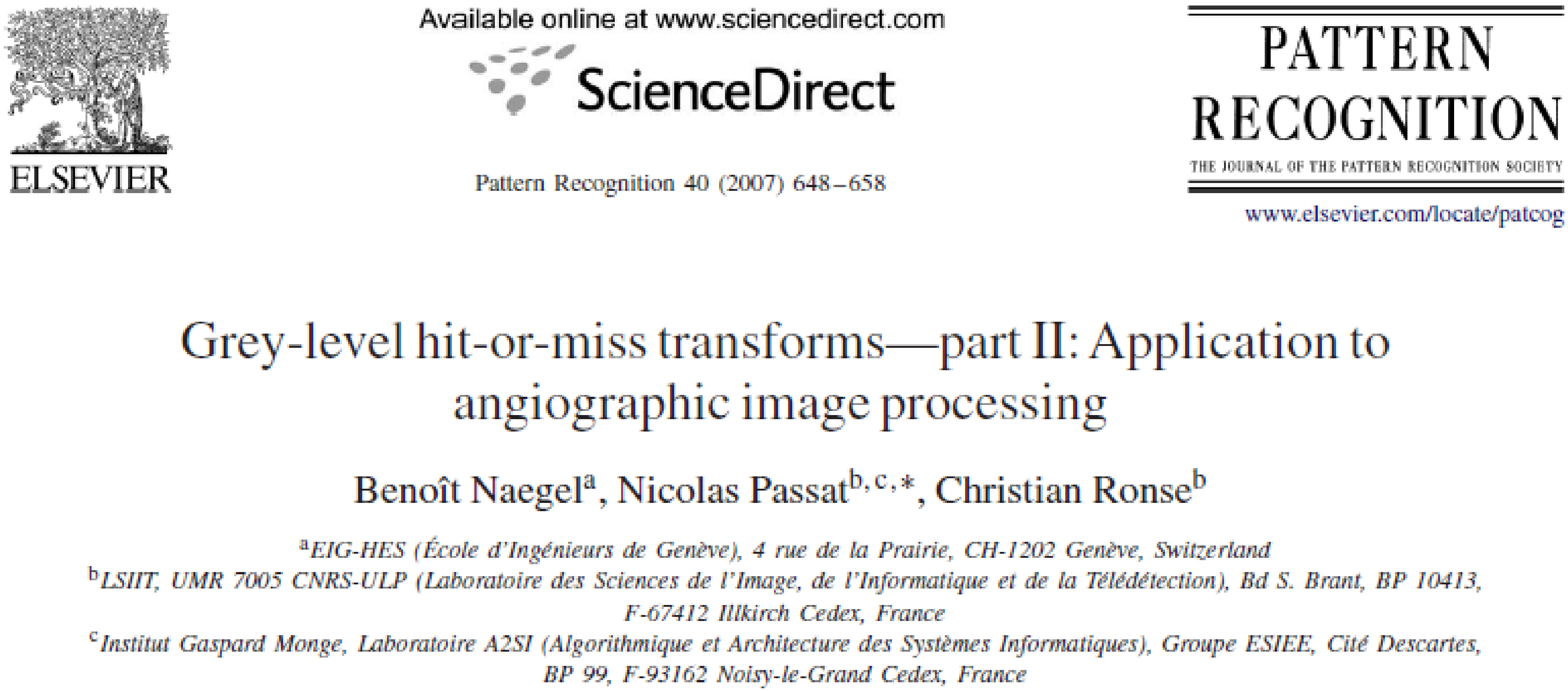

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Grey-level hit-or-miss transforms—part II: Application to angiographic image processing

Benoît Naegel[a], Nicolas Passat[b,c,*], Christian Ronse[b]

[a] *EIG-HES (École d'Ingénieurs de Genève), 4 rue de la Prairie, CH-1202 Genève, Switzerland*
[b] *LSIIT, UMR 7005 CNRS-ULP (Laboratoire des Sciences de l'Image, de l'Informatique et de la Télédétection), Bd S. Brant, BP 10413, F-67412 Illkirch Cedex, France*
[c] *Institut Gaspard Monge, Laboratoire A2SI (Algorithmique et Architecture des Systèmes Informatiques), Groupe ESIEE, Cité Descartes, BP 99, F-93162 Noisy-le-Grand Cedex, France*

Josu Maiora

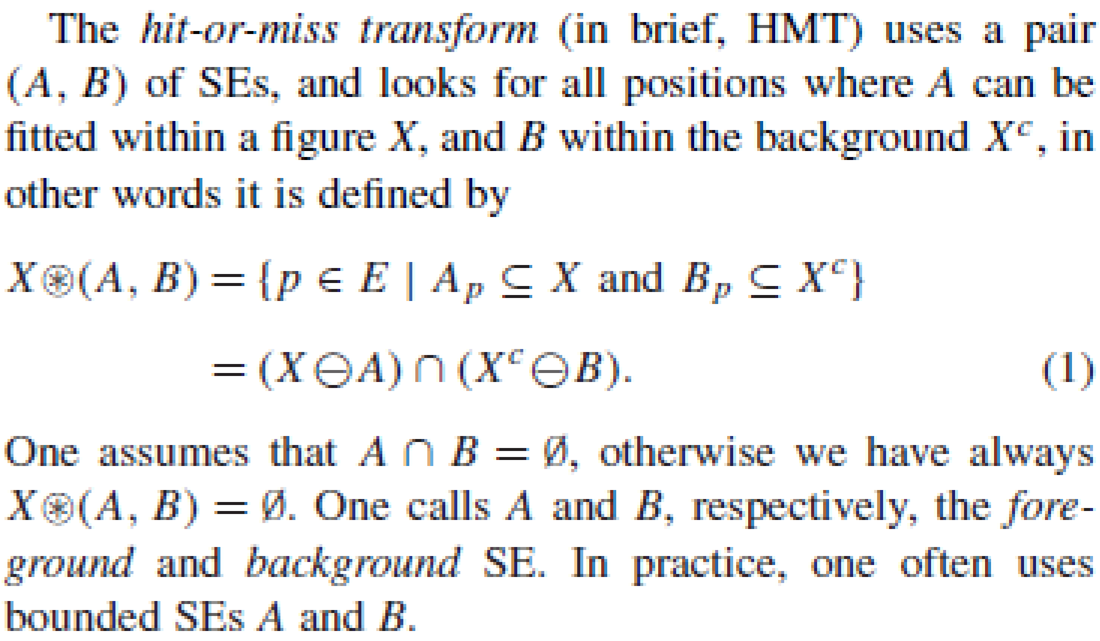
Overview

- The hit-or-miss transform (HMT) is a fundamental operation on binary images
- Its extension to grey-level images is not straightforward
- Approaches to the grey-level HMT
  - Supremal
  - Integral

- Unified theory of the grey-level HMT, which is decomposed into two steps:
  - *Fitting:* associates to each point the set of grey-levels for which the SEs can be fitted to the image; can be *constrained*.
  - Next, a *valuation* associates a final grey-level value to each point
    - *supremal* (as in Ronse),
    - *integral* (as in Soille) and
    - *binary*

Different HMT-based segmentation methods are then described and analysed, leading to concrete analysis techniques for brain and liver vessels.

1. Introduction



The *hit-or-miss transform* (in brief, HMT) uses a pair (A, B) of SEs, and looks for all positions where A can be fitted within a figure X, and B within the background X^c, in other words it is defined by

$$X \circledast (A, B) = \{p \in E \mid A_p \subseteq X \text{ and } B_p \subseteq X^c\}$$
$$= (X \ominus A) \cap (X^c \ominus B). \qquad (1)$$

One assumes that $A \cap B = \emptyset$, otherwise we have always $X \circledast (A, B) = \emptyset$. One calls A and B, respectively, the *foreground* and *background* SE. In practice, one often uses bounded SEs A and B.

2. Use of grey-level HMT for vessel segmentation

- ☐ Its definition in terms of **foreground and background structuring elements** (SEs) is appropriate to the invariant vessel properties in terms of shape and intensity with respect to the remaining tissues.

Then we define $\eta_{[A,B]}$, the *interval operator by* $[A, B]$, by setting for every $X \in \mathcal{P}(E)$:

$$\begin{aligned}\eta_{[A,B]}(X) &= \{p \in E \mid X_{-p} \in [A, B]\} \\ &= \{p \in E \mid A_p \subseteq X \subseteq B_p\}.\end{aligned} \tag{2}$$

2. Use of grey-level HMT for vessel segmentation

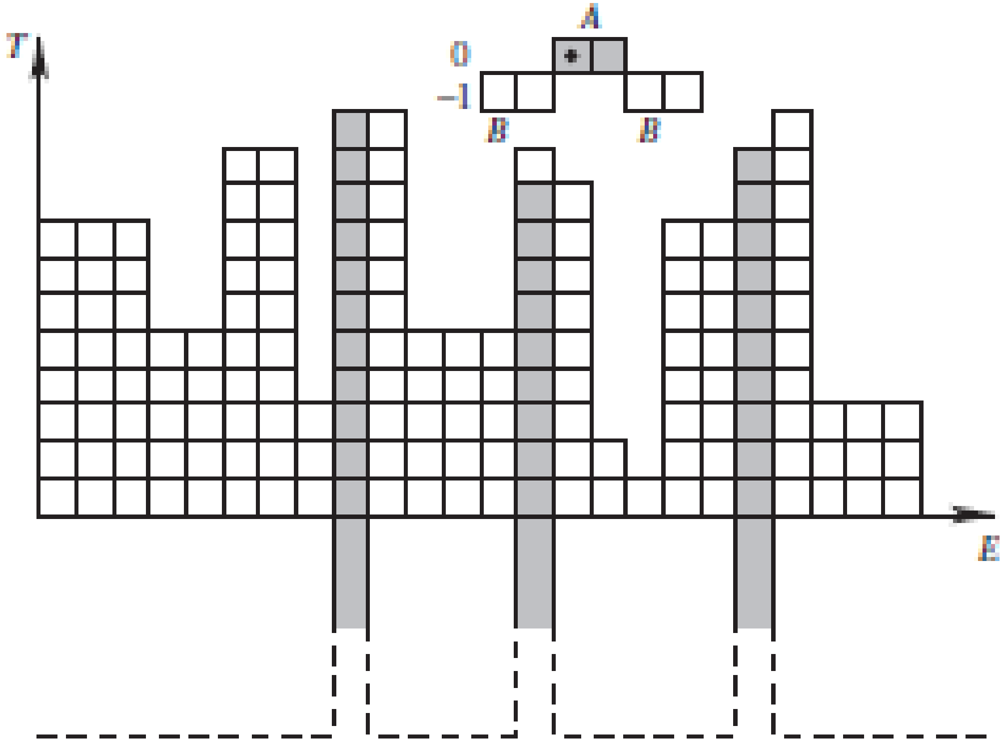


Fig. 2. Here $E = \mathbb{Z}$ and $T = \overline{\mathbb{Z}}$. On top we show the two structuring elements A and B (the origin being the left pixel of A), with the associated levels $a = 0$ and $b = -1$ (thus $V = C_{A,0}$ and $W = C^{*}_{B,-1}$). Below we show a function F, and in grey we have $\eta^{S}_{[V,W]}(F)$, forming three peaks. The left peak would disappear for $b \leqslant -2$, and the right one for $b \leqslant -3$.

3. A few grey-level HMT-based methods

- ❑ The three vessel segmentation methods are devoted to such hepatic and cerebral applications.
  - Two versions of the first method are designed to automatically recognize the entrance of the portal vein (EPV) of the liver.
  - The second method proposes a segmentation of this whole hepatic venous tree
  - The third one enables to segment both venous and arterial structures from MRA of the brain.

3. A few grey-level HMT-based methods

3.1. Choice of structuring functions

- The first issue, the choice of the “shape” of these functions, which means the support supp *(V)* of the foreground function *V* and the dual support Supp* *(W)* of the background function *W*.

- 2 strategies:
  1. Determining a fixed shape for the structuring functions.
     - The erosion of both structuring function
     - Using the HMT with rank-order operators
     - The subsampling or decimation of the structuring function

  2. Considering a large set of elements, each one differing in terms of size and orientation.

3. A few grey-level HMT-based methods

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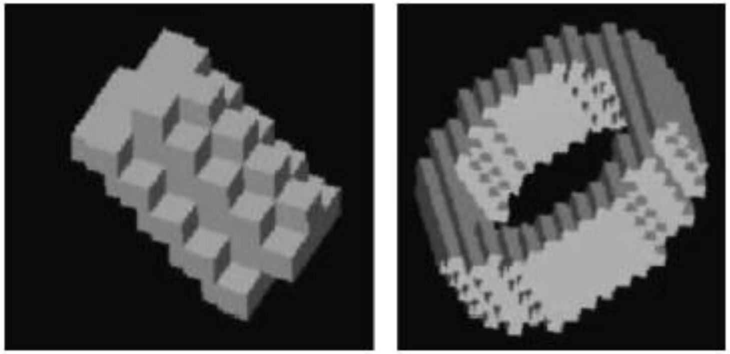


Fig. 3. Shape of the structuring functions used in Ref. [11]. Left: foreground element ($\mathrm{supp}(V)$), right: background element ($\mathrm{supp}^*(W)$).

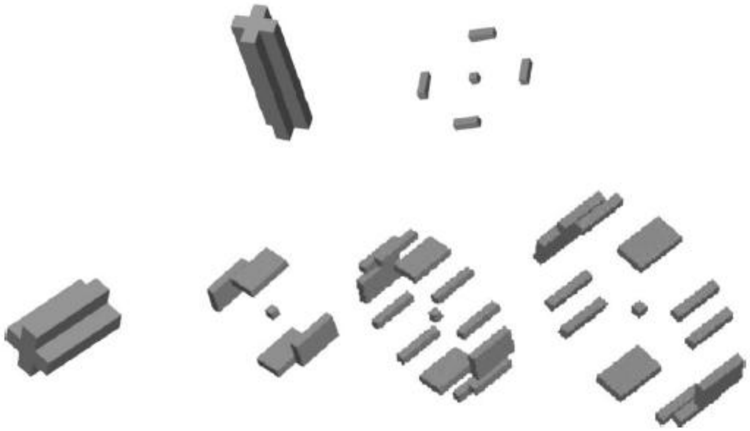


Fig. 4. Shape of the structuring functions used in Ref. [12]. First row: structuring functions used for detecting the SMV. Left: foreground element ($\mathrm{supp}(V)$), right: background element ($\mathrm{supp}^*(W)$). The central point represents the origin and does not belong to $\mathrm{supp}^*(W)$. Second row: structuring functions used for detecting the EPV. From left to right: foreground element ($\mathrm{supp}(V)$), background elements ($\mathrm{supp}^*(W)$). The central point represents the origin and does not belong to $\mathrm{supp}^*(W)$.

3. A few grey-level HMT-based methods

3.1. Choice of structuring functions

2. Considering a large set of elements, each one differing in terms of size and orientation.

   The use of the discrete version of an **isotropic** shape is justified by the presence of **tortuous arterial vessels** which could hardly be detected by elongated structures such as ellipsoids.

   The use of a subset of a discrete circle instead of a whole one enables to obtain more robust results at positions such as bifurcations

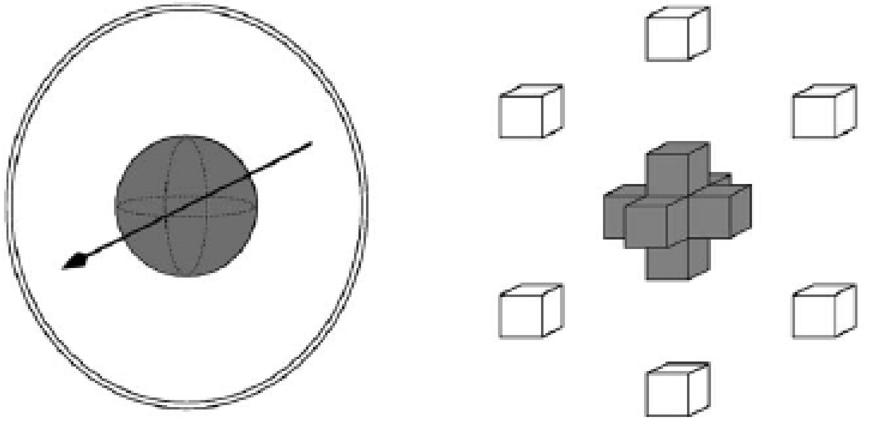


Fig. 5. Shape of the structuring functions used in Refs. [13,14]. Left: theoretical continuous shapes, right: real discrete ones. The foreground elements (supp(V)) are represented in dark grey, while the background ones (supp*(W)) are represented in white.

3. A few grey-level HMT-based methods

3.1. Choice of structuring functions

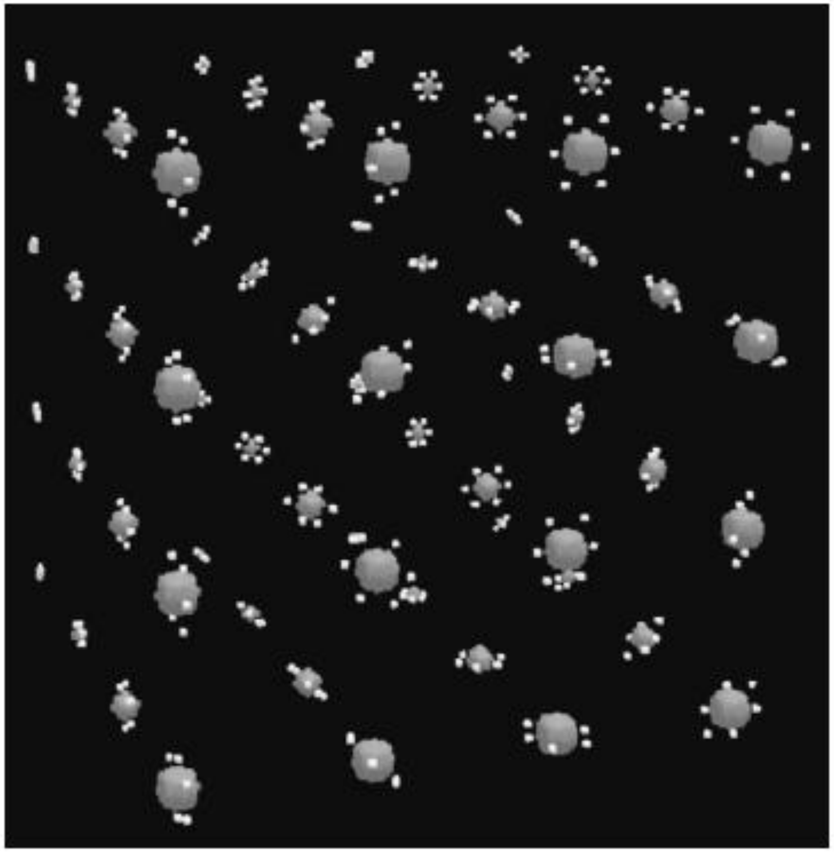


Fig. 6. Subset of the possible structuring function supports used in Refs. [13,14]. The foreground elements ($\mathrm{supp}(V)$) are represented in dark grey, while the background ones ($\mathrm{supp}^*(W)$) are represented in white. They present specific properties in terms of size ($\mathrm{supp}(V)$, $\mathrm{supp}^*(W)$) and of orientation ($\mathrm{supp}^*(W)$).

3. A few grey-level HMT-based methods

3.1. Choice of structuring functions

- The last parameter which has to be determined is the intensity of the structuring functions
- The cylinder of base B and level t is the function $C_{B,t}$
- *V and W are assumed to present each a constant value on supp(V)* and supp**(W). These two values are chosen in such a way that the smallest positive difference between image values on supp(V) and on supp*$\ast$ *(W) leads to a positive response.*

3. A few grey-level HMT-based methods

3.2. A few remarks about the flat/non-flat structuring functions

- The vessel segmentation methods described in this paper only use structuring functions with **constant grey-levels**, flat or not (those structuring functions being cylinders $C_{A,t}$).
- Non-flat SEs with **non-constant grey-levels** enable to segment precise structures not only according to their shape but also to precise **local intensity** properties.

3. A few grey-level HMT-based methods

3.2. A few remarks about the flat/non-flat structuring functions

- ☐ The vessel segmentation methods described in this paper only use structuring functions with **constant grey-levels**, flat or not (those structuring functions being cylinders $C_{A,t}$).
- ☐ Non-flat SEs with **non-constant grey-levels** enable to segment precise structures not only according to their shape but also to precise **local intensity** properties.
  - Partial volume effect
  - Phase Contrast MRA
- ☐ In practical cases (where the purpose is generally to characterise structures from their shape by imposing a constraint on the difference of contrast between the object and a particular neighbourhood), **flat SEs are generally sufficient**.

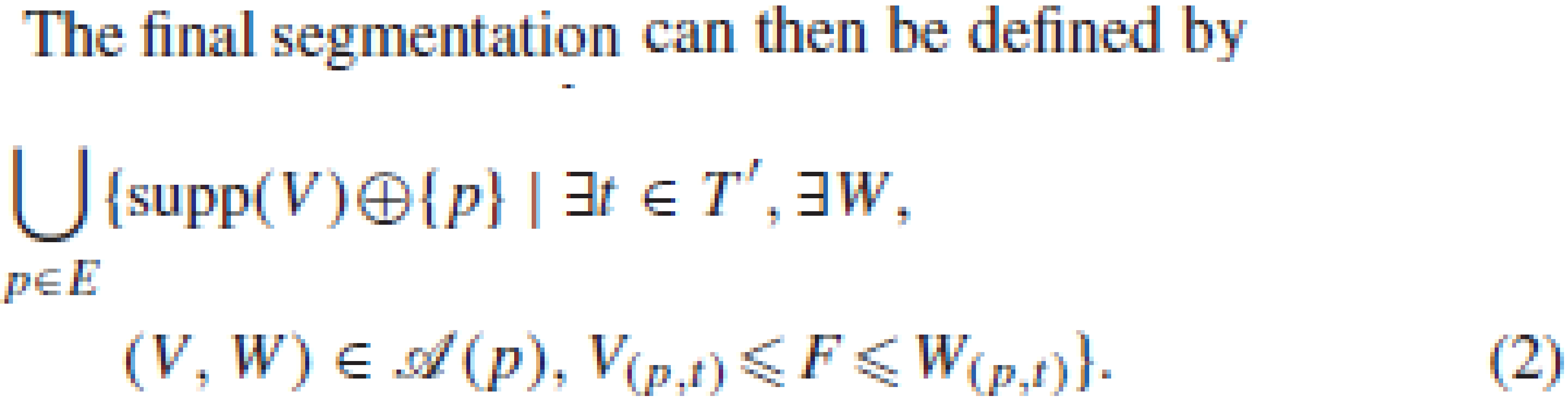
3. A few grey-level HMT-based methods

3.3. Algorithmic process

The grey-level HMT can essentially be used in two main ways:

- in a classical filtering process,
- or as part of heuristic criteria for guidance of iterative segmentation processes.

1. Filtering



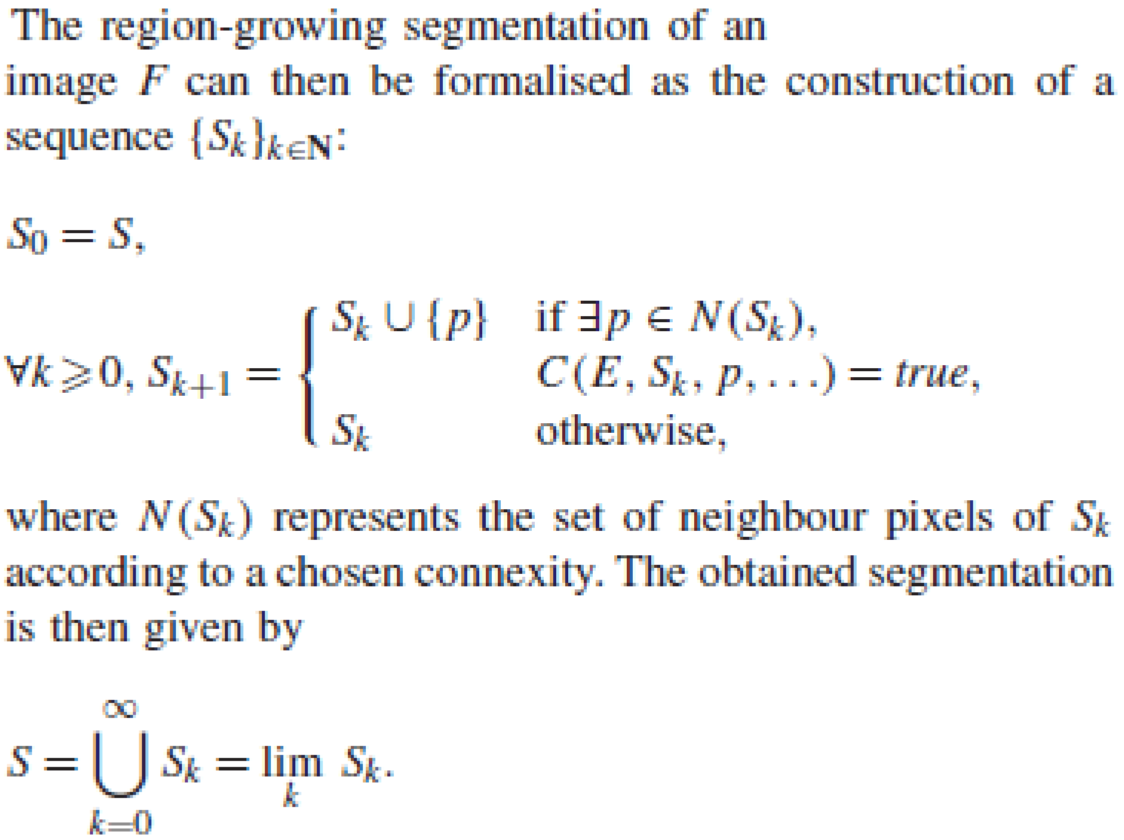
The final segmentation can then be defined by

$$\bigcup_{p\in E}\{\mathrm{supp}(V)\oplus\{p\} \mid \exists t\in T', \exists W, (V,W)\in\mathscr{A}(p), V_{(p,t)}\leqslant F\leqslant W_{(p,t)}\}. \qquad (2)$$

3. A few grey-level HMT-based methods

3.3. Algorithmic process

2. Heuristic criteria for guidance of iterative segmentation processes.
   - The use of HMT as a heuristic criterion is quite different, as it consists in applying it only on candidate points.



The region-growing segmentation of an image F can then be formalised as the construction of a sequence $\{S_k\}_{k\in\mathbf{N}}$:

$$S_0 = S,$$

$$\forall k \geqslant 0,\ S_{k+1} = \begin{cases} S_k \cup \{p\} & \text{if } \exists p \in N(S_k), \\ & C(E, S_k, p, \ldots) = \mathit{true}, \\ S_k & \text{otherwise,} \end{cases}$$

where $N(S_k)$ represents the set of neighbour pixels of S_k according to a chosen connexity. The obtained segmentation is then given by

$$S = \bigcup_{k=0}^{\infty} S_k = \lim_{k} S_k.$$

3. A few grey-level HMT-based methods

3.3. Algorithmic process

2. Heuristic criteria for guidance of iterative segmentation processes.
   - Criterion

$$C(F,p)=\begin{cases} \mathit{true} & \text{if } \max\limits_{i=1}^{3}[SK_{O,R_i}(F)](p)>0, \\ \mathit{false} & \text{otherwise,} \end{cases}$$

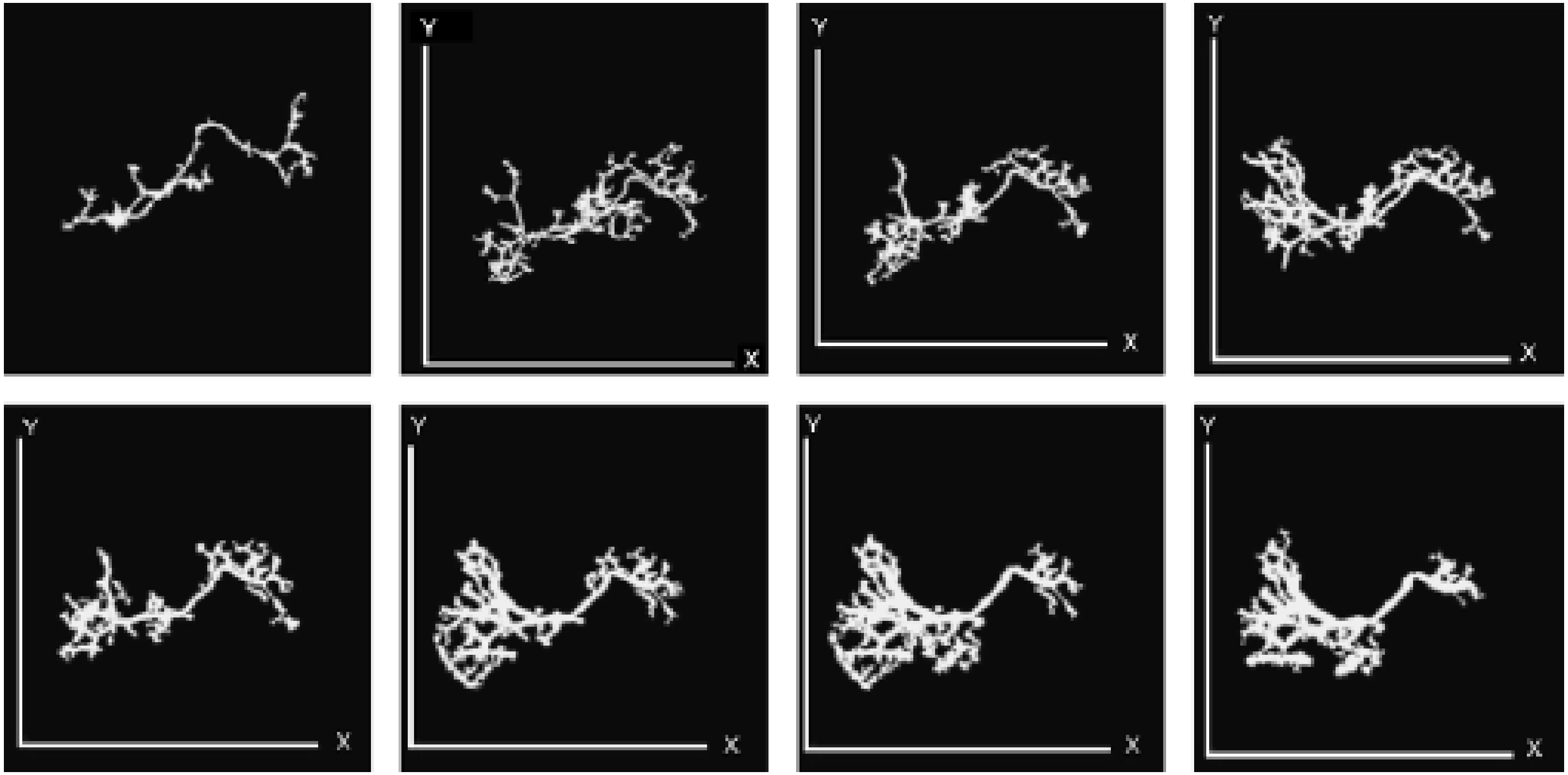
or

$$C(F,p)=\bigvee_{i=1}^{3}([SK_{O,R_i}(F)](p)>0),$$

where $O=i_{0,0}$ ($i_{p,t}$ being the impulse function) is the SE only composed of the origin and R_i ($i=1,2,3$) are SEs used to constrain the point p to belong to a tubular structure.

4. Results

The segmentation methods devoted to the EPV, have been applied on a 16 case dataset. The detection of the EPV was successful for all images, leading to a detection rate of 100%.



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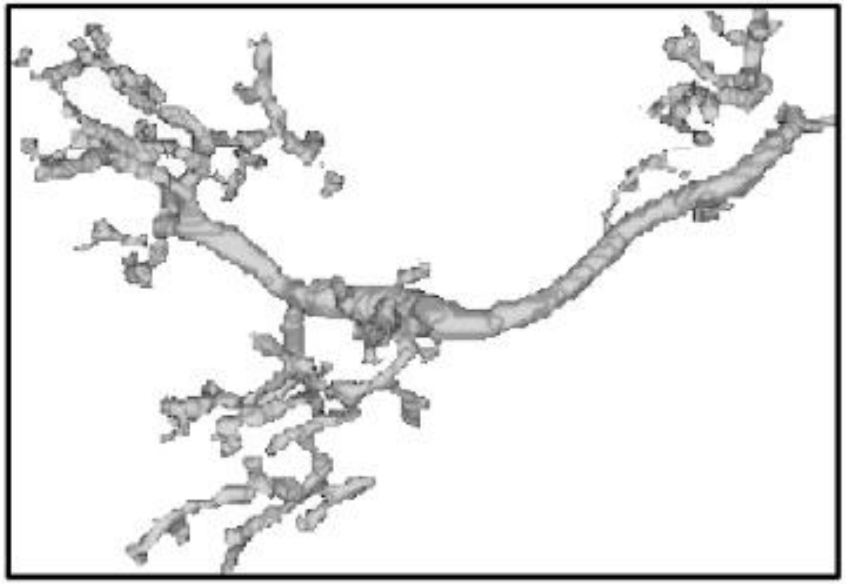

Fig. 11. 3D surface rendering visualisation of the portal network structures segmented from CT-data of the liver.

Fig. 12. 3D surface rendering visualisation of cerebral vascular structures segmented from a phase-contrast MRA of the brain.

4. Conclusion

- ☐ The **underuse** of grey-level HMT is probably **unjustified** in the field of medical image analysis, and more globally in the field of image processing.