Faculty of Electrical Engineering and Computer Science
Institut für Informationsverarbeitung
Appelstraße 9a
30167 Hannover, Germany
http://www.tnt.uni-hannover.de

technicolor

Technicolor
Research & Innovation Hannover
Karl-Wiechert Allee 74
30625 Hannover
http://www.technicolor.com

Efficient Pixel-Grouping based on Dempster's Theory of Evidence for Image Segmentation

Björn Scheuermann (TNT), Markus Schlosser (Technicolor) and Bodo Rosenhahn (TNT)
{scheuermann, rosenhahn}@tnt.uni-hannover.de, markus.schlosser@technicolor.com

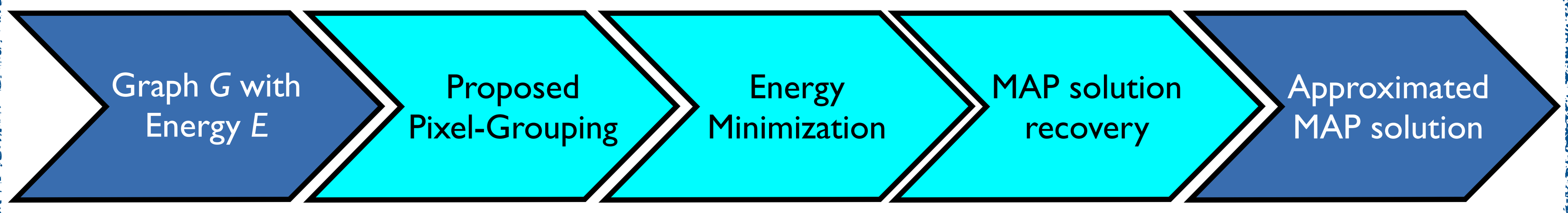
Problem statement

This paper addresses the problem of efficiently segmenting an image/image sequence by discrete energy minimization [1].

Standard approach: maximum flow algorithm
- ✗ fast for low scale benchmark images
- ✗ not applicable for large scale images or videos

Many works on how to approximate large scale problems: parallel implementations, GPU processing, convex optimization, multi-scale approaches, graph reduction

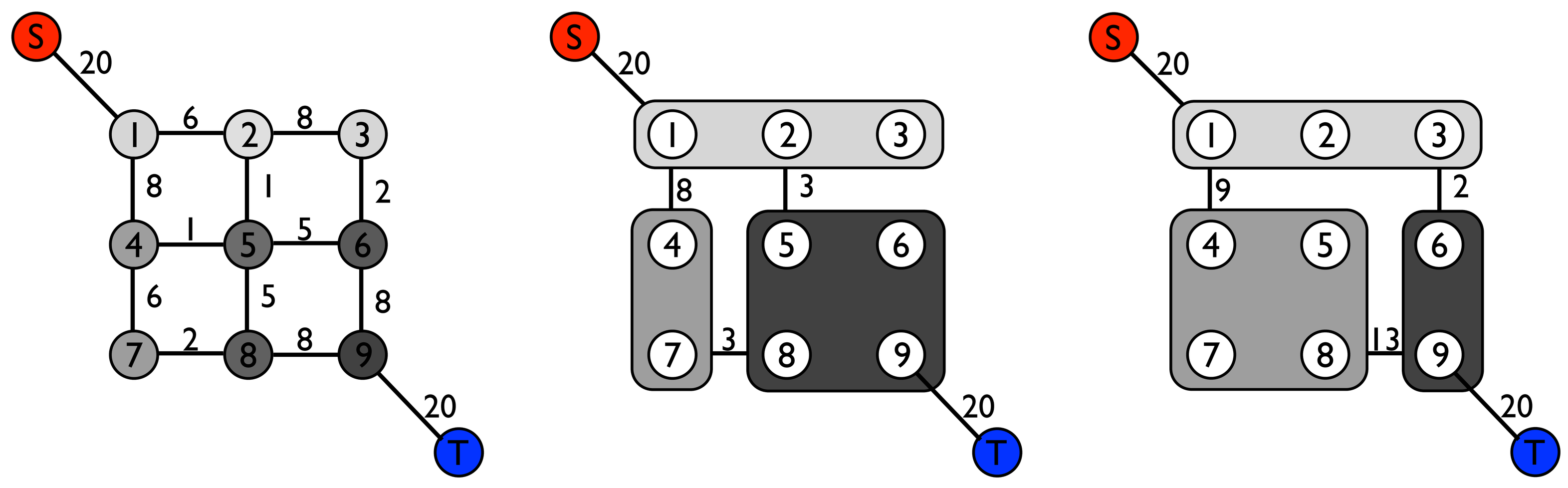
We propose a graph-based method for pixel-grouping to reduce the number of variables defining the energy to be minimized.



- ✓ reduction in computational costs and memory requirements
- ✓ almost identical segmentation results

Contribution

Original Graph $G = (\mathcal{V}, \mathcal{E})$ with Energy E of φ_i and $\varphi_{i,j}$ and and possible reduced Graphs



➡ original graph is reduced by grouping of pixels that are likely to take the same label in the minimum energy state

Our method is based on "efficient graph-based image segmentation" proposed by Felzenszwalb and Huttenlocher [2]:

$(\mathcal{V}'_\mathcal{G}, m)$ = DempsterShaferGrouping(G,φ, w)
Input:
  $G = (\mathcal{V}_\mathcal{G}, \mathcal{E}_\mathcal{G})$ // an instance of the graph
  $\varphi_i, \varphi_{i,j}$ // node and edge energies
  $w : \mathcal{E}_\mathcal{G} \rightarrow \mathbb{R}$ // dissimilarity weights
Output:
  $\mathcal{V}_\mathcal{G}'$ // set of grouped variables
  m // surjective map
Algorithm:
  $\mathcal{V}_\mathcal{G}' \leftarrow \mathcal{V}_\mathcal{G}, \mathcal{E}_\mathcal{G}' \leftarrow \mathcal{E}_\mathcal{G}$
  $m \leftarrow \{(i,i) \mid i \in \mathcal{V}_\mathcal{G}\}$
  $\pi \leftarrow$ sort$(\mathcal{E}_\mathcal{G}, w)$ {sort weights in ascending order}
  for $e = 1, \ldots, |\pi|$ **do**
    $(i,j) \leftarrow \pi_e$
    if $m(i) = m(j)$ **then**
      continue {already merged}
    end if
    if w_{ij} fulfills given constraint **then**
      merge C_i and C_j in $m, \mathcal{V}_\mathcal{G}'$
    end if
  end for

new grouping weights based on Dempster-Shafer

new merging constraint

Dempster Shafer edge weights

Idea: Fuse the terms of energy E with Dempster-Shafer

$$w_{ij}^{pairwise} = \varphi_{i,j}(x_i, x_j) \quad \text{and} \quad w_{i,j}^{unary} = ||\varphi_i - \varphi_j||$$

Resulting edge weight elegantly combines the unary and pairwise terms

$$w_{ij}^{DS} = 1 - Bel(\Omega_1) = 1 - m(\Omega_1)$$

where hypothesis $\Omega_1$means that two pixels are similar

Merging Constraint

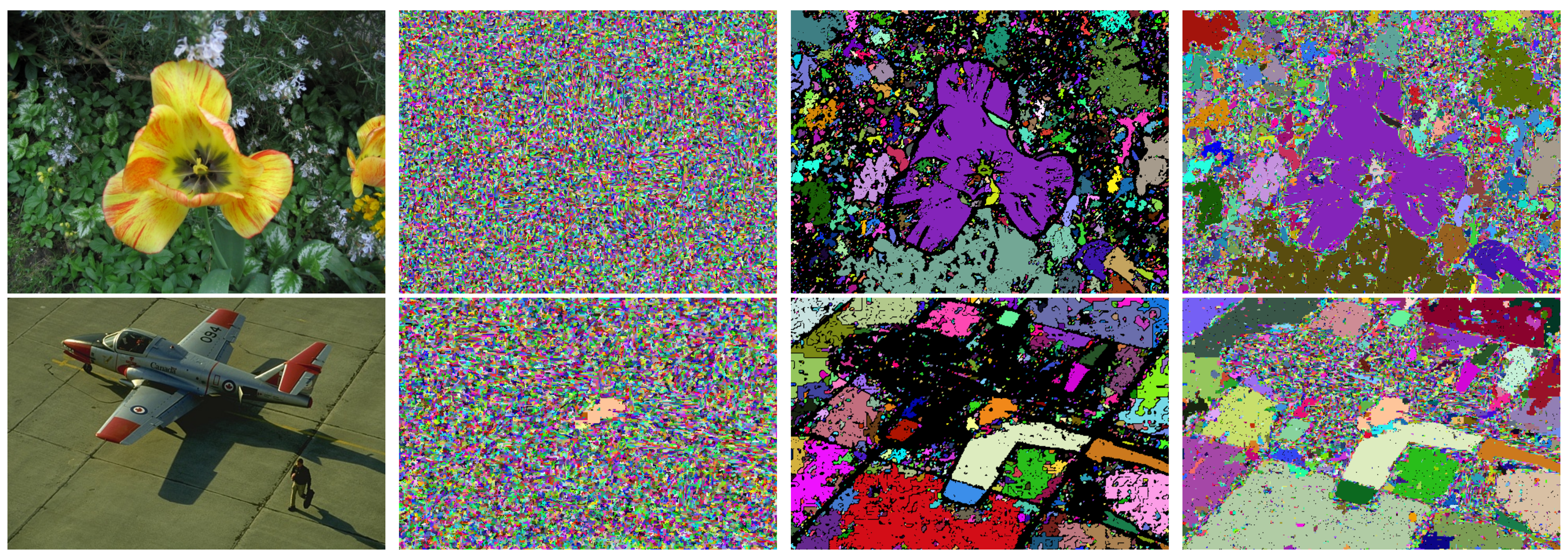
Idea: Allow large groups of pixels in homogeneous regions while maintaining small groups at object boundaries.

$$w_{max}(i,j) := max\{w_{ik}, w_{lj} \mid (i,k),(l,j) \in \mathcal{E}_\mathcal{G}\} \leq W_1 \quad \text{(MAXEDGE)}$$

Combination with [2] to allows compact groups at object boundaries

$$\text{(MAXEDGE) or } w_{ij} \leq \text{MInt}(C_i, C_j) \quad \text{(COMPACTEDGE)}$$

Quantitative results



Example for the different approaches. Columns: (i) image; (ii) grouping using [3]; (iii) proposed MAXEDGE; (iv) proposed COMPACTEDGE.

Qualitative results

Method	Avg. budget	Avg. $R_{mse}(x)$	Avg. $R_{se}(x)$
full MAP (reference)	100% (100)	0p (0)	0.075 (0.058)
FH-alg [2]	10.22% (10.22)	209.74p (209.74)	0.074 (0.063)
UNARYDIFF [3]	10.72% (10.84)	255.1p (219.08)	0.073 (0.065)
MAXEDGE	47.72% (15.21)	58.42p (4.21)	0.069 (0.058)
COMPACTEDGE	6.25 % (5.00)	321.5p (63.52)	0.061 (0.058)

- ✓ proposed method outperforms the others in terms of quality with a smaller budget

Conclusion

- ✓ grouping of homogeneous regions using Dempster-Shafer
- ✓ efficient method for graph simplification
- ✓ segmentation error comparable to the full MAP solution
- ✓ speedup of approx. 12.5 on large scale image (5% budget)
- ✓ up to 10 times faster on image sequences (5% budget)

References:

[1] Boykov, Y., Jolly, M.: Interactive graph cuts for optimal boundary & region segmentation of objects in nd images, ICCV 2001
[2] Felzenszwalb, P.F., Huttenlocher, D.P.: Efficient graph-based image segmentation, IJCV 2004
[3] Kim, T., Nowozin, S., Kohli, P., Yoo, C.D.: Variable grouping for energy minimization, CVPR 2011