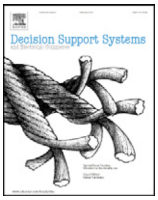
Decision Support Systems 79 (2015) 125–137

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss



Best-matching with interdependent preferences—implications for capacitated cluster formation and evolution

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ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form 19 August 2015
Accepted 19 August 2015
Available online 28 August 2015

Keywords:
Quadratic assignment problem
Genetic algorithm
Evolutionary algorithm
Association/dissociation
Emergence
Collaborative control theory

ABSTRACT

Generalized best-matching refers to matching the elements of two or more sets, on a many-to-one or many-to-many basis, with respect to their mutual preferences and capacity requirements/limits. Generalized best-matching problem (BMP) has a variety of applications in areas such as team and network design, scheduling, transportation, routing, production planning, facility location, allocation, and logistics. The problem is indeed analogous to the *capacitated clustering problem*, where a set of individuals are partitioned into disjoint clusters with certain capacities. This work defines, formulates, and analyzes an important behavior associated with the generalized BMP: The mutual influence of the elements of the same set on each other's preferences, if matched to the same element of the other set. Such preferences are referred to as *interdependent preferences* (IP). A binary program is developed to formulate the problem and provide the basis for analyzing the impact of IP on generalized best-matching decisions from two perspectives: Optimal cluster formation (fixed sets) and evolution (emergent sets). A set of evolutionary algorithms is then developed to handle the complexity of the cluster formation problem, and enable the network of clusters to autonomously adapt to random changes, recover, and evolve. Results from several experiments indicate (a) significant impact of IP on the optimality of cluster formation and evolution decisions, and (b) efficiency of the developed evolutionary algorithms in handling the problem's complexity, and the emergent behavior of matching.

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1. Introduction

1.1. Significance and motivation

Generalized best-matching problem (BMP) [1] is the problem of finding the best match between the elements of two or more sets, on a many-to-one or many-to-many basis, considering certain criteria and conditions. Applications of the generalized BMP range from network design (*e.g.*, supply/sensor networks) to scheduling (*e.g.*, machine/grid scheduling, batching), clustering, transportation and routing (*e.g.*, vehicle routing problem, traveling salesman problem), production planning (*e.g.*, batch loading, group technology, order selection), facility location, allocation (*e.g.*, interns to hospitals; students to schools), logistics (*e.g.*, demand partitioning, sourcing, market clearing), team formation and social networking [2–4]. The ultimate goal of all these (and similar) applications is to form optimally matched, *capacitated clusters*.

The original instance of generalized BMP, *i.e.*, the many-to-one BMP, is analogous to the *capacitated clustering problem*—the problem of partitioning a number of individuals into disjoint clusters with certain capacities. That is, capacitated clustering can be recast as a problem of finding the best two-sided match between the set of individuals (set I) and the set of clusters (set J). For instance, customers, tasks, and interns may represent the sets of individuals to be respectively matched to suppliers, machines, and hospitals, each representing a specific cluster with limited capacity (*e.g.*, a supplier can serve a limited number of customers; a machine can process a limited number of tasks; a hospital can admit a limited number of interns). The difference between the many-to-one BMP and the capacitated clustering problem, however, is in their objectives. The objective of the many-to-one BMP is to maximize a set of matching criteria subject to certain capacity limits and requirements, while the capacitated clustering problem merely ensures that the clusters' capacities are not violated [5].

Matching criteria are diverse, from cost to distance (*e.g.*, between suppliers and customers), performance (*e.g.*, machines processing tasks with different speeds), quality (*e.g.*, dimensional tolerance of assembly products), and stability, depending on the application and scope. Without loss of generality, however, matching criteria can be formalized as *preferences* of the elements of different sets for each other. Such preferences may or may not be fixed and independent of environmental and decisional factors. The purpose of this work is to investigate an important behavior associated with the generalized BMP: The potential influences of best-matching decisions on the individuals' preferences. Specifically, the motivation is to investigate two-sided matching

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http://dx.doi.org/10.1016/j.dss.2015.08.005
0167-9236/Published by Elsevier B.V.

Nomenclature

Acronyms

BMP	best-matching problem
GA	genetic algorithm
QAP	quadratic assignment problem
EA	evolutionary algorithm
IP	interdependent preferences

Indices

i,k	set I
j,l	set J

Parameters

M_j	capacity of $j \in J$
P_{ij}	mutual preference of $i \in I$ and $j \in J$
$\mathbf{c}$	chromosome
$\alpha_{ii'}$	influence of $i' \in I$ on the mutual preference of $i \in I$ and $j \in J$
$p_{i \rightarrow j}$	preference of $i \in I$ for $j \in J$
$\hat{P}_{ij}$	IP of $i \in I$ and $j \in J$
$\mathbf{c}^{\mathbf{m}}$	modified chromosome

Variable

χ_{ij}	1, if $i \in I$ and $j \in J$ are matched; 0, otherwise

instances between sets I and J, where the preference of $i \in I$ for $j \in J$ may be influenced by and represented as a function of matching $i' \in I$, $i' \neq i$, to $j \in J$ (see Fig. 1).

To better comprehend the notion of interdependencies among preferences in best-matching, consider the following example. Suppose you have just arrived at a social gathering and are going to choose a table to sit at (Guests: Set I; Tables: Set J). Besides your initial preference for each individual table (*e.g.*, location; food), your choice may be influenced by the people who are already sitting at each table. It is a natural phenomenon; we have different perceptions and attitudes about different people. The preferences, as described earlier, are merely an abstraction of various matching criteria, and thus, such interdependencies may have certain implications in different application domains. Some practical examples are:

- *Enterprise collaboration*. The "profitability" of a particular coalition for an enterprise may be influenced (increased/decreased) by the members (*i.e.*, other enterprises) of that coalition.
- *Wireless sensor networks*. The choices of an individual sensor for different clusters in terms of "energy consumption" may be influenced by the type, number, and energy level of the sensors in each cluster.
- *Swarm robotics*. The "efficiency" of an individual robot may be influenced by its assignment to different teams, depending on the depending on the type, number, and functionality of the robots in each team.
- *Scheduling*. The optimal allocation of a task to a machine in terms of "makespan" or "cost" may be influenced by the processing and/or setup requirements of the tasks that are already in process or in the queue of each machine.
- *Storage assignment*. The best storage location for a particular product in terms of "total movement time" of material handling devices may be influenced by its *affinity* with the already allocated products.

Interdependencies among preferences can dramatically influence best-matching decisions and lead to non-optimal or even paradoxical decisions, if disregarded. The notion of Interdependent Preferences (IP), coined by Gaertner [6] and Pollak [7] in the 1970s, has been extensively investigated in utility theory, as an indication of the dependencies of the individuals' preferences on the *consumption* or *well-being* of other individuals in their neighborhood [8–13]. Also known as *peer influence*, *neighborhood effect*, *bandwagon effect*, and *conformity* [14], IP leads to either *altruistic* or *envious* behaviors—instead of considering their own absolute payoffs, individuals tend to evaluate their payoffs *relative to* those of others [15,16]. In social sciences and psychology, the notion of IP is known as *interpersonal relations/behaviors/emotions* (*e.g.*, mutual trust [17,18]), and is proven to have significant impacts on social interactions and team/group activities [19,20]. Examples include success/failure of collaborative marketing and sales teams [21], conflicts, job satisfaction, effectiveness, and turnover of interactive nursing units [22], efficiency and rate of errors/ miscommunication in surgical units and operating rooms [23,24], performance, throughput, and cost of construction projects [25], all influenced by certain mutual interactions among individuals.

The major motivations of this study are (a) the widespread applications of IP, (b) the lack of generic and formal analysis in BMP literature, and (c) the impact of IP on capacitated cluster formation and evolution. Accordingly, this work defines, formulates, and analyzes an extension of the generalized BMP with IP (henceforth, BMP-IP), where the elements of the same set influence each other's preferences for the elements of the other set(s), if matched to the same element.

1.2. Outline

For the sake of simplicity and without loss of generality, a many-to-one BMP-IP with two sets is considered, where each element of set I can be matched to up to one element from set J, considering interdependencies among the preferences of the elements of set I (see Fig. 1). The BMP-IP under study is indeed a capacitated clustering problem—each element of set J can be matched to a limited number of elements from set I. The clustering must be performed with respect to the mutual preferences of I's and J's, the capacity limits of J's, and the influences of I's on each other's preferences.

The BMP-IP is first investigated from the cluster formation perspective: Sets I and J are fixed, and all elements are matched simultaneously, given their preferences and respective IP, capacity requirements and limits. The outcome of the capacitated many-to-one BMP is a set of

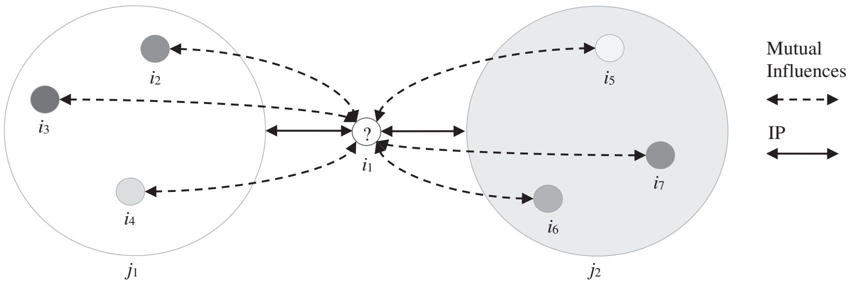

Fig. 1. Generalized BMP (many-to-one) with Interdependent Preferences (IP); The preferences of $i_1 \in I$ for $j_1 \in J$ and $j_2 \in J$ may vary, depending on which other elements of set I have already been matched to j_1 and j_2. For instance, matching i_2 to j_1 may increase, decrease, or not change the preference of i_1 for j_1 (and vice versa).