An EFFICIENT METHOD for STATIC and TRANSPORTATION FACILITY LOCATION ALLOCATION in LARGE SPATIAL DATASETS

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Abstract

This paper solves a location allocation problem about two types of facilities defined as follows: given a set Loc of locations and a set D of weighted objects located in Loc, we seek to allocate the given number n of static facilities (S) with limited capability and m of transportation facilities (T) to the locations in Loc, which aims to minimize both the average reachability distance from D to S and the maximal transportation reachability distance between D and S through T with consideration of capability constraints. The problem is challenging because two types of facilities are involved and need to cooperate with each other to fulfil the goal. In this paper, we propose a capability constraint facility location allocation algorithm to allocate static and transportation facilities and assign demand points to static facilities with consideration of capability constraints. It first uses capability constraint weighted coefficient assignment to assign demand points to static facility, then uses static facility location searching method to locate the static facilities. Next, it uses transportation facility location searching method to locate the transportation facilities. In addition, to be suitable for time-critical applications, we extended the method to an approximate algorithm that is more efficient with limited scarification on accuracy. An experimental evaluation on real dataset demonstrates the efficiency and practicality of the algorithms.

Background and Relevance

Spatial analysis research is an important research field and has a variety of applications. Facility location problem is one type of spatial analysis which solves problems of matching the supply and demand by using sets of objectives and constraints (Owen & Daskin, 1998) (Longley & Batty 2003) (Jain et al., 2002). The objective is to determine a set of locations for the supply so as to minimize the total supply and assignment cost. For instance, city planner may have a question about how to allocate the facility such as hospitals and fire stations for new residence area. The decision will be made based on the local populations and the capability of the limited resources. Research in single type of facility location problem can be separated in to three categories: the P-Median Problem (Arya et al., 2001) (Zhang et al, 2006), the Center Problem (Daskin, 1995) and the Covering Problem (Daskin, 1982) (Pacheco et al., 2008) (Jia et al., 2007).

In reality, we often face two types of facilities location problem when the distribution of the single type of facility within a service area is inadequate, leading to either suboptimal response times or inefficient use of resources. For example, for emergency medical services, we can locate the hospital locations in such a way that achieves full coverage of a service with the minimum total travelling distance, which usually ends up the hospital locations close to the dense community. However, for the residents in the sparse and remote area, since the number of hospitals is limited, in order to offer fast response time, the ambulance should be located to shorten the time to access medical services. In this application, there are two types of facilities, static facility (e.g. hospital) and transportation facility (e.g. ambulance) need to be located in a region. The service is supplied to the customers by the cooperation of these two types of facilities. In addition, dependency relations usually exist between different types of facilities. Specifically, the locations of transportation facilities are dependent on the locations of static facilities and demand objects. For example, the locations of ambulances will be determined by both residence locations and hospital locations. However, none of current methods can apply to the two types of facilities location problem directly.

The other limitation in current capability constraint facility location algorithms is their capability assignment method. (Wong et al., 2007) propose an algorithm for assignment between facilities and demand points based on mutual nearest neighbour. (Ghoseiri & Ghannadpour, 2007) use an urgencies capability constraint facility allocation method that gives an assignment between a facility and a demand point through urgencies, which is a method to define a spatial relationship between points. However, all of these algorithms only consider the spatial priority for assignment. In this paper, we design a new capability constraint assignment method which considers both spatial relations between demand points and static facilities and the demand attribute of demand points.

The key main contributions of the paper are summarized below:

● We introduce a new type of facility location problem regarding to static and transportation facilities and propose a novel heuristic algorithm to solve the problem. Instead of only minimizing the average travelling distance as traditional facility location problem, we consider the constraint between the transportation facilities and static facilities and minimize the maximum travelling distance of transportation facilities.

● We propose a new weighted coefficient assignment in the step of allocating capacitated constraint static facilities, which avoids assigning demand points to static facility by only considering the spatial relations between them and overlooking the amount of demand.

● To make it more applicable on real time applications, we extended the algorithm to an approximate algorithm which dramatically reduces the execution time and still have a very reasonable accuracy.

Methods and Data

The heuristic algorithm we proposed is Capability Constraint Facilities Location Searching Algorithm (CCFLS). The algorithm contains three components, weighted coefficient capability constraint assignment method (WCCAA), static facility location searching method and transportation facility location searching method. The work procedure is shown in Fig. 1.

```
CCFLS(D,Snum,Tnum)
  Input: D is a set of demand objects, Snum is the number of the static
facilities and Tnum is the  number of the transportation facilities
  Output: locations for static facilities S, locations for
transportation facilities T.
/* random choose the initial locations for static facilities in S */
  1  S = locateRandomly (D, Snum)
/* static facilities locations searching step */
  2  SearchStaticFacilityLocations (D,S)
/* random choose the initial locations for transportation facilities in
T. */
  3  T = locateRandomly (Q, Tnum)
/* transportation facilities locations searching step*/
  4  SearchTransportationFacilitiesLocations(D,T)
```

Fig.1. Pseudo code of CCFLS

Weighted Coefficient Capability Constraint Assignment Method

As discussed before, current capability constraint assignment methods only considered the spatial locations of demand objects. In this paper, we define a new weighted coefficient which take account of both spatial locations and demand weight of demand objects. The weighted coefficient of a demand point d is defined as:

$$W(d) = (dist(d, SN(d)) - dist(d, FN(d))) * d.w$$

Where $dist(d, FN(d))$ and $dist(d, SN(d))$ are the distances between demand point d and its closest available static facility $FN(d)$ and its second closest available static facility $SN(d)$, respectively. The demand points with higher weight coefficient values are assigned first.

Static Facility Location Searching Method

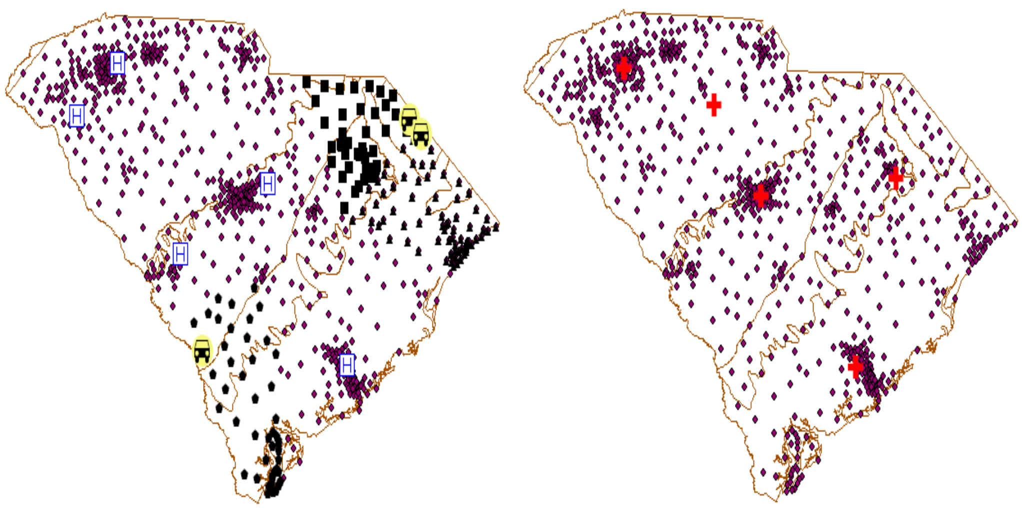
Since usually the number of potential locations for static facilities is very large, it is impossible to allocate static facilities to every potential locations and then pick up a set of optimal locations. So, here we introduce the concept of spatial clustering to reduce the searching space. Spatial clustering is the process of grouping a set of objects into classes so that objects within a cluster have high similarity to one another, but are dissimilar to objects in other clusters (Han et al., 2001). Based on it, we assume that intra cluster locations may be closer to the optimal location of the static facility in the cluster. Thus, in each iteration each static facility and the demand objects assigned to it (by using WCCAA) would be seen as a cluster. Then we search every static facility's optimal location in its cluster and only change one static facility's location to its optimal intra-cluster location which can reduce the average distance most.

Transportation Facilities Location Searching Method

Locations of transportation facilities depend on both locations of demand objects and static facilities. For reducing the computation time, we choose a myopic method in this step. The strategy is that it changes a transportation facility to the location whichever reduces the maximal transportation reachability distance most within each loop and stops if the exchange cannot bring the reduction of transportation reachability distance or the iteration time reaches the redefined times.

Results

This section presents a sufficient-capacity experiment with a real data set, which is to locate five hospitals and three ambulance parking sites in South Carolina. The data set consists of 867 census tracts (Census2000), with each treated as a demand location. The population of a census tract is considered as its demand, which varies from 197 to 16745. The total population (4,212,012) is considered as the overall demand. Centroids of these census tracts are considered as the demand points, which are used to calculate the Euclidean distances among demand locations, hospitals and ambulances. Hospital capabilities range from 800,000 to 1,400,000.



(a) (b)

Fig. 2 Solution to a real dataset : (a) CCFLS (B) Capability Constraint single type facility location algorithm

Figure 2 presents the result of CCFLS (Figure 2(a)) and the result of Capability Constraint single type facility location algorithm (Figure 2(b)). H in Figure 2(a) stands for the location of hospital. stands for the location of ambulance parking site. The points marked by ▲, ⬟ and ■ stand for different ambulance parking site's service area. ✚ in Figure 2(b) stands for the location of hospital. In Fig 2(a), the average reachability distance is 56.2 km, and the maximal accessibility distance is 260 km. In Fig 2(b), the average reachability distance is 59.7km, and the maximal accessibility distance is 322 km.

Conclusions

This paper proposes and solves two kinds of facilities locations allocation problem. The CCFLS algorithm that separates the allocation process into two steps and alternately uses capability constraint assignment method and local optimal location searching method to find the optimal locations in each step. According to our experimental results, CCFLS performs well in the real dataset.

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