Concurrent Image Segmentation by Locally Specified Polygonal Markov Fields on the GPU

Michał Matuszak[1,2] & Patrycja Kamińska[3]

[1] Faculty of Mathematics and Computer Science, Adam Mickiewicz University, Poznań, Poland
[2] Faculty of Mathematics and Computer Science, Nicolaus Copernicus University, Toruń, Poland
[3] Hipolit Cegielski Clinical Hospital, Poznan University of Medical Sciences,Poznań, Poland

Abstract

We introduce a class of multi-coloured polygonal Markov fields driven by local activity functions. Whereas the local rather than global nature of the field specification ensures substantial additional flexibility for statistical applications in comparison to classical polygonal fields. Within the framework of this theory we develop a concurrent image segmentation algorithm based on Markovian optimisation dynamics combining the simulated annealing ideas with those of Chen–style stochastic optimisation, in which successive segmentation updates are carried out simultaneously with adaptive optimisation of the local activity functions. The efficiency of the algorithm has been evaluated in a simple sandbox environment implemented with the use of the NVIDIA CUDA technology.

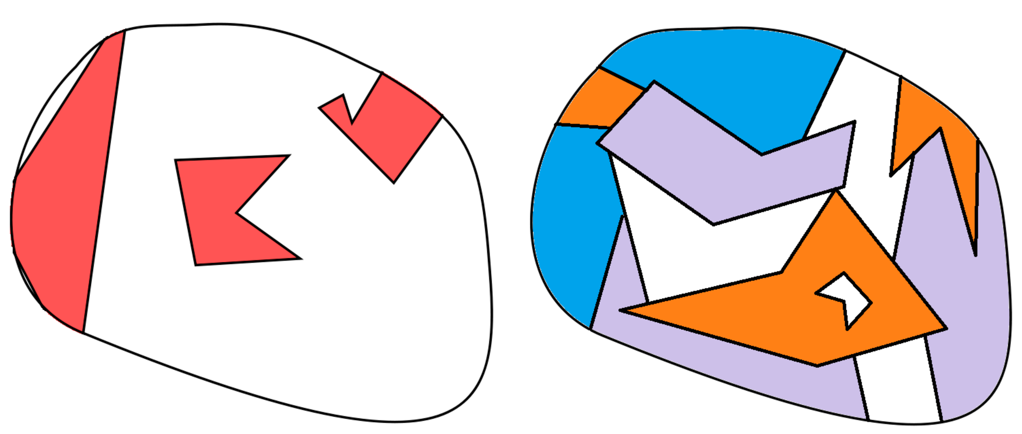
Segmentation

Segmentation is one of the fundamental processes in image analysis and processes. It is a partition of an image elements (pixels) into homogenous regions such that:

- every pixel belong only to one region,
- every region fulfill homogeneity criteria,
- any sum of 2 different regions does not fulfill homogeneity criteria.

Introduction

The polygonal Markov fields, originally introduced by Arak & Surgailis[1] arise as continuum ensembles of non-intersecting polygonal contours in the plane, possibly nested and chopped off by the boundary.

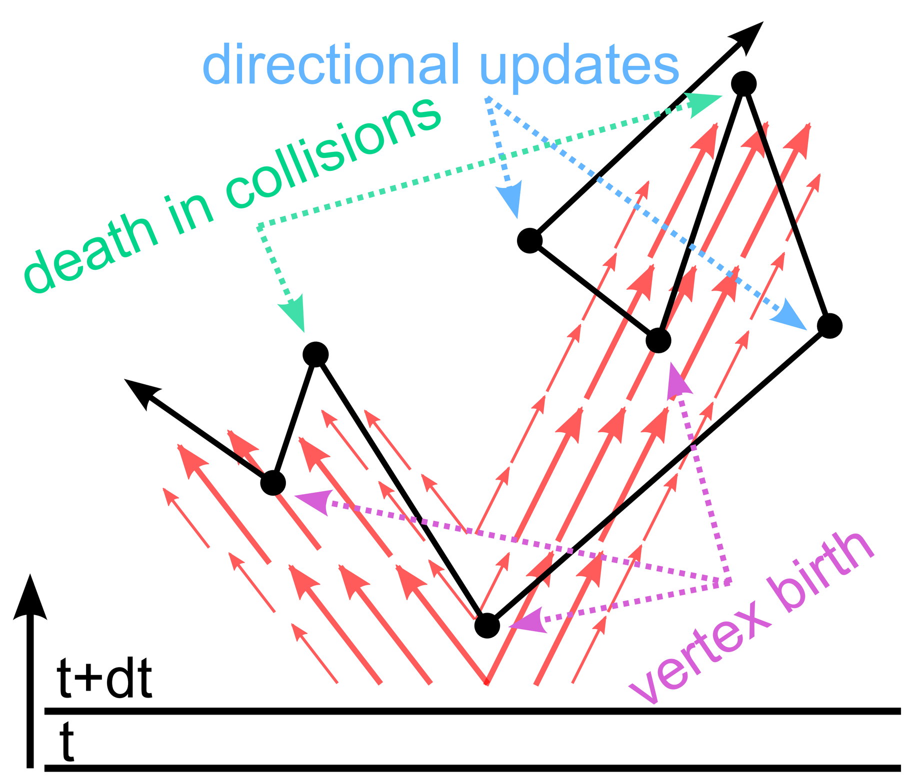


(a) 2 colours (b) 4 colours

Figure : Realizations of Arak process.

An efficient simulation technique for polygonal Markov Fields has been presented in [2].

Dynamic construction

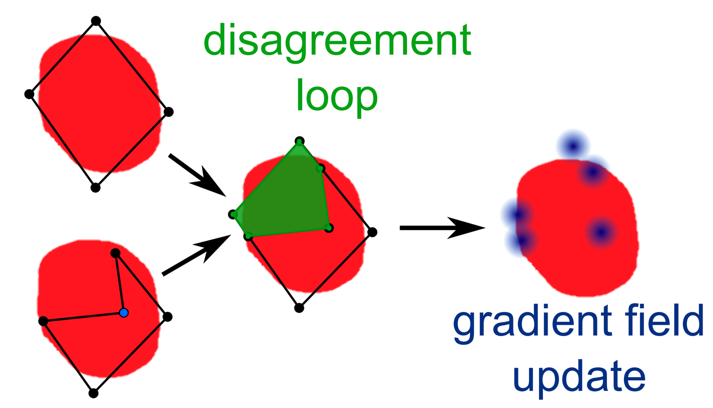


Outline of the construction: (1) According to gradient field intensity (red arrows) draw locations for the vertex birth points. (2) At each vertex birth point create a pair of lines with **time to live (TTL)** drawn from Poisson distribution. The direction of lines should be drawn with respect to vector field direction. (3) The **TTL** should be decreased (slowly if the line is following the gradient field, faster if the angle between gradient field and the updated line is higher. (4) If **TTL** is equal to 0 then **directional update** occurs and the line should change the direction. (5) If the line collide with other line or an edge then follow the rules described later.

Markovian dynamics

Modification rules: **add an extra vertex birth site** or **remove a vertex birth site**, while keeping the remaining evolution rules.

- The concept of disagreement loop make the updates easy to simulate.



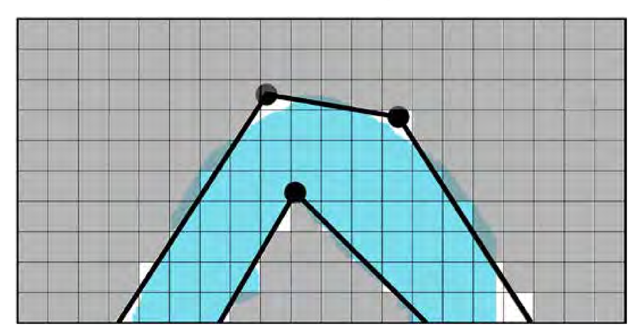
The vector field $\vec{G}_s$ evolves in time together with the polygonal configuration, with the initial condition

$$\vec{G}_0(x) := \nabla\phi(x),$$

for practical reasons possibly modified by convolving ϕ with a small variance Gaussian kernel at the pre–processing stage. At the end of disagreement loop phase the gradient field is updated (reinforced or faded) according to Chen–style stochastic optimisation with Gaussian "bell" curve.

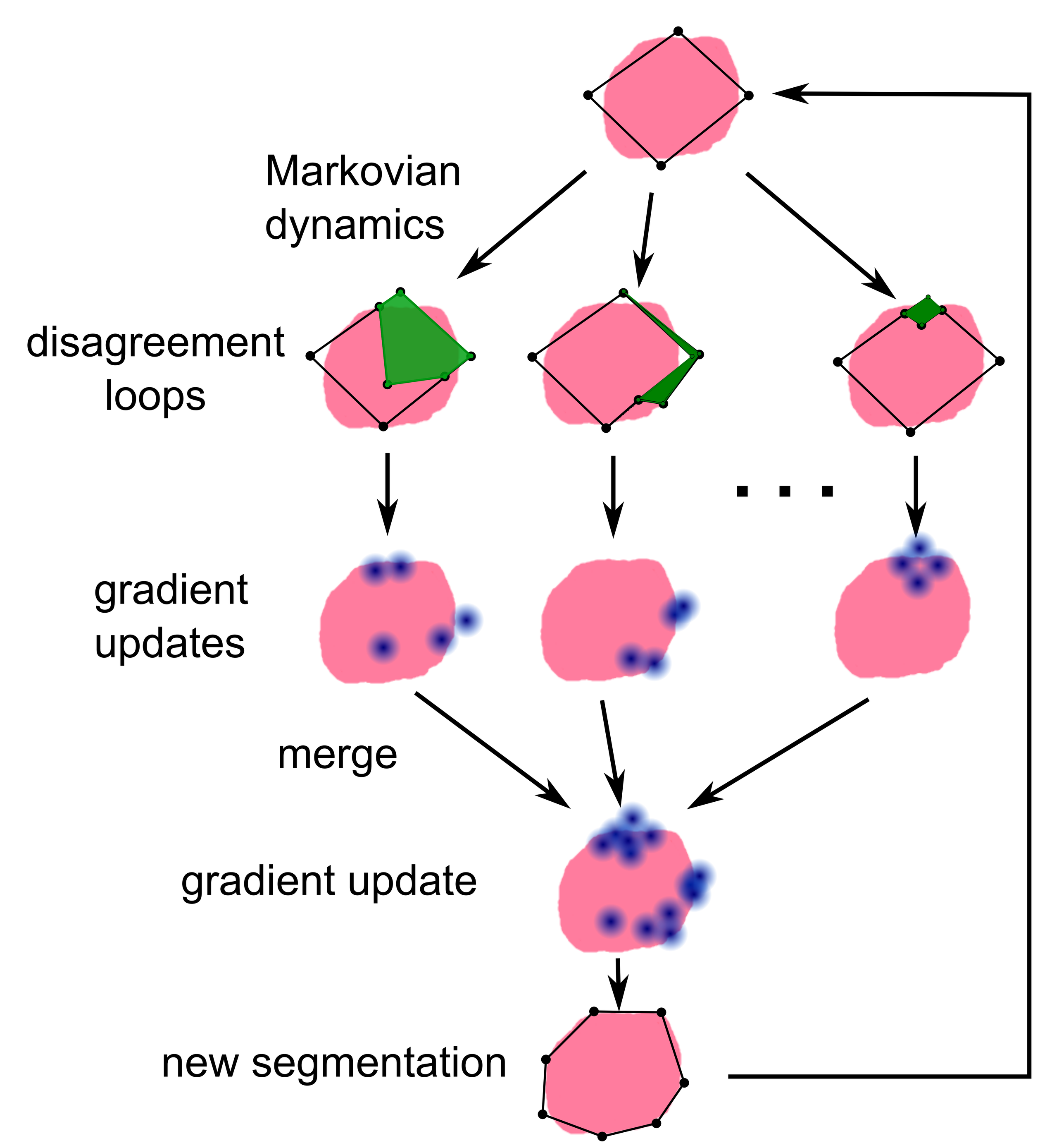
Energy Function

The quality of segmentation (γ) is quantified in terms of an *energy function* which in our case is a positive linear combination of a pixel misclassification ratio, the length element and the number of edges, that is to say



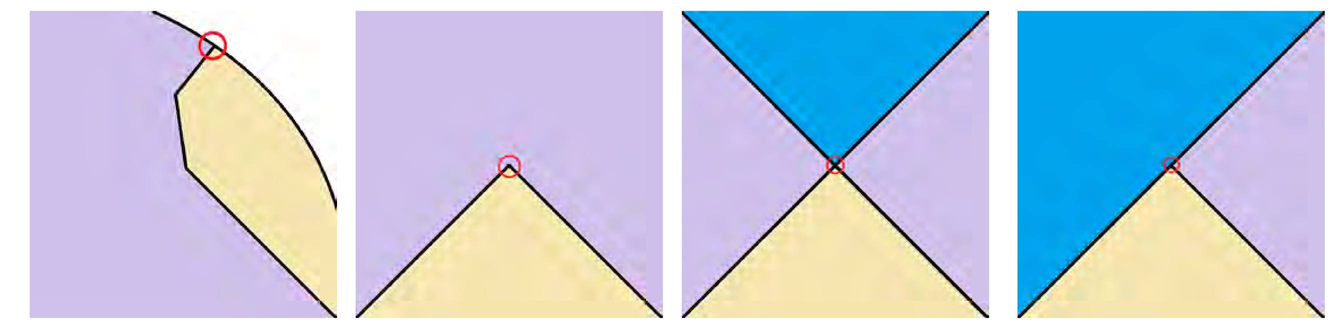
$$\begin{aligned}\mathcal{H}[\gamma] :=& \alpha_2 \min_i \left(\int_D |\phi(x) - s^i_\gamma(x)| dx\right)\\ &+\alpha_1 length(\gamma)\\ &+\alpha_0 card(Edges(\gamma)),\\ &\alpha_j > 0,\ j = 0,1,2.\end{aligned}$$

Parallelization



Collision

When a field edge hits the boundary ∂D, it stops growing in this direction (Img (a)). When two unfolding field edges intersect then V, X or T collision occurs (Img (b)-(d)):



(a) edge (b) V (c) X (d) T

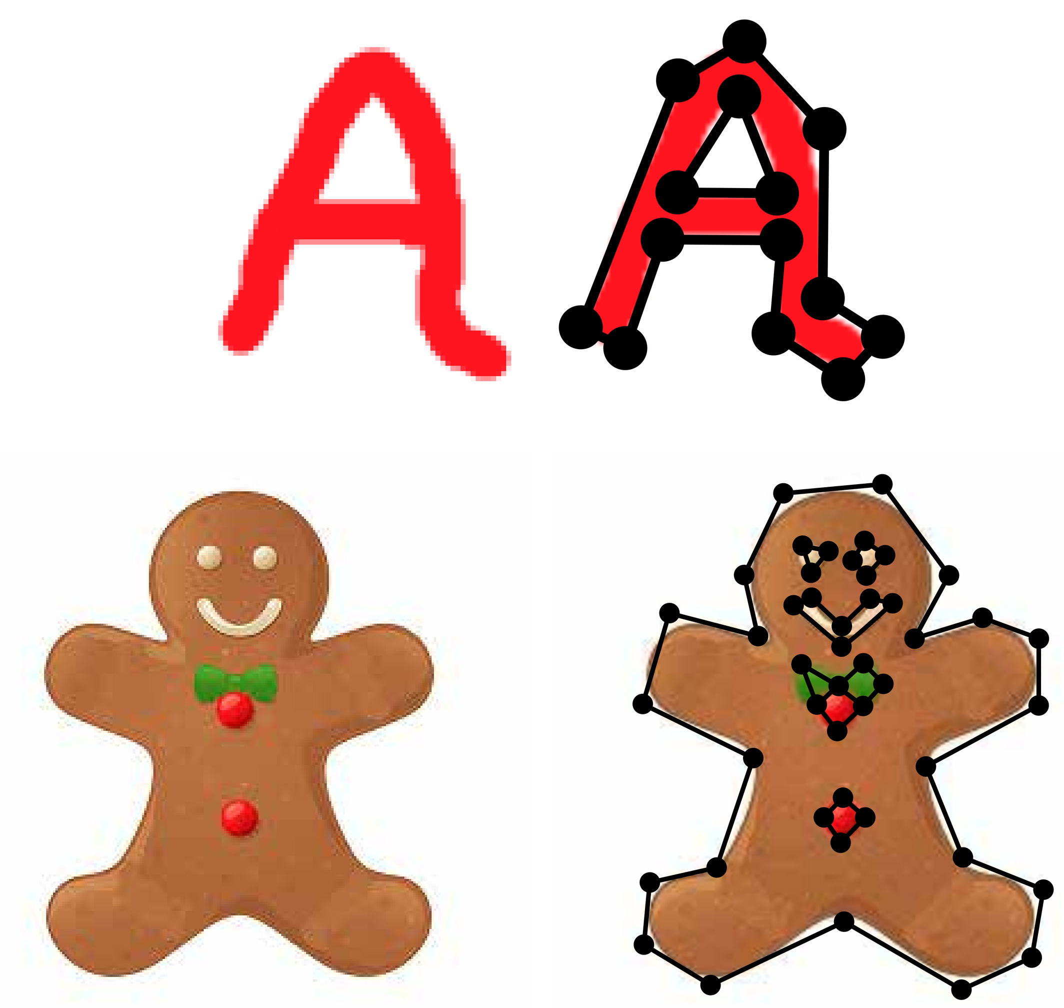
With the admissible number of colours, k, fixed, the family of polygonal fields is parameterized by parameter α_V that controls the density of V-shaped nodes.

$$\alpha_V \in [0,1], \quad \alpha_X = 1-\alpha_V, \quad \alpha_T = \frac{1}{2}(1-\frac{k-2}{k-1}\alpha_X).$$

The parameters α_X and α_T control the density of X- and T -shaped nodes, respectively.

Results

The software, implemented in C++ and C for CUDA programming languages. The segmentations shown in figures below have been obtained with a linear cooling schedule, with mean execution time 0.03 sec per single update on a single core of the Intel Core i7-2600K. The parallel version, executed on NVIDIA GeForce GTX 680 speed up the execution time up to **26.3x**.



Acknowledgements

This research has been supported by the National Science Centre grant 2011/01/N/ST6/00573 (2011-2015). The authors gratefully acknowledge the access to the PL–Grid infrastructure.

Bibliography

[1] Arak, T., Clifford, P., Surgailis, D. Point-based polygonal models for random graphs, *Adv. Appl. Probab.* **25**, 348-372 (1993).

[2] Schreiber, T. Non-homogeneous polygonal Markov fields in the plane: graphical representations and geometry of higher order correlations, *Journal of Statistical Physics*, **132**, 669-705 (2008).

[3] Matuszak, M., Schreiber, T. Locally specifed polygonal Markov Fields for image segmentation, Mathematical Methods for Signal and Image Analysis and Representation, Series: Computational Imaging and Vision, Vol. 41, 2012.