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A decomposition-based multi-objective optimization for simultaneous balance computation and transformation in signed networks

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ABSTRACT

Many social systems have a set of opposite interactions such as friend/enemy, cooperation/competition and support/opposition. In these signed systems, there exist functional imbalances from the system-level view because of the existence of unbalanced interactions. However, it is difficult to compute the unbalance degree and transform unbalanced factors to balanced ones in real signed systems. Earlier studies tackled these two issues separately and gave a unique solution, and thus cannot be well applied to real applications with constraints. In this paper, we devise a decomposition-based and network-specific multi-objective optimization algorithm to solve the balance computation and transformation of signed networks simultaneously. The devised algorithm aims at finding a set of optimal balance transformation solutions, and each of which is the trade-off between the twin objectives (i.e., the minimization of inter-cluster positive links and the minimization of intra-cluster negative links). Of these solutions, the one with the fewest unbalanced links corresponds to the solution to the balance computation. And each trade-off solution corresponds to an optimal balance transformation way under a certain transformation cost. Extensive experiments on four social networks demonstrate the effectiveness of the devised algorithm on both the computation and the transformation of structural balance. They also show that the devised algorithm can provide multiple optimal solutions at the same transformation cost.

1. Introduction

The advance of online social media offers various platforms such as Facebook, Twitter, Web 2.0, online communities and recommender systems for individuals to connect with each other in multiplex patterns that can encompass trust/distrust, friendly/hostile, pleased/disgusting, trusty/trustless or cooperative/competitive relationships [3,6,19,31,36,37,40,42]. These systems can be well described as signed networks with nodes and multiple types of links (i.e., positive, negative and zero links) [26]. And, in some signed systems, the essential interactions are more important than the topology from the view of social theory [8,44]. Moreover, local interactions have great influences on the formation of global system functions

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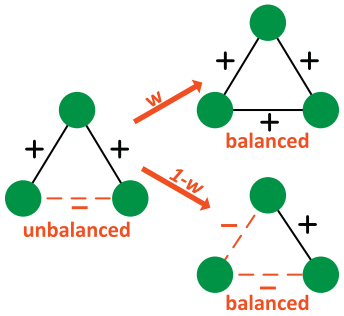

Fig. 1. Illustration of two ways of balance transformation. The solid lines and the dotted lines are positive links and negative links, respectively.

[7,9,24,35]. For instance, the alliance/antagonism relations influence the stability, balance and equilibrium of nations [44]. The true/false comments affect the reliability of e-commerce recommender systems.

Signed networks have many important properties such as community structure [9,11,20] and structure balance [5,15]. Community structure potentially reflects the local and global structure functionalities while structure balance systematically reflects the global conflicts of signed systems. The studies on the structure balance can help us understand the origin of conflicts in signed systems. Structure balance principles and theories are proposed by Heider in the 1940s based on the balances and imbalances of three interconnected people from social psychology view [15], and extended by Cartwright and Harary in the 1950s by graph or network theory [2]. The balance theory allows us to review the structure balance of signed networks from the following two equivalent ways: i) a local view, i.e., the balance of signed triads, and ii) a global view, i.e., the balance of clustering sets [6]. More specifically, the balance theory can be summarized as follows.

- *Structural balance for signed triads*. On the assumption that an edge with $+(-)$ sign indicates a friendly (hostile) relationship between the corresponding two individuals, four social relations in signed triads, i.e., $+++$, $+--$, $---$ and $++-$, are obtained. Based on the general balance theory of Heider, the former two are more balanced than the latter two in sociology and psychology [2,17].
- *Structural balance for completed networks in a local view*. In a completed network, there are $N(N-1)(N-2)/6$ signed triads, where N is the size of the network. If all of its signed triads are balanced, the completed network is balanced [2,6,17,39].
- *Structural balance for arbitrary networks in a local view*. In a local view, "an arbitrary network is balanced if its completed network version by filling in all missing edges labeled with either + or - is balanced" [6,39].
- *Structural balance for arbitrary networks in a global view*. In a global view, "an arbitrary network is balanced if it can be separated into multiple clusters (opposed sets) in such a way that the nodes in the same cluster (set) are interconnected positively whereas those in different clusters (sets) are interacted negatively" [6,39].

The balance computation and the balance transformation of signed networks give us a comprehensive understanding of the imbalance degree of systems and a deep thinking about the evolution of unbalanced systems, respectively [8]. In social systems, unbalanced entities and relationships are the sources of tensions, conflicts or psychological dissonances [25]. To reduce and resolve the tensions, researchers try to identify the unbalanced factors (e.g., unbalanced relationships) and transform them into balanced ones. However, it is difficult to compute and transform the imbalances of signed networks because they cannot be solved in polynomial time [8]. Moreover, there exist multiple balance transformations considered different objectives, e.g., minimization of transformation cost.

Recently, many models and optimization methods have been proposed to solve the balance computation and transformation of signed systems. For instance, Krachhardt et al. [18] put forward three models from the perspective of emotional tension to find the relations between social distance and perceived balance in signed networks. Srinivasan [35] elaborated the effects of the local structure balance on the global functionality and structure of social networks. Facchetti et al. [8] developed an equivalence transformation based method to compute the unbalance of large-scale social networks. Honda et al. [16] presented a clustering-based balance computation method to solve the collaborative filtering problem. Qian et al. [29] generalized the structural balance theory by introducing the relationship strength index for modeling trust in social networks. Especially, in our previous work [22], we computed the imbalances of signed network based on the minimization of an energy function [8]. Moreover, considering the different cost of converting a positive and negative link in reality, we compute the normalized transformation cost of transforming a positive link to a negative link as w, and that of $1-w$ for the opposite transformation (shown in Fig. 1). And thereafter, we devised a balance transformation model based on the minimization of the transformation cost [22]. A systematic review of the balance theory and its applications can be achieved in [44].

Note that, many balance computation and transformation methods (e.g., our previous work MLMSB [22]) suffer from the following issues: i) the balance computation and the balance transformation of signed networks are solved separately; ii) in the balance transformation, each w value corresponds to a transformation optimization model, which makes it