Algorithms for adjusting parameters of combination of acyclic adjacency graphs in the problems of texture image processing

05.13.17 – Theoretical foundations of information

Dissertation for the degree of
Candidate of technical sciences

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General characteristics of the work.

The topicality of the work

- Nowadays the problems of computer data processing are topical. In these problems observations are related in a single array, on elements of the array it is often necessary to make a coordinated decision with regard of adjacent elements
- One of such problems is that of raster texture image processing for the purpose of their segmentation by types of raster textures, for example, the processing of cosmic aerial photographs, two-dimensional scenes, etc.
- The interrelations between the array elements are represented by an adjacency graph
- **Any attempts to reduce the complexity of algorithms while maintaining an acceptable quality of the gained result are topical.**
- In linearly ordered arrays the adjacency graph is a chain. That adjacency allows us to organize the efficient processing of data arrays based on popular approaches such as dynamic programming method and Markov chain theory

General characteristics of the work.

The topicality of the work

- The linear Markov models controlling the change of hidden classes of recognized objects are proved to be extremely efficient
- But for arbitrary adjacency graphs with cycles the segmentation problem is complicated. In particular, the adjacency graph for raster images is a lattice that contains cycles and is not an acyclic one. In these conditions the use of Markov models leads to time-consuming algorithms, and the processing problem (segmentation, recognition) is a NP-problem
- In this work the proposed approach is based on the general idea of complexation of processing operators (algorithms) developed by the Zhuravlev's scientific school
- In particular, raster image processing in this work is based on the idea of replacing the arbitrary adjacency graphs by tree-like ones and linearly combining acyclic Markov models in order to get the best quality of the restoration of hidden classes

General characteristics of the work.

The issue

- In the proposed approach Markov parameters (transition matrix Q) in acyclic models were previously suboptimal without tuning their values on the training set

The purpose of the work

- Developing methods for the optimal tuning of acyclic Markov models in order to significantly improve the quality of solving recognition problems (segmentation of raster texture images)

Main research problems

- **Solving the problem** of adjusting the diagonal element of transition matrix for an acyclic model, and developing algorithms for adjusting the diagonal element for a given acyclic adjacency graph
- **Studying the singular properties** of the basic recognition algorithm (Dvoenko S.D., Kopilov A.B., Mottl V.V., 2001) at the limiting values of the diagonal element
- **Studying the properties** of the previously proposed algorithm for adjusting weights (Dvoenko S.D., 2006) in the combination of acyclic adjacency graphs.
- **Solving the problem** of simultaneously adjusting the diagonal element of transition matrix and weights of the acyclic adjacency graphs in their linear combination. Developing training algorithms based on the adjustment of parameters of the acyclic adjacency graph combination.
- **Experimentally studying** the developed algorithms in the problem of raster texture image segmentation
- **Evaluating the quality** of solving the recognition problem in interrelated data arrays and the statistical properties of decision rule based on the cross-validation method

Positions constituting the scientific newness and being carried out on the defense

- **Formulation of the problem** of searching for the optimal value of the diagonal element of transition matrix Q of a Markov chain corresponding to a particular model of the one-sided Markov random field
- **Algorithms** for adjusting the diagonal element for an acyclic adjacency graph
- **Algorithm** for adjusting the single diagonal element and the weights of the linear combination for a given set of acyclic adjacency graphs
- **Algorithms** for adjusting the diagonal elements and the weights of the linear combination for a given set of acyclic adjacency graphs (First and second scheme)
- **Interactive scheme** for classical independent training on the user's data which provides an acceptable quality of the initial solving
- **Heuristic scheme** for updating a posteriori marginal distributions of hidden classes in order to improve the quality of solving segmentation problem

Approbation and application of the work

Approbation of the work

- XIV Mathematical methods for Pattern Recognition, Suzdaly, 2009
- VI master conference TSU, Tula, 2011
- XXI International conference for students, postgraduate students and young scientists «Lomonosov 2012» , Moscow, 2012
- IX Intellectualization of Information Processing, Montenegro, Budva city, 2012
- GraphiCon 2012, Moscow, 2012

Application of the work

- Research results are applied in Vietnam companies «FPT Software JSC», «FTS company» for processing real images.

Publications

1. Dvoenko S.D., Savenkov D.S., Sang D.V. Acyclic Markov Models in Analysis of Interrelated Data Array // Izvestiya TSU. Natural Sciences. 2010. Vol. 2. P. 173-185.

2. Dvoenko S.D., Sang D.V. Algorithms for Adjusting Parameters of a Tree-like Markov Random Field in the Problem of Raster Texture Image Recognition // Izvestiya TSU. Natural Sciences. 2012. Vol. 1. P. 98-109.

3. Dvoenko S.D., Sang D.V. Algorithms for Adjusting Parameters of Combination of Acyclic Adjacency Graphs in the Problem of Texture Image Recognition // Izvestiya TSU. Technical Sciences. 2012. Vol. 3. P. 253-262.

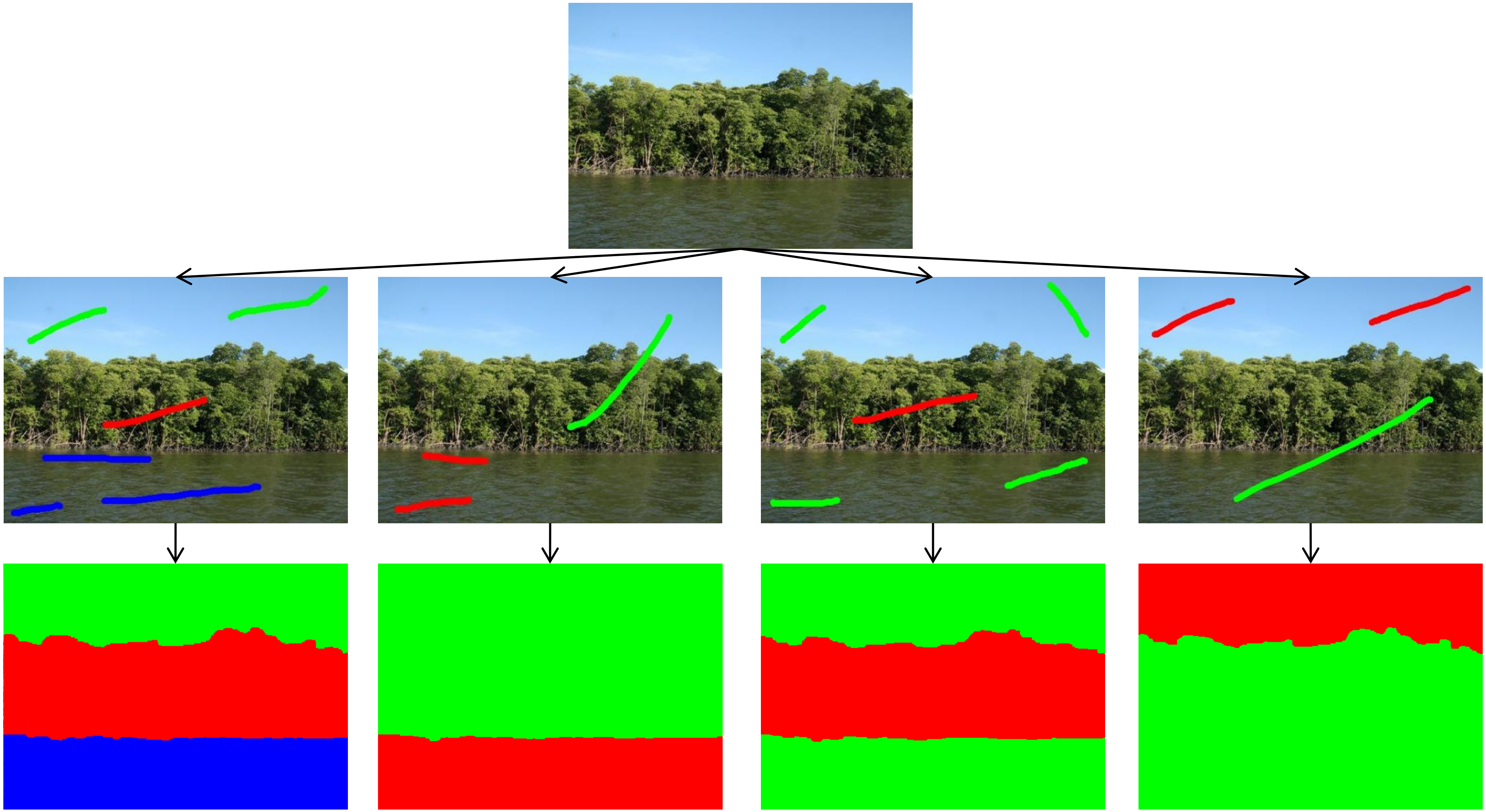
4. Dvoenko S.D., Savenkov D.S., Sang D.V. Combination of Acyclic Adjacency Graphs in the Problem of Markov Random Field Recognition // Proc. XIV conference «Mathematical methods for Pattern Recognition». – Moscow: Maks Press, 2009. P. 441–444.

5. Dvoenko S.D., Sang D.V. Parametric Acyclic Markov Models in the problem of Interrelated Object Recognition // Proc. IX International Conference «Intellectualization of Information Processing». – Moscow: Torus Press, 2012. P. 18–21.

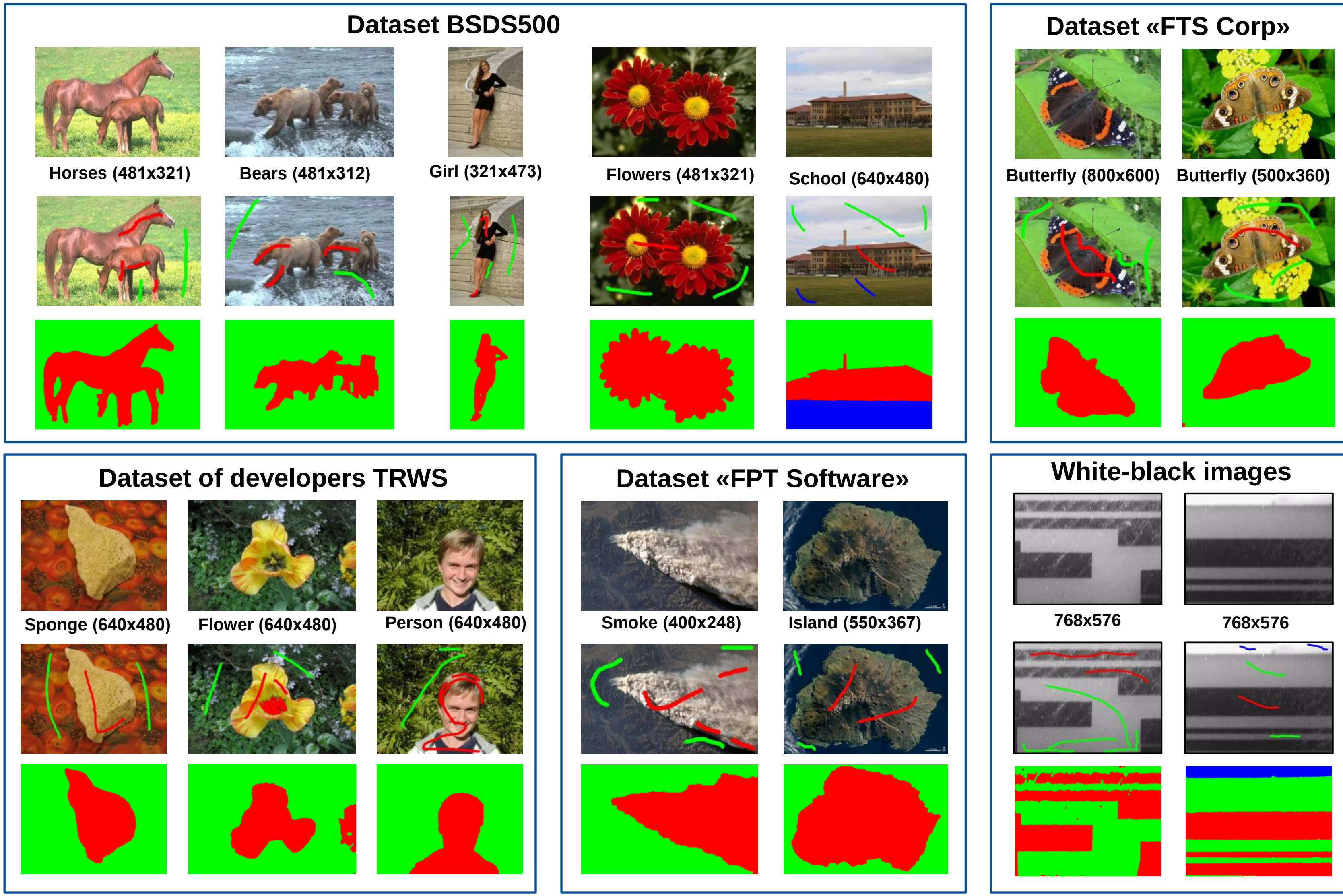
6. Dvoenko S.D., Sang D.V. Raster Texture Image Recognition based on Parametric Acyclic Markov Fields // Proc. XXII International conference in Computer Graphic and Vision «GraphiCon-2012». – Moscow: Maks Press, 2012. P. 139–143.

7. Sang D.V. Algorithms for Adjusting Parameters of Combination of Acyclic Adjacency Graphs in the Problem of Texture Image Recognition // Proc. XXI conference «Lomonosov – 2012» Section «Computational mathematics and cybernetics». – Moscow: Maks Press, 2012. P. 20–21.

Real image processing



Real image processing



Experiments.

Simulated texture images

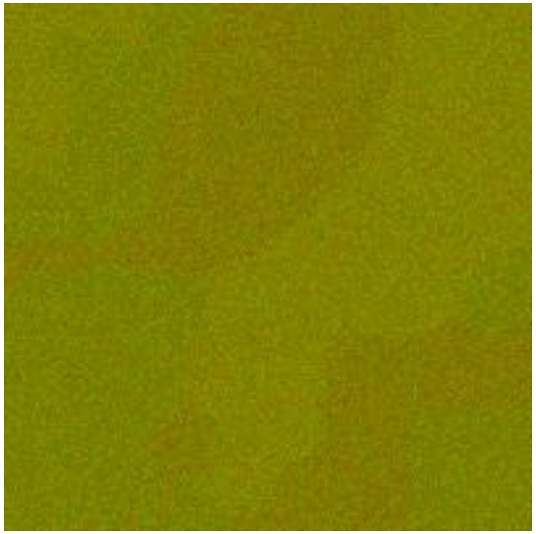
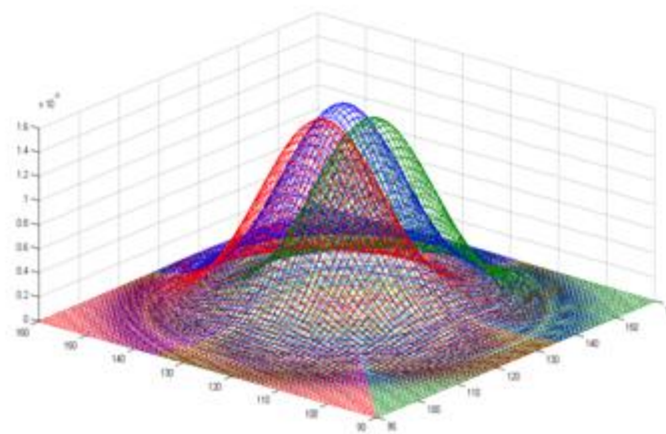
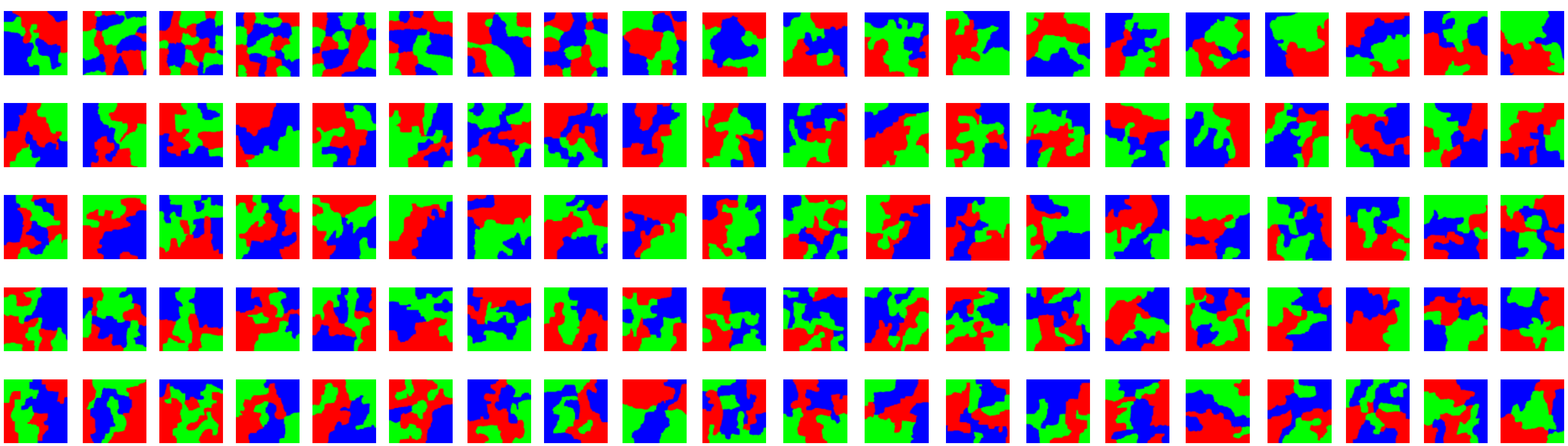


Image № 1 (201×201)

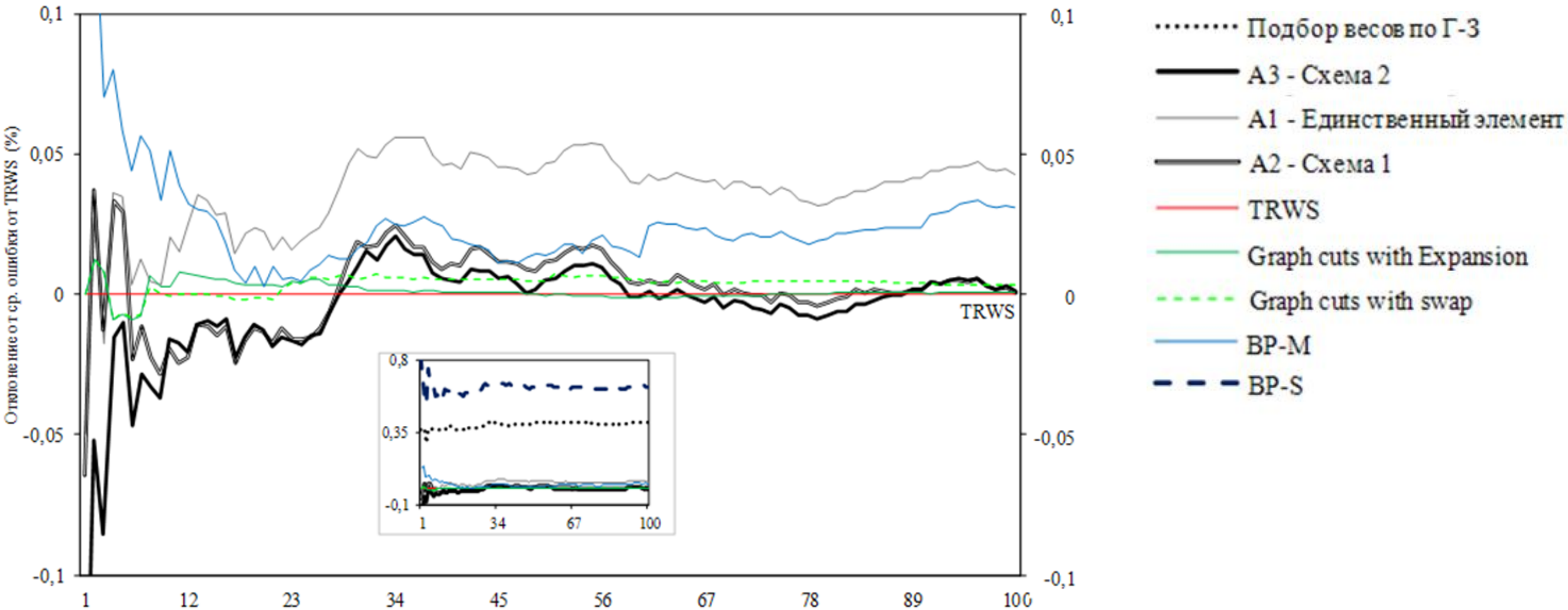


Feature space



Given segmentations of 100 simulated images

Comparing developed algorithms with other popular recognition algorithms



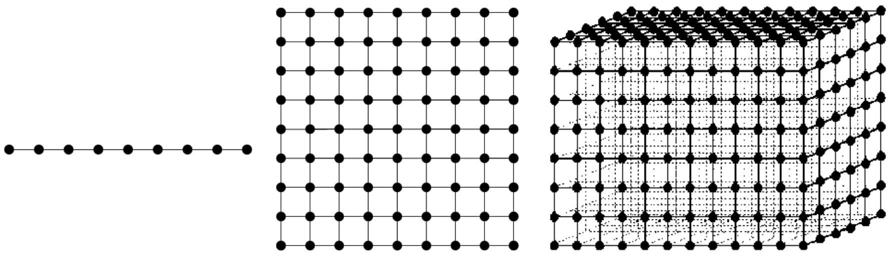
Deviation of error lines

Comparing developed algorithms with TRWS (*Tree Re-Weighted Message Passing Sequential*)

Indicator	Algorithm A1 – Unique diagonal element	Algorithm A2 – First scheme	Algorithm A3 – Second scheme
Number of cases (better than TRWS)	35	55	50
Number of errors (more than TRWS)	1721	17	43

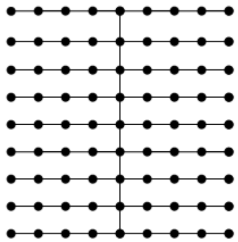
Problem of interrelated data array recognition

- Example of adjacency graph

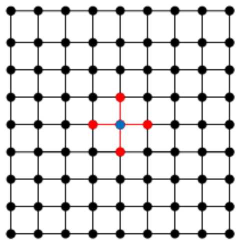


Chain Lattice Data cube

- Acyclic adjacency graph and Markov property of field

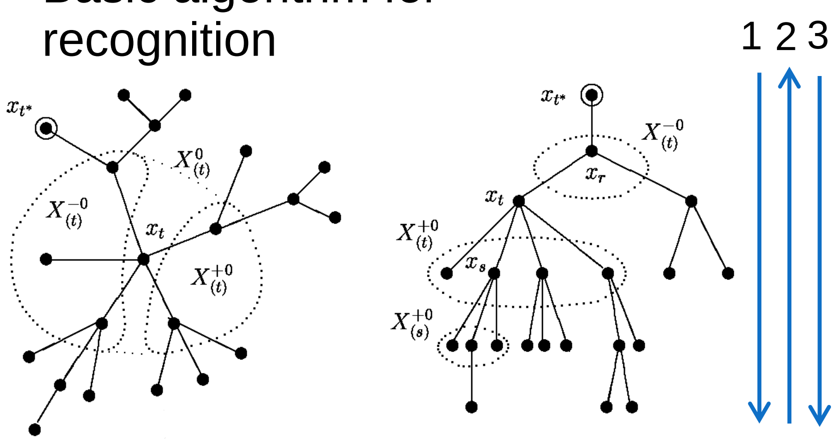


Example of acyclic adjacency graph



Markov property of random field for lattice

- Basic algorithm for recognition



1. Determine a prior marginal distributions of hidden classes

2. Filtration

3. Interpolation

- Particular model of Markov random field (MRF)

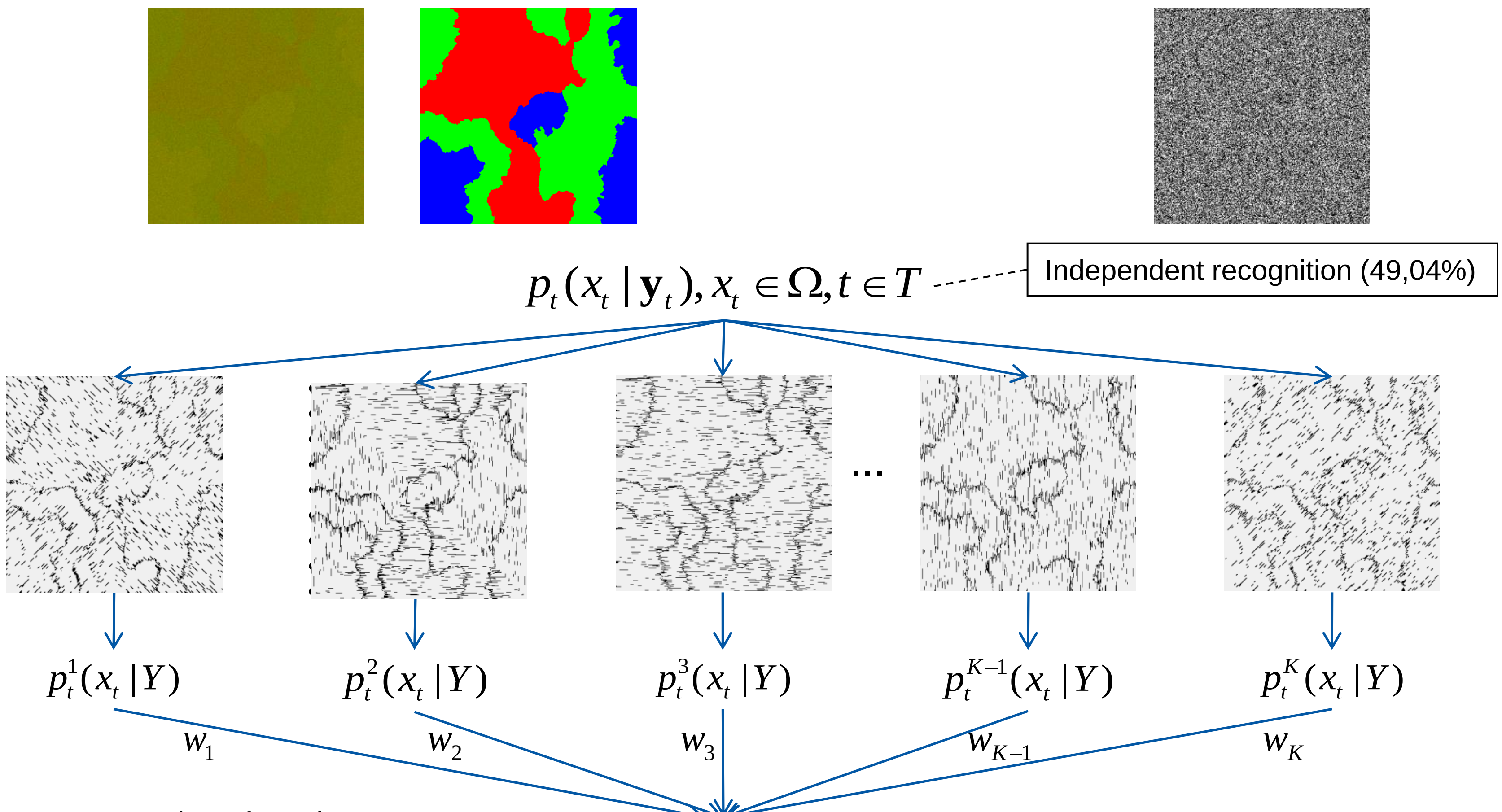
- One-sided MRF is homogeneous, ergodic and reversible.
- MRF is specified by an symmetric and twice stochastic matrix:

$$\boldsymbol{Q}(m,m)=\begin{bmatrix} q & \frac{1-q}{m-1} & \frac{1-q}{m-1} & \cdots & \frac{1-q}{m-1} \\ \frac{1-q}{m-1} & q & \frac{1-q}{m-1} & \cdots & \frac{1-q}{m-1} \\ & & \cdots & & \\ \frac{1-q}{m-1} & \frac{1-q}{m-1} & \frac{1-q}{m-1} & \cdots & q \end{bmatrix}$$

q was previously specified heuristically, for instance, $q=0{,}95$

Combination of acyclic adjacency graphs

Simulated image(401x401)



$$p_t(x_t \mid Y) = \sum_{k=1}^{K} w_k p_t^k(x_t \mid Y)$$

where K – number of graphs,
w_k – weight of k -th graph

Parameters of combination of acyclic adjacency graphs. Natural and structural model parameters

- Parameters of combination of acyclic adjacency graphs: graph weights and diagonal element q of transition matrix
- Model parameters may be natural or structural. But sometimes the difference between them is quite unclear
- Graph weights and diagonal element q can be treated as either natural or structural
- **In this work**:

  - Graph weights – natural; Diagonal element q – structural

  - «Hybrid» approach: Develop algorithms in which the diagonal element q is treated as natural parameter, but the quality of decision rule is evaluated by the cross-validation scheme used in tuning structural parameters

Algorithms for adjusting parameters of combination of acyclic adjacency graphs

Algorithm 1. Adjusting diagonal element and weights of linear combination

All acyclic Markov models corresponding to graphs $G_k, k = 1,...,K$ are specified by a single diagonal element q.

At first all weights are equal: $\mathbf{w}^* = \{w_i = 1/K, i = 1,...,K\}$, where K - number of graphs.

1. Determine: $q^* = \arg\min_{1/m \le q < 1} E(\boldsymbol{w}^*, q)$.

2. Variation step of graph weights

Vary the weight of sequential graph. For each graph G_k determine: $E_k^* = \min_{0 \le w_k \le 1} E(\boldsymbol{w}, q^*), \boldsymbol{w}_k^* = \arg\min_{0 \le w_k \le 1} E(\boldsymbol{w}, q^*)$.

3. Determine $\boldsymbol{w}^* = \boldsymbol{w}_{k*}^*$, where $k^* = \arg\min_{1 \le k \le K} E_k^*$.

4. Repeat steps 1–3 until the recognition error number stops changing.

Algorithms for adjusting parameters of combination of acyclic adjacency graphs

Algorithm 2. First scheme for adjusting diagonal elements and weights of linear combination

Each graph $G_k,\ k=1,...,K$ corresponds to its diagonal element $q_k,\ k=1,...,K$.
At first all weights are equal $\mathbf{w}^*=\{w_i=1/K, i=1,...,K\}$.

1. Determine: $\boldsymbol{q}^*=(q^*,...,q^*)=\arg\min_{1/m\le q<1} E(\boldsymbol{w}^*,\boldsymbol{q})$.

2. **Variation step of graph weights.** Vary the weight of sequential graph. For each graph G_k determine: $E_k^*=\min_{0\le w_k\le 1} E(\boldsymbol{w},q^*), \boldsymbol{w}_k^*=\arg\min_{0\le w_k\le 1} E(\boldsymbol{w},q^*)$.

3. Determine $\boldsymbol{w}^*=\boldsymbol{w}_{k*}^*$, где $k^*=\arg\min_{1\le k\le K} E_k^*$.

4. **Variation step of diagonal elements.** Vary the diagonal element q_k. Determine: $q_k^*=\arg\min_{1/m\le q_k<1} E(\boldsymbol{w}^*,\boldsymbol{q})$.

The new value q_k^* will be used in the variation of remaining diagonal elements $q_{k+1},q_{k+2},...,q_K$. As a result we receive the optimal vector $\boldsymbol{q}^*$.

5. Repeat steps 2–4 while the recognition error number stops changing.

Algorithms for adjusting parameters of combination of acyclic adjacency graphs

Algorithm 3. Second scheme for adjusting diagonal elements and weights of linear combination

Each graph G_k correspond to its diagonal element $q_k, k=1,\dots,K$.

At first all weights are equal $\mathbf{w}^* = \{w_i = 1/K, i=1,\dots,K\}$.

1. Determine: $\boldsymbol{q}^* = (q^*,\dots,q^*) = \arg\min_{1/m \le q < 1} E(\boldsymbol{w}^*, \boldsymbol{q})$.

2. Variation step of graph weights and diagonal elements.

- **Vary the weight of sequential graph.**

For each graph G_k determine: $E_k^* = \min_{0 \le w_k \le 1} E(\boldsymbol{w}, q^*), \boldsymbol{w}_k^* = \arg\min_{0 \le w_k \le 1} E(\boldsymbol{w}, q^*)$.

- **Then vary the diagonal element** q_k in the range $1/m \le q_k < 1$.

Determine: $q_k^* = \arg\min_{1/m \le q_k < 1} E(\boldsymbol{w}^*, \boldsymbol{q})$.

The value q_k^* defines the vector $\boldsymbol{q}_k^* = (q_1,\dots,q_k^*,\dots,q_K)$.

3. Determine the pair of vectors $(\boldsymbol{w}^*, \boldsymbol{q}^*) = (\boldsymbol{w}_{k^*}^*, \boldsymbol{q}_{k^*}^*)$, where $k^* = \arg\min_{1 \le k \le K} E(\boldsymbol{w}_k^*, \boldsymbol{q}_k^*)$.

4. Repeat steps 2–3 until the recognition error number stops changing.

Estimation of Markov parameter based on maximum likelihood

- If the realization of hidden field X is known:

$$\hat{q} = \arg\max_{0<q<1} L(X \mid q) = \arg\max_{0<q<1} \left(p(x_{t^*}) \prod_{s \in T_{(t^*)}} q_s(x_s \mid x_t; q) \right), t \in T_{(s)}^{-0}.$$

Then: $\hat{q} = \dfrac{|V_1|}{|T|-1}$, где $V_1 = \{ s \in T_{(t^*)} \mid x_s = x_t, t \in T_{(s)}^{-0} \}$.

- If the realization of hidden field X is partially known:

Iterative solving of two problems:

- with fixed q and Y solve the problem

$$\hat{x}_t(Y,q) = \arg\max_{x_t \in \Omega} p_t(x_t \mid Y, q), t \in T; \hat{X}(Y) = (\hat{x}_t(Y), t \in T).$$

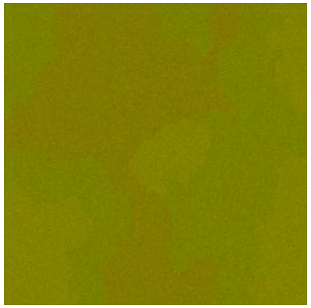
- with fixed X solve the problem $\hat{q} = \arg\max_{0<q<1} L(X \mid q).$

Parameters of algorithm tuning and example of simulated image processing

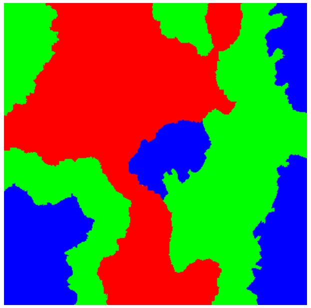
- Example of algorithm tuning on some simulated images

Image	A1		A2		A3	
	weights	q	weights	q	weights	q
1	0,04282	0,86	0,03947	0,90	0,02000	0,75
	0,20338		0,23684	0,89	0,09287	0,93
	0,24000		0,25000	0,91	0,36836	0,92
	0,25690		0,23684	0,90	0,25939	0,89
	0,25690		0,23684	0,89	0,25939	0,89
52	0,16486	0,89	0,46511	0,37	0,15000	0,36
	0,23356		0,13000	0,61	0,21329	0,89
	0,23356		0,14111	0,90	0,21329	0,89
	0,25000		0,14111	0,92	0,21329	0,89
	0,11803		0,12267	0,82	0,21012	0,94

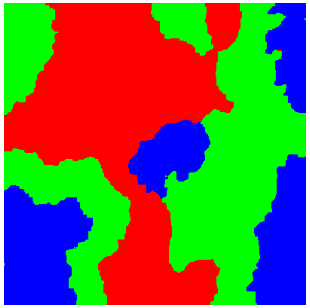
- Example of simulated image processing



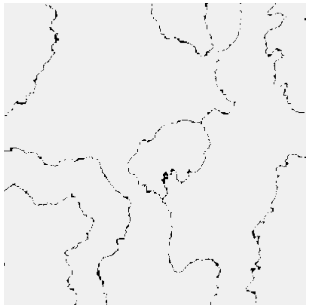
Simulated image



Exact segmentation



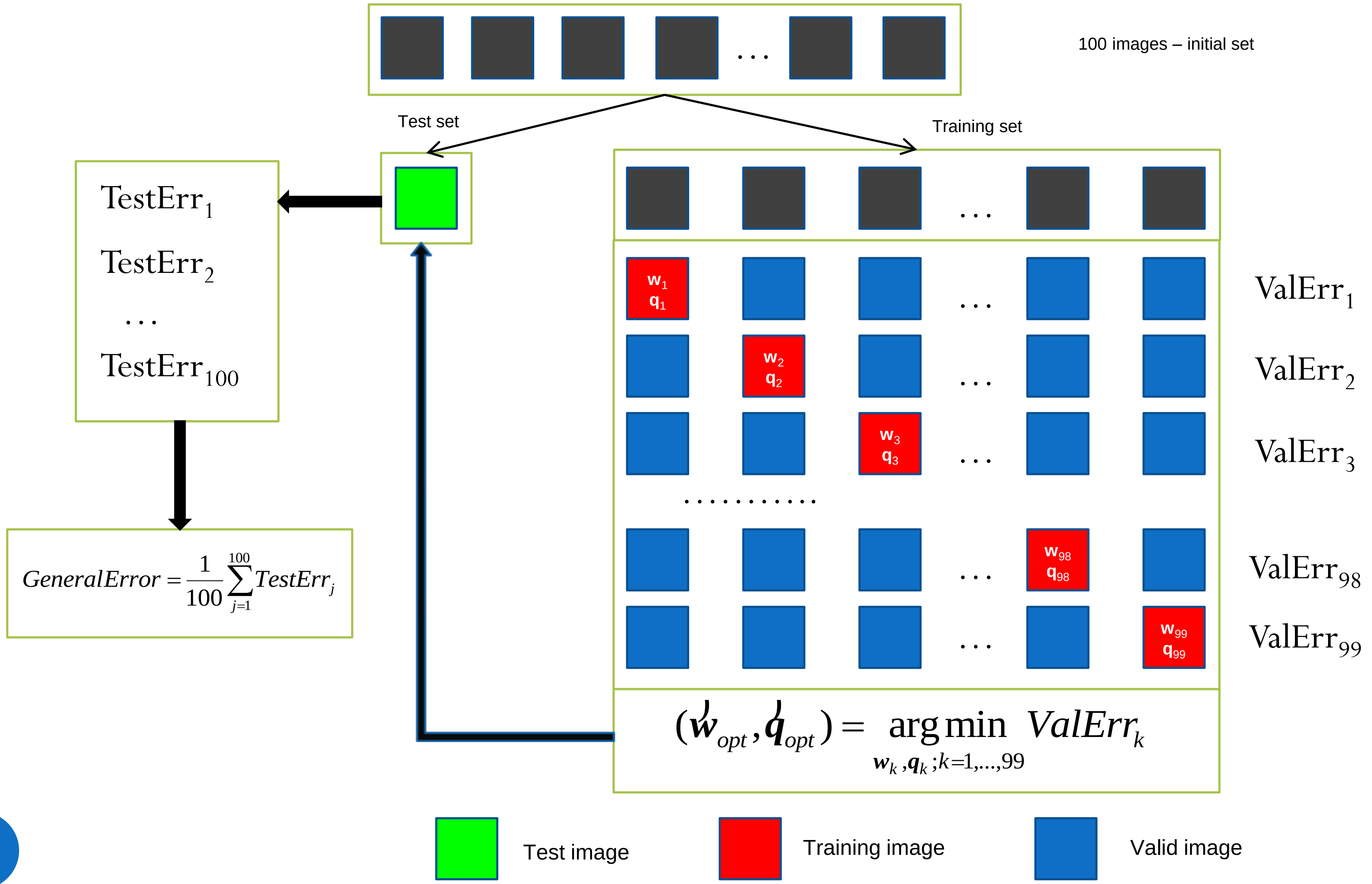
Result of processing



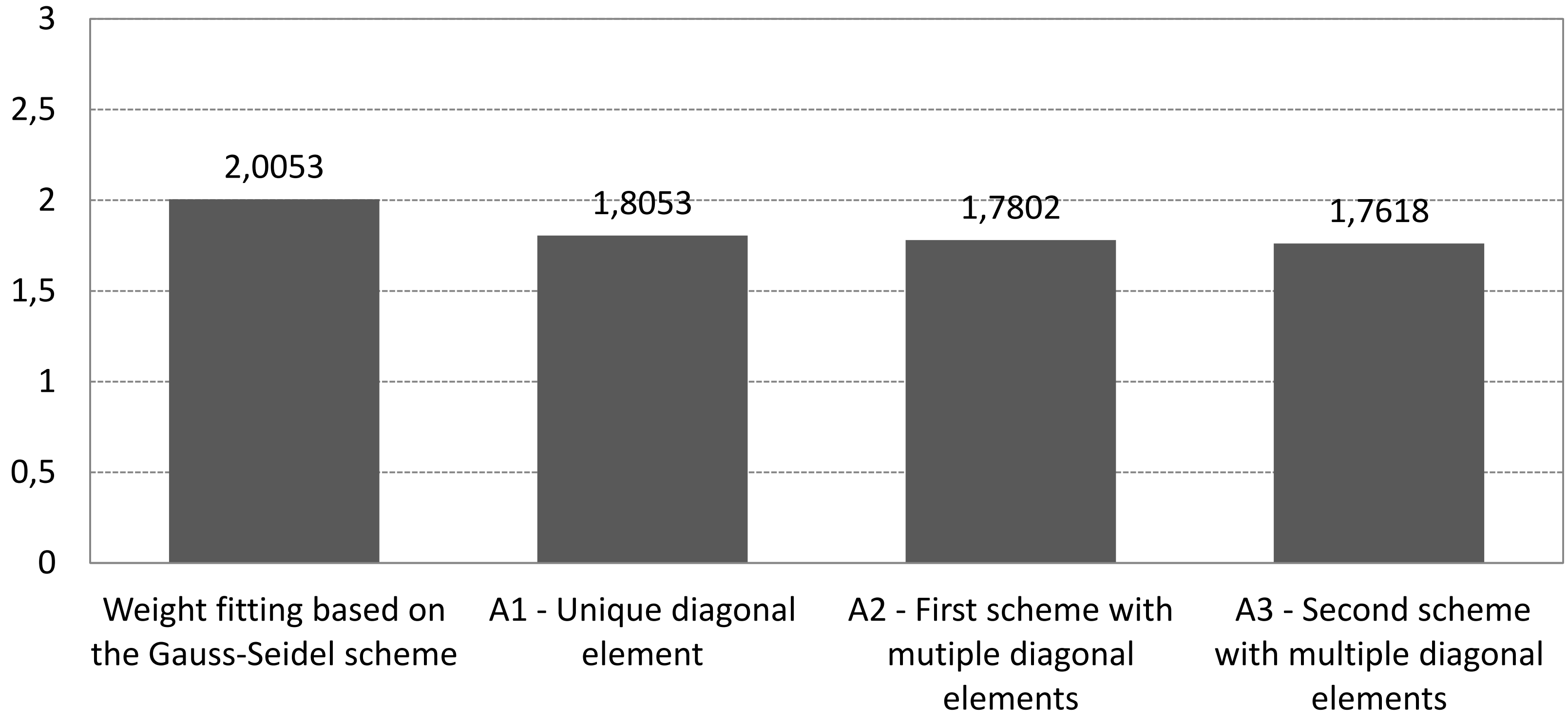
Error of processing

Cross-validation scheme.

Estimation of recognition error on the general set



Cross-validation scheme.
Comparison of general errors

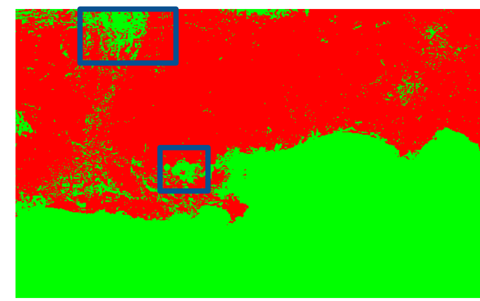


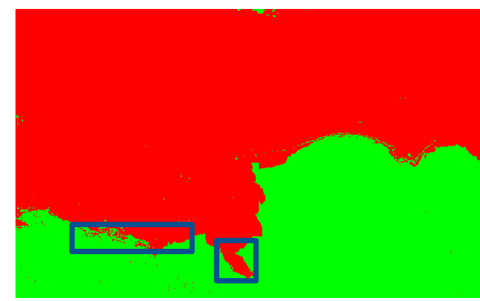
General error gained by different algorithms for adjusting parameters of combination of acyclic adjacency graphs

Real image processing. Interactive scheme of classical independent training based on the user's data

Initial image

Independent training





- Stop condition: There is no undesirable region.
- Stop condition may be unreachable if the classes contain quite alike texture regions

Real image processing. Heuristic scheme for updating a posteriori marginal distributions of hidden classes

- **Problem:**

- The graph combination efficiently removes small undesirable regions only if the distributions of classes are fuzzy

- Increase of iteration number stabilizes data, turning a posteriori marginal probabilities into zeros and ones

- **Update parameters:**

- Update coefficient: $\rho(0 < \rho < 1)$

- Update threshold: $\gamma(0 < \gamma < 1, \gamma\rho > 1/2)$

- **Update principle:**

Update a posteriori distributions of pixels for which the maximal probability is more than the update threshold $p_t^{i*} \geq \gamma$ as follows:

$$\pi_t^{i*} = \rho p_t^{i*},$$

$$\pi_t^j = p_t^j (1 - \rho p_t^{i*}) / \sum_{k=1, k \neq i^*}^{m} p_t^k, \; j = 1, \ldots, m, \; j \neq i^*.$$

Main results of the work

- **The problem** of adjusting the diagonal element of transition matrix for an acyclic model, and developing algorithms for selecting the diagonal element for a given acyclic adjacency graph **is solved**
- **The singular properties** of the basic recognition algorithm at the limiting values of the diagonal element **are proved**
- **The properties** of the previously proposed algorithm for adjusting weights in the combination of acyclic adjacency graphs **are studied**
- **The problem** of simultaneously adjusting the diagonal element of transition matrix and weights of the acyclic adjacency graphs in their linear combination **is solved**
- **The experimental study** of the developed algorithms in the problem of raster texture image segmentation **is done**
- **The evaluation of the quality** of solving the recognition problem in interrelated data arrays and the statistical properties of decision rule based on the cross-validation method **is done**