GREYC
Electronics and Computer Science Laboratory

Ph.D. Thesis proposal - GREYC Research Lab - Image Team - 2023

Deep learning of binary partition trees for image analysis

Keywords : Hierarchical representations, Binary partition trees, Deep learning, Ultrametrics, Computer Aided Diagnosis of Skin lesions.

Team and Lab : IMAGE tream, GREYC (UMR CNRS 6072) Research lab.

Thesis director : Olivier Lézoray (Full Professor at UNICAEN).

Thesis co-advisor : Sébastien Bougleux (Associate Professor at UNICAEN).

Emails : {olivier.lezoray,sebastien.bougleux}@unicaen.fr

Context : Clustering is one of the fundamental tasks in data science. Indeed, data can often be grouped into coherent subsets called clusters. The data assigned to the same cluster are then assumed to be more similar than to that of another cluster. The k-means is the flagship « flat » clustering technique that considers a cost function relative to the intra-cluster inertia. If the data is structured in the form of a similarity graph, clustering algorithms are often formalized in the form of a cut in this graph, grouped under the spectral clustering term. Another popular approach in data science is hierarchical clustering. The principle is to recursively partition a data set into smaller clusters. This is represented by a tree whose leaves correspond to the data, and whose internal nodes each represent a cluster. A hierarchy of this type has several advantages over flat clustering. First, it is not necessary to specify the number of clusters in advance. Second, the tree simultaneously captures the clusters' structure at all levels of granularity. The fundamental assumption of this approach is that the visible structure in the data depends on the chosen scale of observation. In practice, bottom-up merge algorithms are used to build the hierarchical tree using successive merging of similar clusters. This hierarchical binary tree representation is very popular in clustering because it can be easily interpreted by human experts who can interact with the tree (Figure 1). Nevertheless this approach has some drawbacks. While deep learning approaches have recently

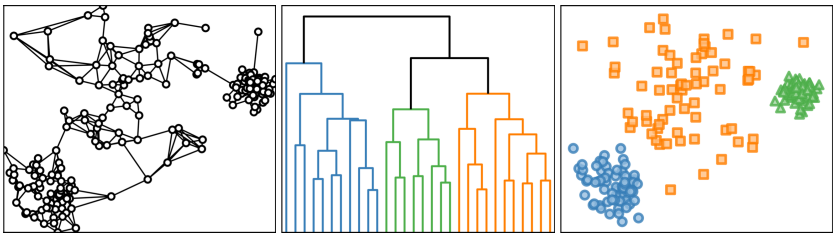

FIGURE 1 – Hierarchical clustering (right) obtained by a cut in a hierarchical tree (center) built from a similarity graph (left) [1].

shown their interest in flat clustering [2, 3], they have hardly been explored in hierarchical clustering [4], and this poses many obstacles to be overcome. Finally, establishing a cut in the graph in order to obtain a final quality clustering can be difficult. In this thesis we propose to conciliate deep learning and hierarchical clustering for image analysis based on hierarchical (binary partition) trees representing them. The supervisors have strong experience in hierarchical representations of images, in particular with graphs [5, 6], as well as in deep learning [7, 8].

Objectives : There are many representations of digital images, each adapted to different contexts. In this thesis we are interested in hierarchical representations of images [9]. These representations allow, from an over-

segmentation (fine partition) of an image into super-pixels (grouping of pixels into regions), to proceed to super-pixel merging at different scales. Such hierarchical representations allow to capture image features at different scales simultaneously, and can be easily interpreted and manipulated by a human. Building relevant hierarchical representations is a very important step in image analysis. Hierarchical representations based on binary partition trees (BPT) have been widely studied [10]; they allow a hierarchical clustering adapted to digital images (Figure 2). Their construction relies on several key elements : an initial partition, a region model, a merging criterion, and

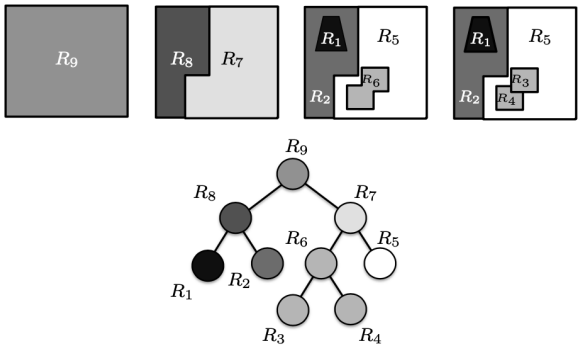

FIGURE 2 – A Binary Partition Tree associated with an over-segmentation [11].

a merging order. This BPT construction often relies on simple super-pixel descriptors [12] that are poorly suited to the data, as well as heuristic and greedy hierarchical clustering methods. We propose to leverage deep learning for the construction and manipulation of BPTs. The tree construction will then be able to exploit deep descriptors of superpixels, to learn the similarity between these descriptors, and finally to have a learned merging criterion. Since an ultrametric is a dual representation of a hierarchical representation [1], deep learning methods can be considered not to learn the BPT but the ultrametric from a graph representing the super-segmentation, by explicitly minimizing a cost function [13, 14]. The semantic segmentation of an image can then be seen as : either a learned labeling of the vertices of the BPT, or the learning of a cut in the BPT (Figure 3). A tree being a graph, convolution neural networks on graphs can be considered for this (convolution and pooling being very particular given the tree structure of the graph).

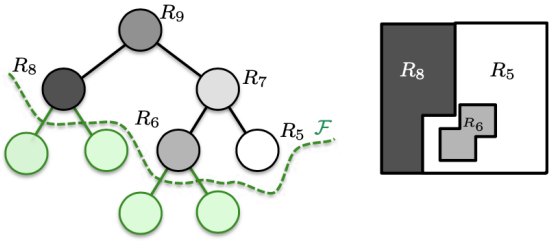

FIGURE 3 – Cut of a binary partition tree [11] (representing the image in Figure 2) to produce a segmentation.

Targeted applications : Two applications will be considered to test the deep learning methods of binary partition trees (DL-BPT) that will be developed. The first one concerns the computer aided diagnosis of skin lesions. In France, the prevention and screening of skin cancer has become a public health issue with the implementation of the Cancer Plan in 2003. One of its objectives is to improve the conditions for early detection of melanoma. Melanoma diagnosis can be aided by image analysis systems allowing the extraction of the studied skin lesion. Our DL-BPT methods will be considered to perform that segmentation. The thesis director has already participated to a French national project (MELASCAN 2011-2014) on the analysis of skin lesions acquired with a multispectral

dermatoscope [15], and coordinated an international project with Algeria (dermato. ai 2019-2021) in which deep learning was used for the diagnosis of skin lesions [16, 17, 8]. The second application concerns the field of satellite imaging. In this domain, BPTs have been widely exploited for segmentation and object detection (trees, roads, buildings). We will compare the performance of our DL-BPT approach with state-of-the-art approaches.

Work plan : The thesis will start with a bibliographic study on hierarchical image representations based on hierarchical clustering. The first year will be devoted to the development of methods for the construction of binary partition trees by deep learning, the second year to their analysis by learning labels or cuts, the third year will be dedicated to applications. The thesis will be directed by Olivier LÉZORAY (Full Professor at UNICAEN) and co-supervised by Sébastien Bougleux (Associate Professor at UNICAEN).

Qualifications : Candidates must have an MSc or engineering degree in a field related to computer science, electrical engineering, or applied mathematics, with strong programming skills (in particular with deep learning frameworks). Experience with image processing will be a plus. Candidates are expected to have abilities to write scientific reports and communicate research results at conferences in English.

Information and application : Applications should include the following documents in electronic format : i) A short motivation letter stating why you are interested in this thesis, ii) A detailed CV describing your past research background related to the position iii) The transcripts for master degrees. iv) The contact information for three references (do not include the reference letters with your applications as we will only ask for the reference letters for short-listed candidates). Please send your application package to olivier.lezoray@unicaen.fr and sebastien.bougleux@unicaen.fr.

The position will start in October 2023 with a salary of 32kEuros gross, and will be located in Caen, France. Ideally located in the heart of Normandy, two hours from Paris and just 10 minutes away from the beaches, Caen, William the Conqueror's hometown, is a lively and dynamic city.

Références

[1] Giovanni Chierchia and Benjamin Perret, "Ultrametric fitting by gradient descent," in *NeurIPS*, 2019, pp. 3175–3186.

[2] Junyuan Xie, Ross Girshick, and Ali Farhadi, "Unsupervised deep embedding for clustering analysis," in *ICML*, 2016, vol. 48, pp. 478–487.

[3] Wengang Guo, Kaiyan Lin, and Wei Ye, "Deep embedded k-means clustering," Tech. Rep., 2021.

[4] Dominik Mautz, Claudia Plant, and Christian Böhm, "Deepect : The deep embedded cluster tree," *Data Sci. Eng.*, vol. 5, no. 4, pp. 419–432, 2020.

[5] Lucas Gnecco, Nicolas Boria, Sébastien Bougleux, Florian Yger, and David B. Blumenthal, "The minimum edit arborescence problem and its use in compressing graph collections," in *SISAP*, 2021, vol. LNCS 13058, pp. 337–351.

[6] Olivier Lézoray, "Hierarchical morphological graph signal multi-layer decomposition for editing applications," *IET Image Process.*, vol. 14, no. 8, pp. 1549–1560, 2020.

[7] Xuan Son Nguyen, Luc Brun, Olivier Lezoray, and Sébastien Bougleux, "A neural network based on SPD manifold learning for skeleton-based hand gesture recognition," in *IEEE CVPR*, 2019, pp. 12036–12045.

[8] Samia Benyahia, Boudjelal Meftah, and Olivier Lézoray, "Skin lesion classification using convolutional neural networks based on multi-features extraction," in *CAIP*, 2021, vol. LNCS 13052, pp. 466–475.

[9] Petra Bosilj, Ewa Kijak, and Sébastien Lefèvre, "Partition and inclusion hierarchies of images : A comprehensive survey," *J. Imaging*, vol. 4, no. 2, pp. 33, 2018.

[10] Philippe Salembier and Luis Garrido, "Binary partition tree as an efficient representation for image processing, segmentation, and information retrieval," *IEEE Trans. Image Process.*, vol. 9, no. 4, pp. 561–576, 2000.

[11] Silvia Valero, *Hyperspectral image representation and Processing with Binary Partition Trees.*, Ph.D. thesis, Grenoble Alpes University, France, 2011.

[12] Jimmy Francky Randrianasoa, Camille Kurtz, Eric Desjardin, and Nicolas Passat, "Binary partition tree construction from multiple features for image segmentation," *Pattern Recognit.*, vol. 84, pp. 237–250, 2018.

[13] Vincent Cohen-Addad, Varun Kanade, Frederik Mallmann-Trenn, and Claire Mathieu, "Hierarchical clustering : Objective functions and algorithms," in *ACM-SIAM SODA*, 2018, pp. 378–397.

[14] Sanjoy Dasgupta, "A cost function for similarity-based hierarchical clustering," in *ACM STOC*, 2016, pp. 118–127.

[15] Olivier Lézoray, Marinette Revenu, and Michel Desvignes, "Graph-based skin lesion segmentation of multispectral dermoscopic images," in *IEEE ICIP*, 2014, pp. 897–901.

[16] S. Benyahia, B. Meftah, and O. Lézoray, "Multi-features extraction based on deep learning for skin lesion," *Tissue and Cell*, vol. 74, pp. 101701, 2022.

[17] Samia Benyahia, Boudjelal Meftah, and Olivier Lézoray, "Hierarchical approach for the classification of multi-class skin lesions based on deep convolutional neural networks," in *ICPRAI*, 2022, vol. LNCS 13364, pp. 139–149.