MULTI-REGION ACTIVE CONTOURS WITH A SINGLE LEVEL SET FUNCTION

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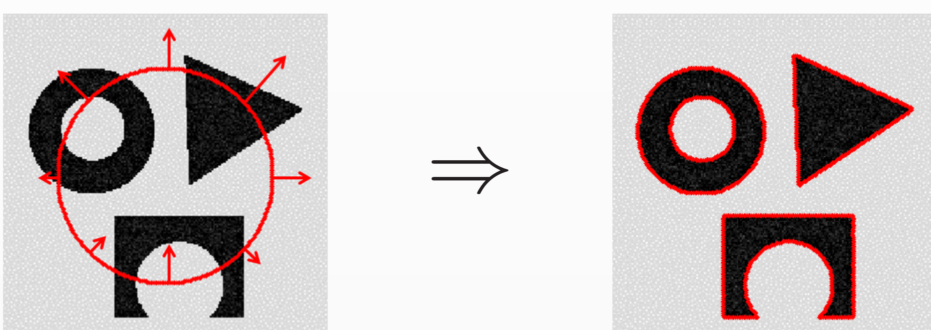
Abstract

Segmenting an image into an arbitrary number of parts is at the core of image understanding. We propose a novel approach to tackle the problem of multiple-region segmentation, which can be applied for an arbitrary number of regions, and generic region and edge appearance models. Object boundaries are modelled by active contours, minimizing the chosen energy functional, while the segmentation update is done by level set evolution. Unlike most existing methods, in our framework, the evolution is executed using a single non-negative level set function, through the Voronoi Implicit Interface Method (VIIM) for multi-phase interface evolution. Our method is shown to obtain accurate segmentation results for various natural 2D and 3D images.

Active contours

Segment image $I(x)$ into multiple regions $\{\Omega_i\}$ by minimizing the energy functional

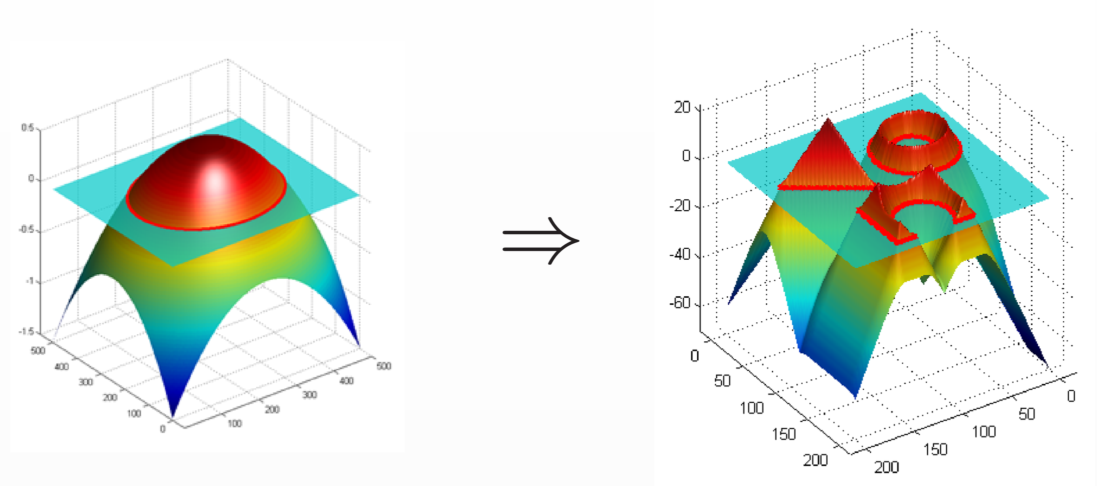
$$E(C) = E_{\text{data}}(C, I) + \mu E_{reg}(C)$$
$$\Downarrow$$
$$C_t = -\frac{\delta E}{\delta C}\mathbf{n} = F\mathbf{n}$$



Level set formulation

Define C implicitly as a zero-level set of a *level set function* $\phi(x)$

$$C = \{\, x \mid \phi(x) = 0 \,\}$$



$$\phi_t = F_{ext}\,|\nabla\phi|$$

2-region segmentation:

$$\text{Object} = \{\, x \mid \phi(x) > 0 \,\}$$
$$\text{Background} = \{\, x \mid \phi(x) > 0 \,\}$$

Extension to > 2 regions is non-trivial!

VIIM

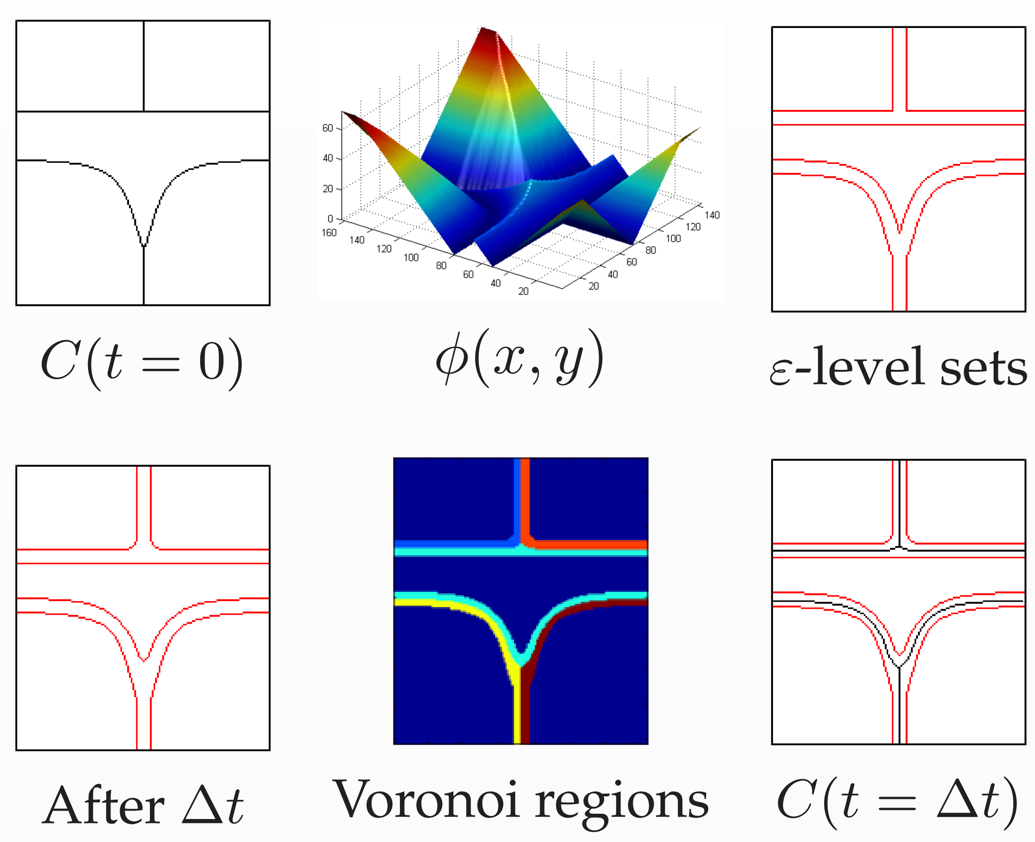
Use a **single** level set function

$\phi(x, y) > 0$ - unsigned distance from C

Observation "Motion of zero-level set corresponding to the interface C is bracketed by the motion of its surrounding ε-level sets".

Algorithm [1]

- Evolve ε-level sets using $\phi_t = F_{ext}\,|\nabla\phi|$.
- Reconstruct C from ε-level sets.



- Implicit treatment of multi-point junctions
- No gaps or overlaps!

Multi-region segmentation

Algorithm

Define: $E(C) \;\Rightarrow\; C_t = F\mathbf{n} \;\Rightarrow\; F_{ext}(x)$

1. Compute ϕ and evolve ε-level sets.
2. Reconstruct C from ε-level sets.
3. Return to Step (2).

Image appearance models

- Region competition model

$$E(C, \{\alpha_i\}) = \sum_{i=1}^{M} \int_{\Omega_i} -\log P\left(I(x)|\alpha_i\right) dx + \frac{\mu}{2} \sum_i \oint_{C_i} g(C_i(s))ds.$$

Special case: Piecewise constant model

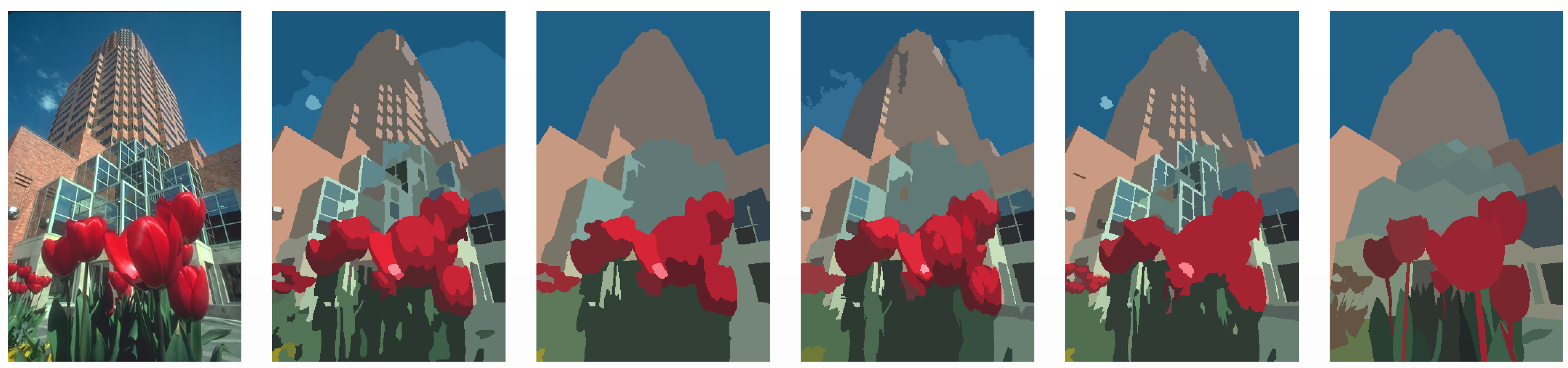
$$E_{data}(C, \{c_i\}) = \sum_{i=1}^{M} \int_{\Omega_i} \left(I(x) - c_i\right)^2 dx.$$

- Pairwise dissimilarity model

$$E_{data}(C) = \sum_i \iint_{\Omega_i \times \Omega_i} w(x, y)dxdy,$$

where $w(x, y) = Dissimilarity(x, y)$.

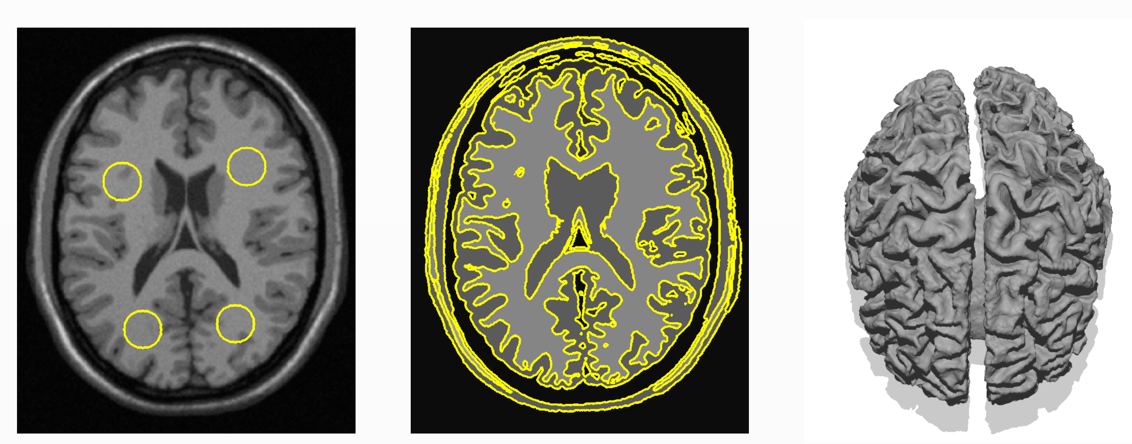
Results



Original image — Results obtained with different methods and parameters — Semantic human seg.

Example from the Berkley Segmentation Dataset BSDS500 [3]

Comparison with the learning approach of Arbeláez et al. [3]. Left to right: original image, our method, two results of [3].



Segmentation of an MRI scan from the BrainWeb dataset. Left to right: initial contour, final contour, white matter exterior boundary.

References

[1] R. I. Saye, J. A. Sethian, The Voronoi Implicit Interface Method for computing multiphase physics, in *PNAS*, 2011

[2] A. Dubrovina et al., Active contours for multi-region image segmentation with a single level set function, in *SSVM*, 2013

[3] P. Arbeláez et al., Contour detection and hierarchical image segmentation, in *TPAMI*, 2011

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