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Common influence region problems

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ABSTRACT

In this paper we propose and solve common influence region problems. These problems are related to the simultaneous influence, or the capacity to attract customers, of two sets of facilities of different types. For instance, while a facility of the first type competes with the other facilities of the first type, it cooperates with several facilities of the second type. The problems studied can be applied, for example, to decision-making support systems for marketing and/or locating facilities. We present parallel algorithms, to be run on a Graphics Processing Unit, for approximately solving the problems considered here. We also provide experimental results and discuss the efficiency and scalability of our approach. Finally, we present the speedup ratios obtained when the running times of the parallel proposed algorithms using a GPU are compared with those obtained from their respective efficient sequential CPU versions.

1. Introduction

This paper studies two common influence region problems: *common influence region queries* and *common influence location problems*. They are related to the simultaneous influence (i.e. the capacity to attract customers) of two sets of facilities of different types, competitive and collaborative. The first type competes against the other facilities of the first type but cooperates with several facilities of the second type.

The three main elements of common influence region problems are facilities, customers and locations. Facilities provide goods or services (warehouses, schools, hospitals, retail outlets) and can operate within a competitive or cooperative framework. Customers, who are the users of the facilities, demand certain goods or services. Locations are spatial positions where facilities and customers are located. In problems like these, knowing the capacity a facility has to influence customers, by taking into account the attractiveness of the facility itself and the neighboring facilities of the customers, is fundamental. To mathematically state the problems we want to solve, we need to model these three integral elements, together with their interactions:

- *Locations*. We represent facilities and customers by points continuously dispersed on a planar domain, where customers can move without any barriers.
- *Facilities*. Each facility is assigned a weight, a measure of its importance or power to influence customers, based on its attractiveness.
- *Customers*. We assume that customers are indifferent when it comes to choosing among their k-nearest facilities.

  From now on, we identify each facility and customer with its location.

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– *Location, facilities and customer interaction*. To reflect that customers select facilities depending on distance and importance, according to the model presented in [1], we assign a weighted distance to each facility, which is the product of the Euclidean distance and the inverse of the facility weighting. The proximity of a facility to customers is an indicator of its potential impact on those customers, however, the capacity that a facility has to influence customers also depends on its neighboring facilities, and this in turn leads to the notion of *k-influence region*. Given a set of facilities that compete against themselves to attract customers, we define the k-influence region of a facility as the set of points of the domain the given facility has among their k-nearest neighbors by considering weighted distances. Consequently, the k-influence region of a facility is the union between the cells in the k-order Voronoi diagram that have this facility as one of the k-nearest neighbor facilities.

On the other hand, we consider the domain partitioned into regions so that each region has associated to it a non-negative weight which represents, for example, population density or the average buying capacity of the region. The *weighted area* of a region of the domain is defined as the sum of the weighted areas of the subregions, obtained by intersecting a given region with the subregions of the domain partition. The weighted area measures, for example, the total population or buying capacity of the region.

1.1. Common influence regions

In this paper we address two families of problems related to the capacity of two sets of facilities of different type, competitive and collaborative, to attract customers. To this purpose, we first introduce the concept of (k, k')-*common influence region* associated to a specific facility of the first type and to a subset of facilities of the second type. The (k, k')-common influence region is the intersection of the k-influence region of the specific facility with the union of the k'-influence regions of the facilities in the subset. Next, we use the weighted area of a (k, k')-common influence region to measure the capacity to influence customers that the given facility of the first type has, by taking into account its neighboring facilities of both types.

1.1.1. Common influence region queries

Nowadays, it has become difficult for businesses to stay competitive without allying themselves with other businesses. Thus, there is an increasing interest in inter-firm relationships with an eye to building successful collaborative strategies that can provide competitive advantages for the firms involved. Collaborative marketing is accomplished by companies working together in cooperative activities, such as product promotion or marketing communication, in order to create synergies and achieve a superior market position for their products and services.

Basically, a common influence region query determines what the facilities are of a set of competitive facilities such that, for each facility of another set of collaborative facilities, the weighted area of the common influence region has a minimum prefixed value. The solutions to common influence region queries, for example, can help decision-makers to develop strategic competitive–collaborative opportunities. Next, we present a motivational example.

Example. An advertising agency would be able to find all the pairs (s, g) of stores and gas stations to the extent where there are at least 30,000 people residing in the region whose points have store s among their 4-nearest stores and at the same time, have gas station g among their 2-nearest gas stations. These pairs are then used to make collaborative advertisements directly aimed at to the residents in the common influence region of each pair. For example, s offers a 5% discount for customers who have bought petrol at g and g offers a 3% discount to customers who have shopped in s, within the same month.

1.1.2. Common influence location problems

The main objective of a single facility location problem is to place a new facility, with respect to a given set of sites, so that certain optimality criterion is satisfied [6,5,17]. The optimality criterion of most classical single facility location problems is based on distances. Many variations have been considered, for example, the maximum distance or the sum of distances from the facility to the sites is typically minimized.

An inherent limitation of classical single facility location problems is that only one optimal location is returned as the answer which, in many cases, is very expensive to compute and is generally too restrictive. However, providing information not only about the optimal obtained location, but also the various new possible sub-optimal locations may prove to be very useful. In some situations, experts consider a sub-optimal location as being the best option when other factors (e.g. construction or transport costs, access to transport, etc.) are taken into account.

Essentially, a common influence location problem finds a region where a new facility, with a known associated weight that will compete with the facilities of a given set of facilities and collaborate with the facilities of another set, can be allocated. The new facility has to be allocated guaranteeing that the weighted area of the common influence region of the new facility and each collaborative facility has a minimum prefixed value. Common influence location problems return an entire region of suitable sub-optimal locations. Solutions to common influence location problems can, for example, help decision-makers to move towards deciding on appropriate locations for a new facility. Next, we present a motivational example.

Example. Suppose that we wanted to find a location to open a new restaurant which will share different advertising campaigns with a group of neighboring cinemas. We might consider that the restaurant would be best located in regions