Partially Ordered Preferences Applied to the Site Location Problem in Urban Planning

Sylvain Lagrue[1], Rodolphe Devillers[2,3], and Jean-Yves Besqueut[4]

[1] CRIL, CNRS - Université d'Artois, Rue Jean Souvraz, SP 18, Lens 62307, France
`lagrue@cril.univ-artois.fr`
[2] Centre de Recherche en Géomatique - Université Laval
Québec (QC), G1K 7P4, Canada
[3] Institut Francilien des GéoSciences, Université de Marne-la-Vallée
5 Bld Descartes, 77454 Marne la Vallée, France
`rodolphe.devillers.1@ulaval.ca`
[4] SOMEI - 115 rue St Jacques, 13006 Marseille, France
`jean-yves.besqueut@somei.fr`

Abstract This paper presents an application that aims at identifying optimal locations based on partially ordered constraints. It combines a tool developed in this project that allows the management of partially ordered constraints and a Geographical Information System (GIS) allowing spatial data mapping and analysis.

Experts in urban planning provides constraints, being in our application a combination of legal constraints and preferences expressed by the property developer. As these constraints can hardly be totally ordered because they are not comparable, constraints are partially ordered.

The experiment was performed using about 3800 cadastral parcels and 12 different constraints, each parcel being characterised for each constraint using GIS analysis operators. Data are then processed by the program mpropre (Managing PaRtially Ordered PREferences) that provides in output one or several optimal parcels. Results are finally validated by an expert and using ortho-images of the geographic area of interest.

1 Introduction

The geographic information field can be applied to a variety of application domains, using for instance Geographical Information Systems (GIS) for mapping or spatial analysis purposes. A typical problem in GIS applied to urban planning is the identification of locations, on a given territory, that best fits with several characteristics [1]. This can be for instance the identification of an optimal location to build a power plant, based on the field characteristics (e.g. field size, topography, slope), proximity of resources (e.g. rivers, electrical and sewer networks), and limiting visual sound pollution. Different works address the problem, generally using multi-criteria approaches that can be linked to GIS software ([2], [3] or [4]). These approaches often use a raster representation of data in order to produce matrices for each criterion of interest [4]. Matrices can then be combined, using certain weights on each criteria according to its importance.

F. Galindo et al. (Eds.): DEXA 2004, LNCS 3180, pp. 151–160, 2004.

However, such approaches have several limits. On one hand they use raster representations of data initially represented by vectors, introducing then error in the model and sometimes causing problems related to a wrong choice of matrices resolutions [5]. On the other hand, the weight of criteria does not allows the identification of some parameters seen as mandatory before considering other criteria. For instance, if the field size is too small, or is not available, it is not necessary to know if it is close enough to the sewer network, the field being directly excluded from the analysis.

Moreover, the different constraints, or preferences (these two terms being used in this paper in their wider definition) provided by the expert should often be comparable to be integrated in these methods. This is a limit, mostly if the constraints are not related to each other. Furthermore, considering these constraints as being equally preferred instead of considering them *incomparable*, often lead to false results because it is too risky.

This paper presents a method using partially ordered preferences for the selection of locations that best fit with certain constraints or preferences. Section 2 presents an application that aims at finding the optimal cadastral parcel for building a house in an urban area. Section 3 presents the method developed to manage partially ordered constraints. Finally, section 4 presents the results of the experimentation for the application and a discussion of these results, identifying advantages and limits of the approach.

2 Problem of the Selection of an Optimal Location for Building a House

The problem of selecting a location that best fits with a set of constraints is a real-life problem occurring frequently in the urban planning and development domain. The objective of this application is to help an expert to find the "best" possible location to build a house according to a set of constraints.

Constraints - Constraints examples are provided in the table1. In this application, constraints can be legal, such as "parcel has to be located at less than 150m from a fire hydrant" or structural, such as a minimal parcel size needed to build the house: "parcel size has to be more than $1000m^2$". These two constraints are strong and are mandatory for cadastral parcels selections.

Similarly, experts may want to express other constraints, like cost ones. It can be for instance the constraint "parcel should be available". Indeed, a parcel being available will avoid demolition fees. Expert may also ask for parcels having a minimum slope to limit excavation fees and increase building stability. Finally, the property developer could express constraints that will make the parcel more attractive to potential customers. It can be for instance "parcel should be located at less than 500m from commercial strip" or "parcel should be located at less than 250m from a river or lake, or be located at less than 500m from a park". These constraints are defined *a priori* and the expert cannot clearly evaluate

Table 1. Constraint examples

Strong constraints (legal & structural)
C_1 : parcel size has to be more than $1000m^2$
C_2 : parcel should be located at less than 150m from a fire hydrant
Cost constraints
C_3 : parcel should be available
C_4 : parcel slope should be minimised
Property developer constraints
C_5 : parcel should be located at less than 500m from a commercial strip
C_6 : parcel should be located at less than 250m from a river or lake or less than 500m from a park

their impact. He only knows that certain constraints have more impact than others.

Constraints Ordering - If the expert provides several constraints, probability is high that no parcel will satisfy all of them. Then, an expert is asked to give preferences on the different constraints. For instance, strong constraints will be preferred to all the other ones. Similarly, property developer can evaluate, without providing a precise quantification, constraints that will have more impact than others. Cost constraints can also be ordered by the expert depending on the cost implied by demolition or excavation for instance. However, expert can't provide preferences between cost constraints and property developer constraints. Constraints can then only be *partially* ordered.

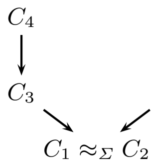

Figure 1. Partial pre-order on constraints

Figure 1 shows how the expert can order constraints. An arrow between two constraints means that the constraint identified by the arrow is preferred to the other one. For instance, constraint C_3 is preferred to constraint C_4. Strong constraints are preferred to all the other ones, cost constraint C_3 is preferred to the cost constraint C_4 and the property developer constraint C_5 is preferred to the property developer C_6. However, no preference can be identified between incomparable cost constraints and property developer constraints, without quantifying precisely the impacts of these constraints.

3 Management of Partially Ordered Constraints

This section presents a method for managing partially ordered constraints. Such method allows to select the best geographic locations, with respect to a partial order based on a set of constraints. This method is based on the concept of comparator which allows comparing subsets of constraints from a partial order of constraints. We first present some basic definitions.

3.1 Basic Definitions

Let $\Sigma = \{C_1, C_2, \ldots, C_n\}$ be a *finite* set of constraints. A partial pre-order $\preceq_\Sigma$ on Σ is a reflexive ($C_i \preceq_\Sigma C_j$) and transitive (if $C_i \preceq_\Sigma C_j$ and $C_j \preceq_\Sigma C_k$ then $C_i \preceq_\Sigma C_k$) binary relation. In this paper, $C_i \preceq_\Sigma C_j$ intuitively means that the constraint C_i is at least as preferred as C_j.

A strict partial order $\prec_\Sigma$ on the set of constraints Σ is an irreflexive ($C_i \prec C_i$ does not hold and transitive binary relation. $C_i \prec_\Sigma C_j$ means that C_i is strictly preferred to C_j. A strict partial order is generally defined from a partial pre-order as $C_i \prec_\Sigma C_j$ if $C_i \preceq_\Sigma C_j$ holds but $C_j \preceq_\Sigma C_i$ does not hold.

The equality is defined by $C_i \approx_\Sigma C_j$ if and only if $C_i \preceq_\Sigma C_j$ and $C_j \preceq_\Sigma C_i$. Intuitively, $C_i \approx_\Sigma C_j$ means that C_i and C_j are equally preferred. We finally define incomparability, denoted by $\sim_\Sigma$, as $C_i \sim_\Sigma C_j$ if and only if neither $C_i \preceq_\Sigma C_j$ nor $C_j \preceq_\Sigma C_i$ holds. $C_i \sim_\Sigma C_j$ means that neither C_i is preferred to C_j, nor the opposite.

In the following, $C_i \npreceq_\Sigma C_j$ (resp. $C_i \nprec_\Sigma C_j$, $a \not\approx b$) means that $C_i \preceq_\Sigma C_j$ (resp. $C_i \prec_\Sigma C_j$, $C_i \approx_\Sigma C_j$) does not hold.

A total pre-order $\leq_\Sigma$ is a partial pre-order such that $\forall C_i, C_j \in \Sigma : C_i \leq_\Sigma C_j$ or $C_j \leq_\Sigma C_i$.

Let $\prec_\Sigma$ be a strict partial order on a set Σ. The set of minimal elements of Σ, denoted by $Min(\Sigma, \preceq_\Sigma)$, is defined as follows: $Min(\Sigma, \preceq_\Sigma) = \{C_i \in \Sigma : \nexists C_j \in \Sigma, C_j \prec C_i\}$. Note that only the strict partial order is useful for determining minimal elements of Σ.

3.2 Comparing Subsets of Constraints

Let $L = \{l_1, l_2, \ldots, l_p\}$ be the set of possible locations. Roughly speaking, the location l_i is strictly preferred to the location l_j, denoted by $l_i \lhd_L l_j$, if the set of formulas falsified by l_j is preferred to the set of formulas falsified by l_i.

Therefore, we need to define a relation of preference on constraints subsets from a partial pre-order on a set of constraints. Such a relation is said to be a *comparator*. There are several ways to define a comparator (see [6], [7], [8] and [9] for more details on comparisons between subsets). We use the following one: a subset of constraints X is preferred to a subset of constraints Y if and only if for each element in Y, we can find a better element in X. More formally:

Definition 1. *Let* $(\Sigma, \preceq_\Sigma)$ *be a set of partially ordered constraints and* $X, Y \subseteq \Sigma$ *(we assume that neither* X *nor* Y *is empty),* X *is strictly preferred to* Y*,* *denoted by* $X \lhd Y$ *iff:* $\forall C_j \in Min(Y, \preceq_\Sigma), \exists C_i \in Min(X, \preceq_\Sigma)$ *such that* $C_i \prec_\Sigma C_j$.

If $X = Y = \emptyset$, we then consider that neither $X \lhd Y$ holds, nor $Y \lhd X$, and it can be demonstrated that $\lhd$ is a strict partial order. Example 1 illustrates this definition.

Example 1. We consider again the case presented on the Figure 1, which was such that

$$\Sigma = \{C_1, C_2, C_3, C_4, C_5, C_6\}$$

and $\preceq_\Sigma$ was such that :

$$\begin{cases} C_1 \approx_\Sigma C_2, \\ C_1 \prec_\Sigma C_3 \prec_\Sigma C_4, \\ C_1 \prec_\Sigma C_5 \prec_\Sigma C_6. \end{cases}$$

Let X be such that $X = \{C_3, C_4, C_5\}$ and Y be such that $Y = \{C_4, C_6\}$. We then have $X \lhd Y$, indeed C_3 is preferred to C_4 and C_5 is preferred to C_6.

We can now introduce our method for choosing the "best" locations for building a house.

3.3 Selecting the "Best" Locations

Let $(\Sigma, \preceq_\Sigma)$ be a partially ordered set of constraints and L the set of all possible locations. We suppose that for each location l, we dispose of all constraints that are falsified by l. This set of falsified constraints is denoted by $\lceil l, \Sigma \rceil$. Note that, in the context of our application, this set of falsified constraints is provided by the GIS. This section aims to show how to compare the different possible spatial locations, according to the partially ordered constraints they falsify.

To achieve this goal, we define a strict partial order $\lhd_L$ on the set of possible locations. Let $l1$ and l_2 be two elements of L, the location l_1 is preferred to the parcels l_2 (denoted by $l_1 \lhd_L l_2$) if and only if the set of constraints that are falsified by l_2 is preferred to the set of constraints falsified by l_1. For comparing these subsets of Σ, we use the comparator defined in the previous section.

Definition 2. *Let* Σ *be a set of constraints and* $\preceq_\Sigma$ *a partial pre-order on* Σ. *Let* L *be the set of possible locations and* l_i *and* l_j *two locations. Then:*

$$l_i \lhd_L l_j \quad \textit{iff} \quad \lceil l_j, \Sigma \rceil \lhd \lceil l_i, \Sigma \rceil.$$

Note that $\lhd_L$ is a strict partial order. We illustrate this definition by the following example.

Example 2. Let us consider again the Example 1. We consider two locations l_1 and l_2. The set of constraints they falsify ($\lceil l_i, \Sigma \rceil$) and the set of constraints they satisfy ($\Sigma \setminus \lceil l_i, \Sigma \rceil$) is presented in the Table 2.

We have $l_1 \lhd_L l_2$. Indeed we have $\{C_3, C_4, C_5\} \lhd \{C_4, C_6\}$ and then $\lceil l_2, \Sigma \rceil \lhd \lceil l_1, \Sigma \rceil$.

Table 2. Example of locations

Location	$\Sigma \setminus \lceil l_i, \Sigma \rceil$	$\lceil l_i, \Sigma \rceil$
l_1	$\{C_1, C_2, C_3, C_5\}$	$\{C_4, C_6\}$
l_2	$\{C_1, C_2, C_6\}$	$\{C_3, C_4, C_5\}$
l_3	$\{C_1, C_2, C_4, C_6\}$	$\{C_3, C_5\}$

Note that our method provides different results compared to approaches only considering the verified constraints. For instance, consider a location l_3 such as $\lceil l_3, \Sigma \rceil = \{C_3, C_5\}$. In this case, l_1 is preferred to l_3: for each constraints falsified by l_1 (C_4 and C_6), there is a preferred constraint falsified by l_3 (resp. C_3 and C_6). On the contrary, if we consider the sets of satisfied constraints ($\{C_1, C_2, C_3, C_5\}$ for l_1 and the sets of satisfied constraints $\{C_1, C_2, C_4, C_6\}$ for l_3), we then do not have $\{C_1, C_2, C_3, C_5\} \lhd \{C_1, C_2, C_4, C_5\}$, which is not suitable.

The problem with the definition of $\lhd_L$ is that it does not verify the property of a strict monotony: $\lceil l_i, \Sigma \rceil \subset \lceil l_j, \Sigma \rceil$ does not imply that $l_i \lhd_L l_j$. This property is not suitable in a framework of reasoning [9]. Nevertheless, it seems to be intuitive to consider that the location that falsifies the less constraints as possible should be preferred. We thus propose a pre-treatment that eliminates locations which are not minimal (as an inclusion) for the constraints they falsify.

Problem of Non-binary Constraints - Our algorithm only manages constraints which are binary, values being *true* and *false*. When the experts want to express more complex constraints, we then break out the initial constraints into several binary constraints. For instance, we decompose the constraints "the parcel should be located near a river" into several constraints ("the parcel should be located at less than 10m from a river", "the parcel should be located at less than 50m from a river", "the parcel should be located at less than 100m from a river", etc.). We then ask the experts to order these constraints with the other constraints. This method can be used when the number of constraints number is not too high.

An Implementation: mpropre - An implementation, *mpropre* (for Managing Partially Ordered PREference) has been programmed in C++. The algorithm selects in a first time, the locations which minimize constraints falsification (as usual inclusions). In a second time, it computes the minimal elements for $\lhd_L$.

These two steps in the research of minimal elements only need polynomial calls in the number of parcels and the number of constraints. It can then be useful for realistic databases, as demonstrated in the following section.

4 Experimentation, Results, and Validation of the Approach

An application has been developed within the European REVIGIS project using real constraints provided by experts for the city of Sherbrooke, Canada. The application objective is to identify one or several cadastral parcels that best comply with a set of constraints defined by the city and the property developer, for the construction of a house.

Figure 2. Subset of the cadastral parcels dataset for the city of Sherbrooke

Different vector geographic datasets has been used to assess how each cadastral parcel respects each constraint (e.g. cadastral parcels, roads, buildings, rivers, lakes). Geographic datasets are produced by different organisations, being the government of Canada (CTI-S), the government of Quebec (MRN) and the city of Sherbrooke, at scales going from 1:1000 to 1:100 000. Each dataset was produced using different data acquisition techniques and according to different cartographic specifications. They then have very heterogeneous characteristics in term of quality (e.g. precision of the objects location, precision of objects shapes, completeness, currentness).

The prototype was developed by associating the program 'mpropre' to the Geographical Information System (GIS) GeoMedia Professional from Intergraph. GIS allow to integrate, manage, analyse, query and display information having a spatial reference. They provide several spatial analysis tools allowing the characterisation of objects spatial relations (i.e. metric and topologic operators). Amongst the set of available data for the region of interest, a first selection was performed according to the constraints identified in the application. For instance, the constraint "parcel should be located at less than 50m from a fire hydrant" requires datasets including cadastral parcels and fire hydrants. In some cases, data were not directly available and has to be derived from existing data (e.g.

punctual road intersections were derived from linear roads; parcel slopes were derived from linear elevation contour lines).

A subset of the available data for the area of Sherbrooke was produced, including urban and rural areas, with a total of 3782 cadastral parcels. Different metric (e.g. distance, buffer) and topologic operators (e.g. inclusion, intersection) allowed identifying how each individual parcel respects or not each constraint. For instance, the metric operator "is within the distance of" allowed to identify all parcels located at less than a certain distance from fire hydrants, commercial strips, parks, etc. These operations allowed to associate a binary value in a database indicating if each parcel respects or falsifies each constraint. This file is then exported to the program 'mpropre' in order to be processed according to the constraints partially ordered by the expert. Once data processing is performed in 'mpropre', the program provides in output a set of object instances ID identifying parcels that best respect constraints according to the partial order defined. It is then possible to identify the selected parcels and visualise them on aerial ortho-images in order to validate the selection.

This method provides results based on the general quality of the parcels. As geographic data qualities can be very heterogeneous, it can be interesting to only select reliable parcels. Based on different quality information issued for instance from metadata (i.e. data describing the different datasets), an average quality is associated to each cadastral parcel. This quality criterion can have three discrete values being "bad", "average" or "good". A first analysis is performed using 'mpropre' for the subset of parcels having a "good" quality. A second analysis relaxes quality by accepting both values "average" and "good". This second analysis allows to include in the parcel selection a larger number of parcels.

Figure 3. Selected parcel 1625

The program has been tested using different orders for the constraints, for the entire parcel dataset. Program execution time is almost instantaneous. Results provided by the program were validated by experts having a knowledge of the area and also by a visual validation using ortho-rectified aerial images. Different tests has also been performed in order to exclude a priori parcels that are not available for construction (e.g. roads - that are represented by polygonal objects similar to parcels - and other public spaces such as parks, parkings, squares, etc.). Figure 4 represents the first of the two parcels selected.

5 Conclusion

This paper presented an original approach of constraint-based reasoning applied to a common geographic information problem. This approach applies an algorithm allowing the management of partially ordered constraints to the problem of selection of an optimal cadastral parcel for building a house.

This innovative approach for the problem of optimal site selection avoid some drawbacks of traditional geographic multi-criteria approaches, being for instance the need to quantify each criterion. Weights are often hard to obtain from the experts and the results depend strongly of this quantification. On the contrary, our method allows an expert, which do not know the selection method, to qualitatively order the constraints. Moreover experts do not have to compare all constraints, which are not always linked between each other.

An application based on real constraints and data was developed in order to validate the approach. The algorithm, tested with 12 constraints and more than 3700 geographic objects showed an excellent performance and provided results validated by an expert.

Future developments could incorporate fuzziness in the constraints. Indeed, the break down into binary constraints is not realistic when the number of constraints increase: the graph of preference becomes no more readable. Another future development could take more into consideration the aspects related to geographic data quality in parcels selections. How to incorporate the quality of data sets in the choice of location when the constraints on this locations are partially ordered ?

Acknowledgments

This work was supported by the European Community through the REV!GIS project ♯ IST-1999-14189 (`http://www.cmi.uni-mrs.fr/REVIGIS`) and by the Ministère de la Recherche Science et Technologie (MRST) of Quebec government, Canada. GeoMedia Professional GIS software was kindly provided by Intergraph inc through SOMEI. Thanks are also due to the city of Sherbrooke, the government of Quebec (MRN) and the government of Canada (CTI-S) for providing the geographic datasets.

References

1. Church, R.L.: Location modelling and GIS. In Longley, P., Goodchild, M., Maguire, D., Rhind, D., eds.: Geographical information systems (2nd Ed.), New York, John Wiley (1999) 293–303
2. Schärlig, A.: Où construire l'usine? La localisation optimale d'une activité industrielle dans la pratique. Dunod (1973)
3. Pereira, J.M., Duckstein, L.: A multiple criteria decision-making approach to GIS-based land suitability evaluation. International Journal of Geographical Information Systems **7** (1993) 407–424
4. Joerin, F.: Méthode multicritère d'aide à la décision et SIG pour la recherche d'un site. Revue internationale de géomatique **1** (1995)
5. Monmonier, M.: A case study in the misuse of GIS: Siting a low-level radioactive waste disposal facility in new york state. In: Proceedings of the conference on Law and Information Policy for Spatial Databases, Tempe (USA) (1994)
6. Halpern, J.Y.: Defining relative likelihood in partially-ordered preferential structures. Journal of AI Research **7** (1997) 1–24
7. Cayrol, C., Royer, V., Saurel, C.: Management of preferences in assumption-based reasoning. In: Proceedings of Information Processing and the Management of Uncertainty in Knowledge based Systems (IPMU'92), Springer (1992) 13–22
8. Benferhat, S., Dubois, D., Lang, J., Prade, H., Saffiotti, A., Smets, P.: Reasoning under inconsistency based on implicitly-specified partial qualitative probability relations: a unified framework. In: Proceedings of the 15th National Conference on Artificial Intelligence (AAAI-98). (1998) 121–126
9. Benferhat, S., Lagrue, S., Papini, O.: Reasoning with partially ordered information in a possibilistic framework. Fuzzy Sets and Systems **144** (2004) 25–41