis is conducted. This study is conducted to get the users' feedback and acceptance on introducing them to a coalition formation that uses the human or social factors in order to decide the coalition.

## 1.7 Contributions

This research chooses to find a way to have a more human approach of applying coalition formation to group people instead of machines.

This thesis works on identifying suitable factors in this human-based coalition formation, thereby proposing the use of social factors. Besides the social factors, the research also suggests that coalition factors are also identified and merged with the social factors. This work produces a representation schema to accommodate a coalition formation. However, this work also stresses that this schema can be used and applied on different domains and applications. Ounnas (2010) has presented a schema for a learning-based group formation, however traits like trust value and personality is not extended in the representation, and focus is mainly on the role of a person and the interests. In this research, the representation schema is developed to incorporate the traits for relationship, trust and personality.

A new coalition formation framework is proposed with the help of an ontology. The motivation is to produce a knowledge-base for the coalition formation application so that the knowledge created within the process can be captured and stored. This is a contribution to the coalition formation model, where it incorporates a knowledge base in the coalition formation. The representation schema produced from the identified factors is added in this knowledge base. This new coalition formation framework is proposed as a model that can later be adapted to several other functions in an organization where building a collaborative team or group is concerned. For instance, a possible adaptation will be using the model to facilitate coalition formation in healthcare organization to form a surgical team. Another possible adaptation is a

coalition formation for academic institutions, where groups can be requested to perform tasks such as assignments and even non-academic related tasks. The idea of this model is to be able to capture knowledge that is related to people and making use of this knowledge to assist coalition formation.

In addition, a clustering approach is used for the coalition formation. This thesis studies the clustering method, known as the Combinatorial Particle Swarm Optimization (CPSO) by Jarboui et al. (2007). The original CPSO is studied and two levels of enhancements of this algorithm are presented: 1) Combinatorial Particle Swarm Optimization with Crossover Operator (CPSO-CGA) 2) Combinatorial Particle Swarm Optimization with Crossover and Simulated Annealing-based Mutation Operator (CPSO-SAGA). The enhanced and modified algorithm is tested in two types of experiment. First, to compare the enhanced algorithms with the original algorithm. Using mostly the same datasets used by original CPSO work (Jarboui et al., 2007), the comparisons of the results can be made, to determine whether the enhancement has contributed to improvement of the algorithm in terms of the quality of the solution.

Secondly, the original CPSO and modified CPSO (CPSO-SAGA) is applied to coalition formation problem. However, the algorithms are further tuned to suit one of the coalition formation requirements of limiting the number of people in a group or cluster. In the case where certain coalition formation requirement does not restrict the number of people, the CPSO can be used without the additional modification.

Calculation for the objective functions for the SKCF is introduced in order to operationalize the social and coalition factors. This objective function takes into



consideration that this is a multi-objective function, and developed to handle the different types of objectives for the coalition formation.

## **1.8 Thesis Structure**

The organization of this thesis is as follows:

**Chapter 2** presents the literature review of the research. It gives an introduction of the theory to get insights on the concepts. The review studies existing works in coalition formation to investigate the factors used as well as works in social science that focused on factors that influence a group. This chapter then presents some work on knowledge representation for coalition formation. This chapter also includes reviews on optimization techniques specifically clustering and meta-heuristics algorithms and then focuses on Particle Swarm Optimization (PSO) algorithm and its enhancements imposed by researchers.

**Chapter 3** describes the research methodology. Firstly, it elaborates on the research design. This chapter also discusses the proposed framework for the Social- and Knowledge-Based Coalition Formation model, and discusses each layer of the framework. The datasets used in the experiments in this research and the evaluation methodology are also presented.

**Chapter 4** looks into the social and coalition factors that are adapted into the coalition formation model. The organization of these factors in an ontology format is presented as a schema. The structure of the representation is also shown.

**Chapter 5** deals with the algorithms to form the coalition, specifically the clustering algorithm using improved PSO called the Combinatorial Particle Swarm Optimization (CPSO). In this chapter, two algorithms with enhancements made to the CPSO algorithm are proposed: 1) Combinatorial Particle Swarm Optimization with Crossover Operator (CPSO-CGA) 2) Combinatorial Particle Swarm Optimization with Crossover and Simulated Annealing-based Mutation Operator (CPSO-SAGA). Common benchmark datasets are tested and the results are presented and discussed.

**Chapter 6** incorporates the factors from the ontology schema (SKCF model) and the modified CPSO, the CPSO-SAGA. It also discusses details of the objective functions used for optimizing the coalition formation. Two sets of real case datasets are used to show how the CPSO-SAGA works on the SKCF model and the results are discussed.

**Chapter 7** covers the user acceptance study of the real case experiments and the evaluation aspects of it. The chapter discusses the detail of the study conducted, and presents the results from the case study in order to evaluate and validate the proposed SKCF model.

Finally, **Chapter 8** discusses the conclusions as well as providing suggestions of possible future work and improvements related to the work. The contributions and findings from this work are presented to conclude this thesis.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

In this chapter, the literature review is presented, focusing on the related works in coalition formation, the techniques for coalition formation, and works that discussed social and knowledge aspects to grouping and coalition formation, as these are the main aspects to model the Social- and Knowledge- based Coalition Formation (SKCF). Figure 2.1 shows the roadmap or the organization of the literature covered in this chapter.

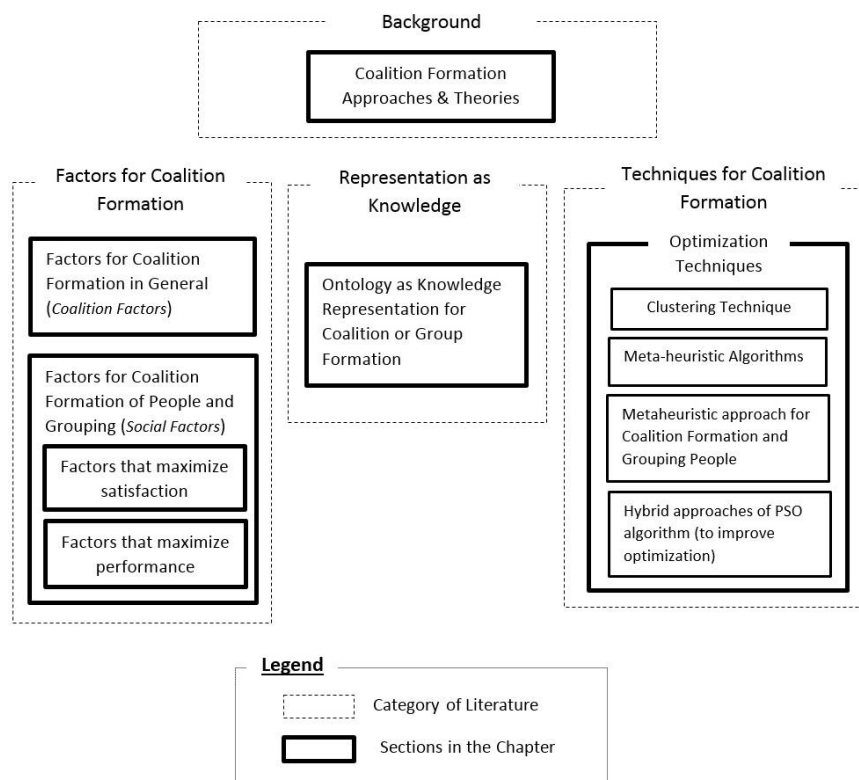


Figure 2.1: Roadmap of the Literature Organization

The first section of the literature, Section 2.2 covers the background of coalition formation, from its earliest theory to the computational approach of coalition formation. Next, the literature focuses on the coalition formation and sociology areas to investigate on suitable factors that can be adopted for a social-based coalition formation.

In Section 2.3, the focus lies on the factors used by existing works in coalition formation. In Section 2.4, the focus is on the social factors that can be adopted to the coalition formation, thus existing works in social science related to grouping of people or dynamics of team formations are studied. Section 2.4 is divided into two parts: 1) Section 2.4.1 - related works that studied factors that maximize a group or team's satisfaction 2) Section 2.4.2 - related works that studied factors that maximize a group or team's performance.

The knowledge aspect of the coalition formation is studied by looking into existing works on knowledge-based grouping system. This is presented in Section 2.5, where the ontology technology that was used as a knowledge tool in the related works are discussed.

One of the important parts in the SKCF is the technique used for the formation. Thus, the techniques or algorithms from some existing works are presented in Section 2.6. In the first sub-section, Section 2.6.1, the clustering approach is discussed as the coalition distribution is similar to the clustering approach, where the coalition formation in this research aims to cluster people into sub-coalitions or clusters. In Section 2.6.2, the literature review discusses the meta-heuristic algorithms as meta-heuristic algorithms are widely known to be efficient in optimization problems.

Section 2.6.3 focuses on existing technique used in coalition formation and grouping mechanism using the meta-heuristic algorithms.

Strength of the Particle Swarm Optimization (PSO) algorithm over other heuristic algorithm are reported by many researchers; such as strength of PSO over Genetic Algorithm (GA) as claimed by Sooda and Nair, (2011), Azadeh et al. (2013), Mohan et al. (2014), and Khansary and Sani (2014); strength of PSO over Simulated Annealing, as claimed by Ethni et al. (2009) and Mohammadi et al (2016); and also over Ant Colonization Optmization (ACO) as claimed by Azadeh et al. (2013). The nature of PSO mimics the social behavior of bird flocking to look for a better path to look for food source. Thus, the human-based coalition formation that is motivated to look for the social cohesion based on the social factors seem to be similar to the solution search in the PSO. In order to study the possibility of enhancing PSO algorithm that can be applied to coalition formation problem, existing works that developed hybrid approach or enhancement to the conventional PSO are studied.

Therefore, in Section 2.6.4, the literature review focuses on the existing works that enhanced or hybridized the PSO algorithm. The focus is also given to research that used enhanced PSO algorithm for clustering problem as the clustering representation is seen to be applicable to represent sub-coalitions in the SKCF. By looking into the existing works, the research gap in terms of enhancing the optimization of the coalition formation can be identified. The research gap from the literature and the direction of the proposed work in this thesis, is presented in Section 2.7. The summary of Chapter 2 is presented in Section 2.8

## **2.2 Background: Coalition Formation Approaches and Theories**

Gamson (1961) stated that “coalition formation is a pervasive aspect of social life” (p. 373). The coalition formation concept is derived from the game theory introduced by Neumann and Morgenstern (1944), where it estimates possible payoffs to derive the potential coalition behavior. The coalition theory presented by Gamson (1961) underlined that the model needs these requirements: 1) Initial distribution of resources – identifying relevant resources and how much resources are controlled by the agents 2) Payoff for each coalition where each coalition has some sort of payoff value 3) Preferences of non-utilitarian strategy – to have a form of rank ordering of the agents preferences to join a coalition 4) Effective decision point – specifying amount of resources formally needed to control a coalition decision.

The work by Gamson (1961) and Neumann and Morgenstern (1944) were both used as basis for theories and approaches of coalition formation over the years. The prospects in the coalition concepts presented by Gamson (1961) and Neumann and Morgenstern (1944) especially in the computing field is mostly on how the concepts can be adopted into a computing process, thus opened wide opportunities for the researches to explore.

When computational coalition formation approach is taken, the decision process of the coalition formation depend on the technical setting of the coalitional model that can be translated and processed by a machine. In technical and computer approach, the coalition formation problem is explored in different approaches. There are works that studied the state of a coalition where the dynamic perspective of a coalition is studied and represented in modeling. Some works explored the coalition formation to solve a real-based scenario and modeled it as a computer system or

software. Some researchers worked on the formulation of coalition formation by presenting algorithms that suit the type of coalition formation in their works.

Ray and Vohra (2014) worked further on the theory of dynamic coalition formation, by presenting an extensive analysis of a coalition formation as a dynamic process. Ray and Vohra (2014) presented on how the equilibrium process exists in coalition formation. A benchmark solution was taken using familiar concepts from existing literature, and presented a dynamic coalition formation model using the game theory approach, and applying the equilibrium. The definition of coalition process in dynamic coalition formation were described as follows.

Take  $N$  as a set of players,  $X$  as a set of states, and  $S$  is a coalition (nonempty subset of  $N$ ). For each state in  $X$  and each coalition  $S$ , there is possible set of coalitional moves by  $S$  to some subset of states. So, a dynamic process on  $X$  happens when the current state of  $X$  is mapped to a probability distribution over set of all possible coalitional moves. These moves are associated with actions taken by coalitions, and this is what is described as the process of coalition formation. Figure 2.3 shows how this process is mapped.

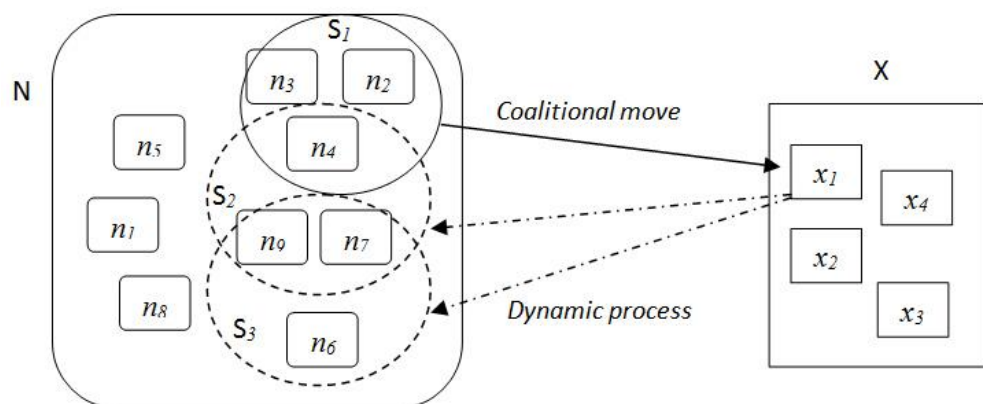


Figure 2.3: The coalition formation as a dynamic process (Ray and Vohra, 2014).

The dynamic approach also focused on probabilistic solutions. The uncertainty of a coalition process can be put in two ways: 1) A coalition can invoke states which are not comparable in payoffs, and can randomize its moves. The movement can also be probabilistically chosen 2) At some state, several coalitions can have possible access to profitable moves, chosen randomly. In strategic form games, randomization occurs quite naturally as randomization is usually necessary for an equilibrium process to subsist.

Looking at the coalition formation from a game theory perspective, the simplest starting point are games with common payoffs. It is shown that for such games, the equilibrium needs to achieve efficient outcome. The equilibrium however, has to be stochastic process for the coalition process, where the process of coalition formation expresses the probability transitions from one state to another. The profitable move is used as restrictions in the process of coalition formation. The formulated profitable move and equilibrium process of coalition formation as presented by Ray and Vohra (2014) is shown in Figure 2.4.

Following the definition, a state can move to another state only if all members in a coalition agree to move to a new state and where better optional state is not available. If there is strictly profitable move, the state needs to change by at least one move that is seen to strictly profitable. The movement is not insisted on and also the strictly profitable does not guarantee a positive probability.



$p$ : process of coalition formation  
 $x$ : for a state  
 $S$ : for a coalition  
 $v_i$ : represents a player's payoff from any state,  $x$  under the process  $p$

whereby  $p$  triggers a value function  $v_i$  for each player  $i$

$S$  has a weak profitable move from  $x$  in  $p$ ,  
 if  $y \in F_S(x)$  (with  $y \neq x$ ), where  $v_i(y, p) \geq v_i(x, p)$  for all  $i \in S$

$S$  has a strictly profitable move from  $x$ ,  
 if  $y \in F_S(x)$  (with  $y \neq x$ ), where  $v_i(y, p) > v_i(x, p)$  for all  $i \in S$

A move,  $y$  is seen as efficient for  $S$  as long as there condition is not  
 overtaken by other move for  $S$ , for example a move,  $z$ ,  
 where  $v_i(z, p) > v_i(x, p)$  for all  $i \in S$

$p(x, y) > 0$  for some  $y \neq x$ ,  
 where in  $S$ ,  $y$  is a (weakly) profitable and efficient move from  $x$  to  $S$   
 and,  
 when there is strictly profitable move from  $x$ ; then  $p(x, x) = 0$ ,  
 and there is strictly profitable and efficient move  $y$  when  $p(x, y) > 0$

Figure 2.4: Formulation of profitable move and equilibrium process in dynamic coalition formation (Ray and Vohra, 2014).

Ray and Vohra (2014) introduced features such as the protocol for the probability of coalition choice, to help determine which coalition is active and inactive. The work of Ray and Vohra (2014) also defined the approach of a dynamic coalition in two different situations 1) Blocking approach: cooperative games 2) Bargaining approach: non-cooperative games.

Coalition is the primary unit of decision making in cooperative game theory, where it depends on the concept of coalitional blocking. Blocking approach is where an allocation is blocked by a coalition if there is another allocation that is more feasible in terms of the payoffs. Ray and Vohra (2014) presented the blocking approach in a

more positive way, as claimed; by making the blocking as a generator of actual moves, involving the coalition formation and its structures.

The bargaining approach is based on non-cooperative games, where all negotiations are expressed formally. There two ways of bargaining: 1) Bargaining with irreversible agreements – a formed coalition cannot disintegrate or shared with a larger group. When a coalition is made, the process of coalition formation comes to an end but this does not necessarily end the payoffs 2) Bargaining with reversible agreements – a time limit may be induced where agreements are valid in this specified period. There is possibility for renegotiating on existing agreement, thus the agreement may be reversible. However, for existing agreement to be changed, it needs approval from existing signatories. In summary, the research on the dynamic coalition formation introduced the features of a coalition that is in a more dynamic state as well as producing methods on representing the dynamic coalition formation. The technical aspects of a coalition formation were addressed in detail and this provided a good foundation for coalition formation researches. Ray and Vohra (2014) also stated that the presented dynamic coalition formation was just another approach suggested and not a general theory, thus it is open to be adopted, improved or further explored. However, other computational aspects such as the optimization and efficiency of the coalition which were not the focus in the work by Ray and Vohra (2014), need to be addressed in order to provide a more robust solution.

Elkind et al. (2013) presented an extensive study on the computational aspects of coalition formation in multi-agent systems (MAS). Coalition formation in a multi-agent system involves multiple interacting intelligent agents in a computational environment. There are two approaches of the coalition formation for MAS which are the 1) Selfish agents, where the agents are only concerned on their own payoffs, for

example the distribution of the gains from the coalition, since the agents need to gain some incentive or benefit in order to participate in the coalitional solution. 2) Cooperative agents, where the agents share a common goal and in terms of a solution with the motivation lies in finding the optimal collaboration pattern or on finding the best way to distribute agents into groups. Elkind et al. (2013) reviewed existing works on coalition formation and showed that many works focus on either one of the approaches and did not combine the approach to maximize the benefit of the coalition formation. There are some works that combined these approaches without explicitly stating that these approaches were combined such as work by Pillai and Rao (2016), Goradia and Vidal (2007) and Shehory and Kraus (1995). However, coalition formation involving human grouping such as work by Sless et al. (2014), Boella et al. (2009) and Pechoucek et al. (2002) focused more on the cooperative agent approach on how to group the coalition without focusing on the payoff benefits or the equilibrium of the coalition. Thus, this is seen as a gap in the computational coalition formation where the combined approach can maximize the strength of both approaches for a particular domain problem that uses the coalition formation approach.

Cho et al. (2013) presented a comprehensive survey on coalition formation that have multi-objectives and multi-techniques. The survey by Cho et al. (2013) is seen to indirectly highlight the importance of combining both cooperative agent and selfish agent. The main focus of the survey was to discuss the three main approaches to solve multi-objective optimization problems in coalition formation which are conventional techniques, evolutionary algorithms (meta-heuristic), and game theoretic approaches; however no implementation or experiment is conducted to test the techniques. The factor trust is suggested as a payoff of a coalition formation involving human grouping, but Cho et al. (2013) mentioned the need to define the payoff in a way to satisfy

multiple objectives. This is seen as a gap in the research in human-based coalition formation that needs to be further explored.

### **2.3 Factors in the Coalition Formation**

Besides the different approaches available in coalition formation area, the domain problems that use the coalition formation approach also vary. Some researches used this approach to solve specific machine problems such as energy constraints problem in multi-agent coordination problem (Farinelli et al., 2013), collaborative mobile computing (Xiang et al., 2015) virtual machines (Pillai and Rao, 2016) and so on. Some used the coalition formation approach specifically for human-based formation or grouping in an organization (Sless et al., 2014) or have explored the human-based factors in coalition formation such as work by Cho et al. (2013). Boella et al. (2009) also worked on human-based coalition formation and proposed a model for formation based in social networks setting whereas Pechoucek et al. (2002) worked on knowledge-based coalition formation to group people for humanitarian efforts. In a more broader domain where researchers tackle the coalition formation as a multi-agent systems (MAS), such as works by Liu et al. (2016a), Hoefer et al. (2015), Goradia and Vidal (2007), Lau and Zhang (2003) and Shehory and Kraus (1998); which can be used for computing processes as well as representation of human communication in a system. As mentioned by Elkind et al. (2013), there are two approaches which are the cooperative agent and selfish agent.

In this section, the literature review is carried out on some researches that work on coalition formation to solve their respective problem in their respective domains. The works that have dealt with human-based coalition formation is discussed, as well