Université Bretagne Sud

# Efficient Remote Sensing Image Processing

## Report Mathematical Morphology

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# 1986 - 1989

## Advances

The papers by Destival (1986) and Flouzat (1989) proposed a powerful new way for analyzing remote sensing imagery. They focused on overcoming the limitations of purely spectral (color/brightness) analysis introducing the **spatial and geometric structure** of objects as study base.

Back in the mid-1980s, the key promises of Mathematical Morphology for remote sensing were:

### 1. Feature Extraction

Traditional spectral methods often failed when the spectral signature of a thin linear feature was mixed with the surrounding background. MM promised to revolutionize the **extraction of long, thin, and directional features** (like roads, rivers, and field boundaries). By using elongated **Structuring Elements (B)** and directional filters, allowing for automatic detection of networks and boundaries regardless of slight variations in pixel intensity.

### 2. Improved Object-Based Analysis and Segmentation

Techniques like the **Morphological Gradient** promised more reliable edge detection than linear filters, enabling better **segmentation** by defining boundaries based on geometric criteria.

### 3. Noise Reduction and Data Cleaning

MM introduced non-linear filters that were effective at preserving object boundaries while eliminating noise. Using **Opening and Closing** operations could effectively suppress salt-and-pepper noise and clean up small, misclassified areas (isolated pixels) without blurring the true edges of large structures, a common error of linear smoothing filters.

### 4. Scale and Context Integration (Morphological Profiles)

MM integrate **scale information** into classification. They introduce **Morphological Profiles** could generate rich, multi-scale descriptors for every pixel. This was crucial for classifying complex heterogeneous areas (like cities) where objects needed to be distinguished not just by color, but by their size (e.g., separating small houses from large industrial buildings).

5. **Execution time improvement**

**morphological analysis** can be split up into **elementary operators**, which are conducive to rapid implementation.

# Limitations

1. **Dependency on the Structuring Element (SE)**

The performance of classical MM is **highly sensitive** to the shape and size of the chosen **Structuring Element**. Selecting the optimal SE requires significant **manual tuning** and prior knowledge about the exact geometry of the features. For scenes with highly varied geometries, a single EE were not enough.

2. **Information loss**

Due to the transformations are not linear, they are no reversible, so in case we can revert the process there is a loss.

# 2000 - 2010

The Mathematical Morphology (MM) community faced significant challenges in applying foundational MM operators to complex, high-resolution imagery. The state-of-the-art evolved dramatically from the 1980s by embracing new theoretical constructs to overcome issues of instability, over-segmentation, and vector data complexity.

## 1. Challenges

The main difficulties arose from the nature of the data (complex RS scenes) and the limitations of early morphological and classical processing techniques:

| Challenge Area | Specific Problem |
|---|---|
| **Segmentation** | The classical watershed segmentation approach causes over-segmentation due to irrelevant local minima, maxima, and texture effects. |
| **Complex Image Scenes** | Fine-resolution satellite images or aerial imagery, particularly in urban areas, present low radiometric contrast, low spatial resolution, geometric complexity, and shadow effects. These factors lead to texture and border effects and ambiguity in object/background distinction. |
| **Local Contrast Dependence** | Traditional dual morphological filters (like opening or closing) produce outputs that depend entirely on whether the target structure is brighter or darker than its surroundings (local contrast). In Earth Observation (EO) data, this contrast frequently varies, making dual filters unreliable. |

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|---|---|
| **Multichannel Data Processing** | The core morphological theory relies on lattices to compute minimum and maximum. No formal way exists to order vectors in multispectral data. |

## 2. Evolution and New Promises

1. Use the Morphological Profile (MP) and its Derivative (DMP) using residuals from geodesic opening and closing transforms. This allows for multiscale segmentation by exploring a range of Structuring Element (SE) sizes and finding the size that gives the maximum response.
2. The new segmentation methods incorporate a hierarchy that drastically reduces the over-segmentation typical of the classical *watershed* method.
3. Promoted the use of self-dual or self-complementary filters (e.g., the morphological center or morphological gradient) whose results are independent of the local contrast of the structures being searched, making them suitable for variable EO data.
4. The Derivative of the Morphological Profile (DMP) acts as a structural or morphological signature for pixel discrimination, analogous to the spectral signature used in multispectral images. This allows for the characterization of objects by their morphology (e.g., buildings labeled as radiometric "convex" curvature and roads as "concave" curvature).
5. Introduced rank-based morphological filters which allow tuning the flexibility of the SE fit by specifying how many pixels are allowed not to fit the structure, dramatically improving immunity to noise.
6. Developed extensive strategies to handle multivariate data, classifying various vector ordering schemes (Marginal, Lexicographical, Reduced, Bit Mixing) to impose a necessary total ordering on vector space.

## 3. Limitations

Despite these significant advances, the sources highlight several inherent limitations and practical drawbacks of the new methodologies:

1. **Heavy Computational Burden:** The multiscale approach based on the Derivative of the Morphological Profile (DMP) requires looking at a range of increasing opening and closing by reconstruction operations. This iterative process may cause a heavy computational burden.
2. **DMP Simplification Assumption:** The mathematical characteristic function derived from the DMP assumes a "simple" behavior where each structure is supposed to have only one significant derivative maximum. This assumption may be limiting in more complex environments (e.g., large spatial domain, nested regions, spatial periodicity).
3. **Lack of Universal Vector Ordering Scheme:** For multichannel (multivariate) data, there is still no single ordering scheme appropriate for all kinds of multivalued input. The suitability of schemes (Marginal, Lexicographical, Reduced) is highly dependent on the semantic meaning of the individual channels and the particular task under consideration (e.g., noise reduction vs. classification).

4. **Trade-Off in Noise Reduction Capability:** Vectorial approaches, which impose an order to preserve the original vector composition (spectral signature), are limited in their output. As a result, they exhibit reduced smoothing capacity compared to the marginal approach when dealing with uncorrelated noise, which can output vectors not present in the original image to better approximate noise-free values.
5. **Asymmetry of Total Orderings:** Total orderings (such as lexicographical ordering or bit mixing) inherently prioritize certain vector components. While this is necessary for unique extrema, it can cause problems if important information is located in lower-priority channels. For instance, if channels are highly correlated (like RGB), prioritizing red over green and blue leads to poor smoothing quality in the latter two channels.

# References


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