Generalized Connected Morphological Operators for Robust Shape Extraction

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Chapter 7

Summary

7.1 Conclusions

THIS thesis describes three extensions to the theory of connectivity in mathematical morphology. Connectivity plays a key role in the development of robust and efficient tools and operators for both image analysis and processing. The work presented and analyzed in this book is not limited to the theoretical aspects of connectivity only, but emphasizes on the practical issues of it as well. In each one of the three extensions, together with the mathematical background, sets of operators are given based on which attribute filters can be designed. Aiming at transferring these methodologies to real world problems, each thematic section is accompanied with an appropriate algorithm that implements the developments presented. Experiments that demonstrate the features, capabilities and limitations of the proposed filters and operators are also given in each section. CPU timings and efficiency evaluations together with comparisons to other methods in some cases, aim at giving the reader the opportunity to draw personal conclusions on the usability of each framework and suitability for integration to other external modules. The overall work covered in this thesis breaks down to five chapters which are briefly summarized below.

Chapter 2 presents the concept of mask-based second-generation connectivity in which the previously individual clustering-based and contraction-based connectivities are now hosted. Connectivity openings associated to this new type of second-generation connectivity make use of mask images rather than structural operators, eliminating dependencies on their properties. The connectivity of images in question is no longer dictated by the choice of operator or the size of the structuring element used but instead on the mask patterns. Masks can be generated in custom ways to meet the demands of any given problem. Application examples with operators previously not supported are filters acting on image pairs of the same scene taken in different frequency bands (e.g., optical/IR combinations) or using different imaging modalities (optical/range imaging or registered CT/MRI pairs).

Attribute filters configured with mask-based or regular second-generation connectivity can be computed efficiently using the dual-input Max-Tree (DIMT) algorithm introduced in Chapter 2. This tree-based image representation algorithm operates on both 2D and 3D images and supports a wide range of different attributes. Experiments on this new framework demonstrate its clear advantages against regular clustering based operators. To gain a further insight into the parameters influencing the performance of clustering-based operators, Chapter 3 deals with this issue exclusively. Apart from the obvious effect of the attribute threshold, the role of the structural operator chosen and the size of the structuring element used, in the case of regular second-generation connectivity, are investigated together with the way attributes are computed. The work is complemented with a concurrent implementation of the dual-input Max-Tree algorithm, presented in Chapter 4. The method involves an intuitive parallelization strategy recently introduced for regular Max-Trees, that is based on the Union-Find algorithm for efficient merging of the subtrees - one for each thread. The speedups reported and experiments on 3D data suggest that the DIMT algorithm can handle large data sets efficiently and at reasonable timing.

The problem of oversegmentation, a condition appearing in both regular contraction-based and mask-based connectivity, is dealt with in Chapter 5. Starting from Serra's original work on image partitions, a new type of connectivity class, the $\pi-$ connection, was presented. The definition involves classes of image partitions which are used in ways analogous to masks by mask-based second-generation connectivity. The $\pi-$connectivity opening presented, differs from its mask-based equivalent in that it handles pathwise connected image regions previously treated as sets of singletons, as independent entities to which meaningful attributes can then be assigned. Though this resolves in part the oversegmentation problem in practical applications, the $\pi-$ connected operator is shown to be limited. That is because extensions to gray-scale violate certain hierarchical ordering properties required by the existing filtering rules. Bypassing this remains a topic for further investigation. It is possible though to compute gray-scale connected pattern spectra by restating certain assumptions. A brute force algorithm is given and a set of experiments on texture-based image classification of diatoms proves that the method is more reliable compared to regular contraction-based connected pattern spectra and in some cases outperforms regular connected pattern spectra based methods too.

The last chapter, Chapter 6 touches upon the notion of hyperconnectivity. Developments in this field were minor primarily due to the fact that there is no operator up to date that given a point on the image returns a hyperconnected set of maximal extent. It is shown though, that in gray-scale image analysis and under certain conditions, this can be bypassed making use of k-flat zones. This feature was used to define attribute filters involving contrast information together with structural characteristics. The associated operators are configured with a "base" connectivity class from which a combination of nested connected components and flat zones can be extracted as individual hyperconnected sets of maximal extent.

The work was motivated by the loss of fine, bright structures usually observed at higher levels that usually fail the regular filter's criterion. Employing this scheme, it is now possible to retain such structures assuming they rest on a high contrast region of the image that meets the criterion. That, in a sense, suggests that they are part of what rests below them. By contrast, undesired structures resting on the background that would previously be accepted by the filter are now suppressed. In both cases the contrast range is controlled by the parameter k which can be set interactively during the filtering stage of the algorithm, that comes along with this theory. The algorithm was designed intentionally like that to avoid rebuilding the tree-based image representation structure for each new value of k. Experiments show that the method which can complement any existing attribute filter, and yields far better results when compared with those of the same filter configured with standard connectivity. Moreover, setting $k = 0$ reduces the hyperconnected to a regular connected filter and this allows for easy comparisons between the two methods.

7.2 Future Work

The introduction of mask images in second-generation connectivity eliminated constraints imposed from earlier frameworks on the ways an image can be connected. Masks can be generated from any arbitrary operator and need not to originate from the input image. From the experimentation on protein images in Chapter 2 it became apparent that involving directionality/orientation as a criterion for mask generation can resolve a number of problems such as noise clustering and leakage. Though in 2D this is feasible, attempts to carry out similar experiments in 3D showed that the time overhead was prohibiting. Deriving efficient 3D mask generation algorithms that make use of such criteria remains an open challenge. Efficient steerable filters which need not be morphological, and spatially variant mathematical morphology [4, 5] might also be of use here. Work is also taking place on similarity criteria for clustering purposes.

Cases involving contractions are also under investigation. Though in Chapter 5 it was shown that oversegmentation can be countered in part with the aid of π-connected operators there remains the need of an efficient algorithm that computes attribute filters and pattern spectra configured with this type of connectivity in gray-scale. Concerning the diatom classification problem, it is believed that different classifiers using the existing feature vectors may increase the success rates further.

Oversegmentation may also be countered through reconstruction. Masks generated by anti-extensive structural operators usually contain compact structures (stable components) which can be used as seeds to retrieve the desired missing details. The challenge here is finding appropriate shape attributes to limit the reconstruction operators to the regions of interest. This is related to the work on reconstruction criteria [80] and viscous lattices [71].

The field of hyperconnectivity, being relatively new, offers many challenges both in theory and in algorithmics. It is seen as priority to formalize an operator capable of returning hyperconnected components. This is an essential step for exploring hyperconnected morphology and its operators. The specific type of hyperconnectivity presented in Chapter 6 though limited, allowed the introduction of the first hyperconnected attribute filter, which was shown to deliver promising results. Experimentation on this field is taking place to exploit the benefits of customizing the hyperconnectivity class presented with different types of base connections.

Both in connectivity and hyperconnectivity, we have only studied anti-extensive filters. Though the extensive counterparts follow by duality, auto-dual filters [13, 48, 50, 60], and beyond [75] are not trivially handled by the techniques developed in this thesis. However in the auto-dual case it is plausible that a combination of a dual-input Max-Tree and Min-Tree could yield a second-generation connected equivalent to the level-line tree of [49].

Connected and hyperconnected morphology have strengths that make them competitive to many other image analysis and processing methods. It is an active field of research that finds use in many modern computer vision applications including medical imaging. This thesis has contributed new ways of grouping pixels together in meaningful ways to represent objects more robustly.