A Performance Comparison Between two GIS Multi-Criteria Decision Aid methods: a Case Study of Desertification Evaluation

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Abstract. *Desertification is widely recognized as one of the most relevant environmental problems to be evaluated. In many cases, it requires processing large amounts of data and is also computing intensive. The present study sheds light on this problem in the context of a desertification analysis of the Brazilian Semiarid, using the PROMETHEE Multi-Criteria Decision Aid method, which is a multicriteria analysis method used to identify the outranking relation for a pair of alternatives tackling spatial problems such as site selection problem and land use/suitability analysis. We describe the design and implementation of a practical solution to this problem, based on state-of-the-art theoretical advances and further improvements to deal with large datasets. We compare the performance of our solution with the GRASS software environment. The performance evaluation indicates that our solution can address the problem; it is up to 720 times faster than the GRASS alternative, for the evaluated scenario.*

1. Introduction

Desertification is an environmental problem that is highlighted to be assessed by the most important agencies and institutions all over the world, such as IPCC, ONU, USGS, NASA (GEIST, 2017; IPCC, 2007). Desertification is featured by the soil degradation, which impacts negatively the environmental, social and economic spheres of the countries (TOMASELLA et al. 2018; BESTELMEYER, et al. 2015; OLAGUNJU 2015).

Regarding the desertification evaluation, the high amount of variables which is commonly required to assess the desertification process usually leads to the generation of large datasets to be analysed, directly impacting the computational costs of the analysis (BRITO, et al. 2018; MARIANO, et al. 2018; VIEIRA, et al. 2015).

A recent development (LIMA, 2017) which has applied the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), which is a Multi-Criteria Decision Aid (MCDA) method, based on 27 criteria (including land concentration, social inequality, deforestation and others), to analyse the desertification of the Seridó Region (part of the Brazilian Semiarid - BSA) illustrates this problem. The Seridó region which is composed of 32 municipalities, for a total area of 11.194,696 km^2, has a total of 187.000 pixels (considering a 300m spatial resolution). Considering this number of pixels and the 27 criteria, the total number of alternatives is up to 5.000.000. The size of the dataset for the Seridó region is up to 35MB. Even for this small region, the GRASS software environment (OSGeo project, 2015) took a dozen hours to execute its PROMETHEE analysis on a workstation. The analysis of the whole Brazilian Semiarid dataset, which is up to 350GB, would be infeasible to execute using the GRASS system (since its PROMETHEE implementation has a quadratic complexity).

Furthermore, although recently approximation methods have been developed to reduce the complexity of the calculation of PROMETHEE, for example, the use of piecewise linear functions (EPPE and DE SMET, 2014), we designed and developed an optimized PROMETHEE implementation based on a subquadratic exact solution of the PROMETHEE algorithm presented in Calders and Van Assche (2018). Our implementation attests that is possible to improve the computational cost efficiency by preserving the exact PROMETHEE method. In addition to this improved complexity, our implementation also adopted some optimizations to handle large datasets.

In this study, we briefly describe our solution (Section 2) and provide a performance comparison with the GRASS system (Section 3). The results obtained indicated that, for the datasets analysed, our solution is up to 720 times faster than the GRASS alternative (in fact, this speed up would increase as the dataset grows, due to the improved complexity). Finally, in Section 4, we discuss relevant future work.

2. MCDA Tools

In this section, we introduce the GRASS system and our optimized MCDA tool highlighting the differences between them. Although the GRASS system includes not only MCDA features, we restraint the discussion to its implementation of the PROMETHEE method.

2.1. GRASS

The Geographic Resources Analysis Support System (GRASS) GIS is a widely used (thus a suitable alternative to our performance comparison described in Section 3) open source software for geospatial management, data analysis and image processing (OSGeo project, 2015). The design of GRASS is based on a plugin architecture (add-ons) which allows extending its feature set. Its PROMETHEE plugin, which follows the original proposition of the method (VINCKE and BRANS, 1985), is implemented in the C language. Despite GRASS popularity and overall quality, its

MCDA implementation has a performance limitation that turns it unsuitable to our scenario.

2.1. Optimized Implementation

Our tool is a C++ optimized implementation of the PROMETHEE method designed to process large GIS datasets[1]. It is also important to highlight that although the method optimized in the present study is the PROMETHEE II (once it considers the fluxes differences), in the remaining of the text it is named as PROMETHEE rather than PROMETHEE II, only to simplify the reading. Our implementation is based on a linear algorithm that improves the original PROMETHEE II method (which has quadratic complexity) for the linear and level preference functions (CALDERS and VAN ASSCHE, 2018). In addition to the speed up provided by adoption of the sub-quadratic algorithm, our implementation dealt with a practical aspect of its implementation when analysing large datasets: how to keep the data in memory during the execution of the analysis; in some cases, the datasets are larger than the amount of available memory. To this end, we design and developed two optimizations. First, for each criterion, the analysis of alternatives is made up in a partial fashion (to avoid keeping the whole dataset in memory) and stored in stable storage. Second, we avoid loading into the memory segments of the dataset which show consecutive alternatives of the same value.

3. Performance evaluation

In this section, we describe the experiments we have executed to compare the performance of the GRASS (version 7.4.1) system and our optimized solution. In the first experiment, we aimed to analyze how these solutions behave as the number of alternatives grows. To this end, we executed the multi-criteria analysis on synthetic samples, made of randomly generated values, of 4096, 16385, and 65536 alternatives (in all these cases, we analysed a single criterion). In the second experiment, we compared the average time to execute a multi-criteria analysis of a sample of the target study area (the Seridó region), considering only two criteria (instead of 27); the duration of experiment, considering the whole dataset, would be prohibitive to execute using the GRASS. To ease the reproducibility of results, we made available both datasets used in these experiments[2].

We configured an experimental environment based on a Linux workstation which runs both the GRASS and our optimized solution. The workstation runs the Linux kernel version 4.4.0-134, based on the Ubuntu 16.04.5 release. The workstation has an octa-core Intel i7-4770 3.10GHz CPU with 8GB of main memory, and a 1TB SEAGATE 7200 RMP hard disk, ST1000DM003 model.

In both experiments, the performance was given as the duration to run the MCDA. This duration is given by the elapsed time between the start of the program until the time it finished (after it writes its output to stable storage). Each execution starts by flushing the operating system memory caches. By flushing these caches, we avoid that one execution affects the subsequent one.

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[1] https://github.com/simsab-ufcg/Promethee2
[2] https://github.com/simsab-ufcg/landsat-samples/tree/master/geoinfo-2018

3.1 Results

Figure 1 shows how the duration of the multi-criteria analysis varies, on GRASS and in our optimized implementation, according to the number of alternatives evaluated (from 4096 to 65536). The Figure shows the results of 10 analysis, for each configuration of the number alternatives, for both the implementations. The duration is given in logarithm scale.
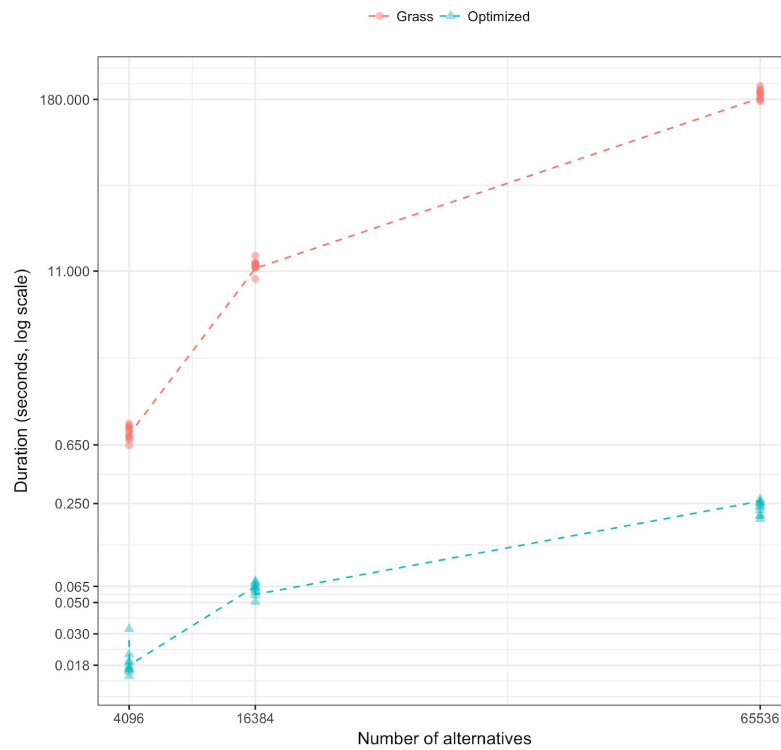

Figure 1. Duration of the analysis for the GRASS and our optimized implementation. The experiments considered three different scenarios: 4096, 16386, and 65536 alternatives. The optimized is no less than 21 times faster than the GRASS tool. For the largest scenario, the optimized solution is 720 times faster.

Considering the optimized solution, the duration of the analysis for the scenario of 4096 alternatives is up to 0.03 seconds, up to 0.065 seconds for 16384 alternatives, and no more than 0.25 seconds for the largest scenario, of 65536 alternatives; all the executions are in the subsecond range. Due to the inherent, unnecessary complexity of the GRASS implementation, the duration of the analysis is 0.65, 11, and 180 seconds, respectively for the scenarios of 4096, 16384 and 65536 alternatives. For the smallest scenario (4096 alternatives), the optimized implementation is up to 21 times faster than the GRASS, and for the lager scenario (65536), it is 720 times faster.

Table 1 shows the duration of the multi-criteria analysis, for the Seridó region, on both the GRASS system and in our optimized implementation. We considered two

criteria in this analysis, thus 350000 alternatives in total. The duration and its standard deviation are given for an average of 10 executions. The results for our optimized solution are still in the subsecond range, 0.004 minutes (0.26 seconds), while for the GRASS the mean duration is more than 30 minutes. Note that, the duration of our optimized solution is almost the same duration for the experiments shown in Figure 1, with 65536 alternatives, even though the current dataset is about five times larger. The reasons for this speed-up are twofold: (i) the experiments shown in Table 1 analyze more than one criteria, and, in this case, our solution can take advantage of the multiple processors of the workstation used in the experiment (the analysis of each criterion runs in parallel); (ii) differently from the dataset analyzed for the first experiment, which was generated randomly, the data from the Seridó region has some degree of duplication, which leads to less data loading into memory during the execution.

	Duration in minutes (mean; std deviation)
Grass	(30.64; 0.19)
Optimized	$(0.004; 4.21 \times 10^{-5})$

Table 1. Duration of the analysis of the Seridó region for the GRASS and our optimized implementation. The mean and standard duration are based on the execution of 10 experiments. The experiments considered two criteria, totalizing more than 350000 alternatives. For the GRASS alternative, the mean duration is approximately 30 minutes, while for our optimized solution is approximately 0.004 minutes (0.26 seconds).

4. Conclusions and Future Work

In this work, we considered the challenge of performing the multi-criteria analysis of large GIS datasets. In doing so, we provided two major contributions: (i) we developed and made publicly available an implementation of the algorithm proposed by Calders and Van Assche (2018), which provides exact solutions instead of approximate ones such as the piecewise linear functions (EPPE and DE SMET, 2014); to the best of our knowledge, there was no such implementation available yet; (ii) we designed further optimizations on the original proposal to cope with the analysis of large datasets including the partial computation of the analysis (on chunks of the dataset) and the use of a compact data format that avoids the store (and analysis) of duplicated alternatives.

The initial assessment described in this work can be extended to characterize our proposed design better. For example, a hardware resource utilization analysis could help us to identify opportunities for further improvements (e.g. to better parallelise the execution of the algorithm). In addition to that, we plan to improve our evaluation of the data compression feature by studying how the variability of the input data affects the performance of our tool. Also, we plan to compare our approach with parallel data processing tools (such as hadoop), as a comparison baseline; note that, however it is

feasible to process the PROMETHEE analysis in a cluster/distributed environment, the associated costs (or resource usage) would be much higher than in our proposed solution.

5. References

BESTELMEYER, Brandon T. et al. Desertification, land use, and the transformation of global drylands. Frontiers in Ecology and the Environment, v. 13, n. 1, p. 28-36, 2015.

BRITO, S. S. B. et al. Frequency, duration and severity of drought in the Semiarid Northeast Brazil region. International Journal of Climatology, v. 38, n. 2, p. 517-529, 2018.

CALDERS, T.; VAN ASSCHE, D. PROMETHEE is not quadratic: An O (qnlog (n)) algorithm. Omega, v. 76, p. 63-69. 2018

EPPE, Stefan; DE SMET, Yves. Approximating Promethee II's net flow scores by piecewise linear value functions. European journal of operational research, v. 233, n. 3, p. 651-659, 2014.

GEIST, Helmut. The causes and progression of desertification. Routledge, 2017.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). Working Group II: Impacts, adaptation, and vulnerability. 2007.

LIMA, R. C. C. Sistema de avaliação e comparação espacial do processo de desertificação no Seridó potiguar e paraibano, semiárido brasileiro. Tese (Doutorado em Recursos Naturais) – Programa de Pós-Graduação em Recursos Naturais, Centro de Tecnologia e Recursos Naturais, Universidade Federal de Campina Grande. Campina Grande, 2017, 150 f.

MARIANO, Denis A. et al. Use of remote sensing indicators to assess effects of drought and human-induced land degradation on ecosystem health in Northeastern Brazil. Remote Sensing of Environment, v. 213, p. 129-143, 2018.

OLAGUNJU, Temidayo Ebenezer. Drought, desertification and the Nigerian environment: A review. Journal of Ecology and the Natural Environment, v. 7, n. 7, p. 196-209, 2015.

OSGeo project. (24 de 02 de 2015). GRASS GIS - Bringing advanced geospatial technologies to the world. https://grass.osgeo.org/documentation/general-overview/.

TOMASELLA, Javier et al. Desertification trends in the Northeast of Brazil over the period 2000–2016. International Journal of Applied Earth Observation and Geoinformation, v. 73, p. 197-206, 2018.

VIEIRA, RM da Silva Pinto et al. Identifying areas susceptible to desertification in the Brazilian northeast. Solid Earth, v. 6, n. 1, p. 347-360, 2015.

VINCKE, J. P.; BRANS, Ph. A preference ranking organization method. The PROMETHEE method for MCDM. Management Science, v. 31, n. 6, p. 647-656, 1985.