

Discrete Morse Theory for predictive mapping from regional geophysical data

Benjamin Le Teurnier, Jihad Bourassi, Pierre-Alexandre Reninger, Aurelie Peyrefitte, Frederic Lacquement

BRGM, French Geological Survey

Interpretation of regional geophysical data most often involves the precise delineation of areas exhibiting contrasting signals to understand the subsurface structure. At the regional scale, we lack labeled data for the use of supervised machine learning methods. Thus, traditional unsupervised clustering methods are usually employed to address this problem [1], [2], [3]. Those methods are not designed to detect reliable transitions within the data. With this in mind, we developed a methodology based on Topological Data Analysis (TDA) [4] to automatically detect delineations, open or closed, that separate the topological features present in the data [5], [6]. Our approach is based on discrete Morse theory to identify critical points and model their relationships within a topological complex, providing a robust representation of the data structure. At the same time, we also apply this analysis to criteria such as the gradient norm, allowing us to trace paths following the greatest spatial variation in the geophysical data. This enables us to associate a shape to the topological features. In order to select the most significant delineations, we hierarchically merge the delimited areas with their neighbours using an ordering that takes into account the topological persistence and the local contrast.

This approach offers an alternative to classical segmentation that is easier to interpret and more robust thanks to the use of topological analysis to guide the extraction of structures and shape in regional geophysical data.

[1] Y. Wang, A. K. Ksienzyk, M. Liu, et M. Brönnner, « Multigeophysical data integration using cluster analysis: assisting geological mapping in Trøndelag, Mid-Norway », *Geophysical Journal International*, vol. 225, no 2, p. 1142-1157, mars 2021, doi: 10.1093/gji/ggaa571.

[2] G. Martelet, C. Truffert, B. Tourlière, P. Ledru, et J. Perrin, « Classifying airborne radiometry data with Agglomerative Hierarchical Clustering: A tool for geological mapping in context of rainforest (French Guiana) », *International Journal of Applied Earth Observation and Geoinformation*, vol. 8, no 3, p. 208-223, sept. 2006, doi: 10.1016/j.jag.2005.09.003.

[3] D. Eberle, D. Hutchins, S. Das, A. Majumdar, et H. Paasche, « Automated pattern recognition to support geological mapping and exploration target generation – A case study from southern Namibia », *Journal of African Earth Sciences*, vol. 106, p. 60-74, juin 2015, doi: 10.1016/j.jafrearsci.2015.03.011.

[4] G. Rote et G. Vegter, « Computational Topology: An Introduction », in *Effective Computational Geometry for Curves and Surfaces*, J.-D. Boissonnat et M. Teillaud, Éd., Springer Berlin Heidelberg, 2006, p. 277-312. doi: 10.1007/978-3-540-33259-6_7.

[5] T. Ophelders, A. Schenfisch, W. Sonke, et B. Speckmann, « Computing Geomorphologically Salient Networks via Discrete Morse Theory », *LIPICs, Volume 332, SoCG 2025*, vol. 332, p. 70:1-70:17, 2025, doi: 10.4230/LIPICS.SOCG.2025.70.

[6] J. P. Bullenkamp, T. Kaiser, F. Linsel, S. Krömker, et H. Mara, « Discrete Morse theory segmentation on high-resolution 3D lithic artifacts », *it - Information Technology*, vol. 66, no 6, p. 191-205, oct. 2024, doi: 10.1515/itit-2023-0027.