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Editorial — Virtual Special Issue: "Hierarchical Representations: New Results and Challenges for Image Analysis"

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ABSTRACT

This editorial introduces the Virtual Special Issue: "Hierarchical Representations: New Results and Challenges for Image Analysis" that was handled between May 2019 and June 2020.

1. Context

Image representations based on hierarchical, scale-space models and other non-regular grids have become increasingly popular in various image processing and computer vision tasks over the past decades. Indeed, they allow a modeling of image contents at different, complementary levels of scales, resolutions and semantics. Methods based on such image representations have been able to tackle various complex challenges such as multi-scale image segmentation, image filtering, object detection, recognition, and more recently image characterization and understanding, potentially involving higher semantic levels. This Virtual Special Issue, entitled "Hierarchical Representations: New Results and Challenges for Image Analysis" was opened to extended and updated versions of papers published at the recent ICPRAI 2018 conference[1], as well as any submission proposing innovative methods in the field of image representation with emphasis on computer vision and image processing, medical imaging, 2D and 3D imaging, multi-modality, remote sensing image analysis, image indexation and understanding.

The main topics of this Virtual Special Issue include, but are not limited to:

- image decomposition on the basis of frequency spaces (Fourier, wavelets, etc.);
- hierarchies linked to the image space, mathematical morphology, connected operators;
- scale-space representations;
- non-regular / irregular grid image representations;
- multi-scale representation in computer-vision;
- evaluation of hierarchical image representations.

The aim of this Virtual Special Issue is to popularize the use of hierarchical methods in image processing and analysis. Indeed, although these methods have become very popular in computer vision over the last 20 years, their potential impact is largely underexploited.

2. Contributions

We received 36 high-quality manuscripts from 17 different countries all around the world (Brazil, Canada, China, France, Germany, Hungary, India, Israel, Japan, Lithuania, the Netherlands, Singapore, Spain, Sweden, United Kingdom, USA, Vietnam), emphasizing the international interest of the community for the topics of hierarchical representations.

Each of them was reviewed by two referees, according to the guidelines and standards of the Pattern Recognition Letters journal. Finally, 23 manuscripts were selected for publication in this Virtual Special Issue.

Hereinafter, we briefly point out and summarize these articles, that have been published in different volumes of Pattern Recognition Letters, edited in 2019 and 2020.

Hierarchical representations often require to use specific data-structures, most often trees. The following contributions are geared towards optimizations of existing data-structures, or even the development of new ones.

Silva et al. (2020) focus on the computation of node attributes in the component-tree. They present a review of a previously published method to compute such attributes, by incrementally counting patterns while traversing nodes of the component tree.

[1] https://users.encs.concordia.ca/~icprai18

The method foundation is detailed by presenting a novel theoretical background and algorithm correctness intuition. Algorithmic improvements for run-time execution and precision analysis are also proposed.

Morimitsu et al. (2020) propose an improved way of building the component-hypertree (that generalizes the concept of component-tree to multiple, increasing neighborhoods). They present some properties used to obtain optimized neighborhoods for component-hypertree computation. From these properties, they explore a new strategy to obtain neighboring elements based on hierarchy of partitions, leading to a more efficient algorithm.

Ouzounis (2020) proposes two new ways of building an alpha-tree, namely the non-target clustering and attribute maximization strategies, that give access to segments that could not be defined with previous variants of alpha-tree constructions. Collectively they enable the handling of texture-rich regions that cannot be clustered into meaningful segments, and compute the unsupervised segmentation of images by seeking for extreme attribute values.

Gigli et al. (2020) investigate the construction of the minimum spanning tree in streaming for images. They focus on the problem of computing a minimum spanning tree of the union of two graphs with a non-empty intersection. They show how the solution to that problem can be applied to streaming images, by decomposing the data into a stable part and an unstable part that needs further information before becoming stable. The correctness of the proposed algorithm is proven and the approach is applied to a hierarchical morphological segmentation task.

Alves et al. (2020) investigate ultimate levelings, a family of operators that extract image contrast information from a scale-space based on levelings. They introduce a new hierarchical structure, called residual tree, to discriminate relevant regions vs. undesirable regions from ultimate levelings. From this structure, they extract attribute vectors, which can be involved in image processing and machine learning approaches.

Huynh et al. (2019) introduce an extension of the tree-based shape-space for segmentation of objects of interest made of many connected components. Building upon the concept of second-generation connectivity and tree-based shape-spaces, they propose an extension of the usual shape-space paradigm into a generalized shape-space. This new paradigm allows to analyze any graph of connected components hierarchically and to filter them thanks to connected operators.

The following contributions aim at modifying, simplifying or combining trees.

Damiand and Zara (2020) propose a simplification strategy for the combinatorial pyramids, that provide topological information at different levels of details, at the cost of a high memory consumption. They define a compact version of combinatorial pyramids, based on the definition of a new operation that simultaneously merges regions and simplifies their boundaries. This approach leads to a new representation that uses less memory space and improve computation time.

Perret et al. (2019) propose an efficient algorithm that removes unimportant regions from a hierarchical partition tree, whereas preserving the hierarchical partition structure. The regions of the simplified hierarchy are regions or unions of regions of the initial hierarchy. The method can be used as a pre- or post-processing step to enhance the quality of hierarchical segmentation algorithms.

Adão et al. (2020) propose an approach dedicated to realign a tree modeling an image so that every region containing an object (or its parts) is at the same level. They explore the use of regression models to predict score values for regions belonging to a hierarchy of partitions, which are used to realign it. They also propose a new score calculation and a new assessment strategy considering all user-defined segmentations that exist in the ground-truth.

Santana Maia et al. (2019) study the problem of combinations of hierarchical watersheds, that can be characterized through binary partition trees. After analyzing which combinations evaluated in a previous work result in flattened (simplified) hierarchical watersheds, they provide a sufficient condition for a combination to always output flattened hierarchical watersheds, and a new combining function that outputs flattened hierarchical watersheds.

The following contributions propose new methods that build upon hierarchical data-structures for various image processing and analysis purposes.

Grossiord et al. (2020) use component-trees for analyzing Positron Emission Tomography (PET) images in the context of oncology. They show that the second-order paradigm of shaping, which broadly consists of computing the component-tree of a component-tree, provides a relevant way of generalizing the threshold-based strategies classically used by medical practitioners for handling PET images.

Brandt et al. (2020) propose a stereo matching method for applications where limited computational and energy resources are available. The algorithm is based on a hierarchical representation of image pairs by max-trees, which is used to restrict disparity search range. They propose a cost function that takes into account region contextual information and a cost aggregation method that preserves disparity borders. Such a method is suitable for use on embedded and robotics systems.

Tuna et al. (2020) investigate the ways to represent and analyze image sequences with morphological hierarchies. A review of different strategies to build spatial, temporal and spatial-temporal hierarchies from an image sequence is provided. They propose algorithms to update such trees when new images are appended to the series and they compare them with tree building from scratch. They apply these approaches for the min- and max-tree on grayscale data provided by satellite image time series.

Beyond the actual data-structures, the underlying concepts of scale-spaces and space of hierarchies are also explored by the following contributions.

Molina-Abril et al. (2020) investigate a new boundary scale-space theory. They introduce the homology boundary scale-space (hbss) model that consists of a hierarchical graph whose nodes are the homology generators of the different boundary scale levels and whose edges are specified by homology generators of consecutive boundary scale indices linked by preserving homology classes. Various codes for each connected sub-

graph of an hbss model are defined, which besides being fast and efficient similarity measures for cellular structures, are also relevant interpretive tools for the hbss-model.

Fehri et al. (2020) propose a framework for image characterization using hierarchies of segmentations. They organize the space of hierarchies using the Gromov-Hausdorff distance, and they explore different ways of combining hierarchies and study their properties thanks to this distance. They expose how to leverage the combinatorial space of hierarchies to derive efficient image representations, opening a path for a controlled exploration of the combinatorial space of hierarchies.

Cayllahua Cahuina et al. (2020) investigate hierarchical segmentation based on the Felzenszwalb-Huttenlocher dissimilarity that computes for each edge of a graph the minimum scale in a hierarchy at which two regions linked by this edge should be merged. They provide an explicit definition of the (edge-) observation attribute and Boolean criterion that are at the basis of this method. Then, the authors propose an algorithm to compute all the scales for which the criterion holds true. Finally, they propose new methods to regularize the observation attribute and criterion and to set up the observation scale value of each edge of a graph.

Multiscale analysis is also an important topic, studied from various points of view in the following contributions.

Sahu and Chowdhury (2020) address two problems in egocentric video analysis: generating multiscale summaries, and priority-based ranking of various actions present in such videos. A new algorithm, Multiscale Egocentric Video Summarization and Action Ranking, with agglomerative clustering as its backbone, is proposed to tackle the above problems. This algorithm follows an "analyze once, generate many" principle to generate multiple summaries in a single run and subsequently rank actions from the generated summaries.

Nguyen et al. (2020b) propose a method to overcome issues that negatively impact on encoding chaotic motions for dynamic texture representation. After a multiscale Gaussian-based kernel pre-processing pointing out robust and invariant features, the Local Rubik-based Pattern is introduced to capture both shape and motion cues of dynamic textures. In addition, they also address a novel thresholding to take into account rich spatio-temporal relationships extracted from a new model of neighborhood supporting region.

Giraud et al. (2020) introduce the dual superpatch, a novel superpixel neighborhood descriptor. This structure contains features computed in reduced superpixel regions, as well as at the interfaces of multiple superpixels to explicitly capture contour structure information. A fast multi-scale non-local matching framework is introduced for the search of similar descriptors at different resolutions in an image dataset. The proposed dual superpatch enables to accurately capture similar structured patterns at different scales and can be involved in supervised labeling applications.

Bejar et al. (2020) propose a hierarchical graph partitioning based on optimum cuts in graphs. This method encompasses as a particular case the single-linkage algorithm by minimum spanning tree and gives superior segmentation results compared to other approaches, usually requiring a lower number of image partitions to accurately isolate the regions of interest with known polarity. The method is supported by new theoretical results involving the usage of non-monotonic-incremental cost functions in directed graphs and exploits the local contrast of image regions.

Finally, hierarchical representations are also investigated in the field of deep neural networks, in the following contributions.

Ak et al. (2020) introduce an enhanced Attentional Generative Adversarial Network, for semantically consistent hierarchical text-to-image synthesis. An integrated attention module utilizes both sentence and word context features and performs feature-wise linear modulation to fuse visual and natural language representations. Several enhancements are proposed to improve image quality and text/image similarity whereas stabilizing the training.

Nguyen et al. (2020a) tackle the issue of handwritten mathematical expressions analysis. They propose a method based on CNNs to extract the representations for an handwritten mathematical expression. Symbols in various scales are located and classified by a combination of features from a multi-scale CNN. The authors use weakly supervised training combined with symbols attention to enhance localization and classification predictions. Then, they propose a multi-level spatial distance between two representations for clustering purposes.

Radvanyi and Karacs (2020) explore the automatic detection of information patterns. They propose a general, task independent method that locates interesting patterns on binary images by creating a hierarchical layered structure based on neighborhood topography of connected components, and identifies object groups applying saliency principles. The proposed algorithm mostly contains standard topographic instructions and can then be implemented on processor arrays.

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