Continuous Global Optimization for Image Segmentation and 3D Reconstruction

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Contributions

This work is based on the continuous global image segmentation method [1]. We present:

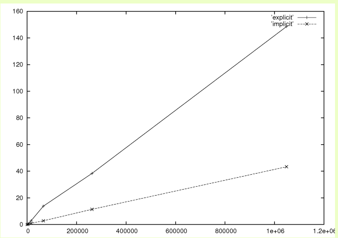
- an efficient implementation,
- a comparison to discrete optimization,
- an extension to 3D segmentation and multiview reconstruction.

Fast Minimization via SOR

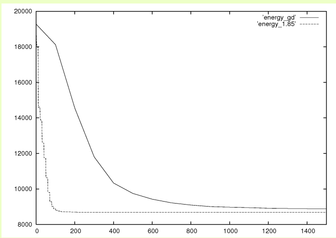
The convex Mumford-Shah based Image Segmentation functional [1]

$$E(u) = \int_\Omega \left((I-c_1)^2 - (I-c_2)^2\right) u(x)\,\mathrm{d}x + \nu \underbrace{\int_\Omega |\nabla u|\,\mathrm{d}x}_{\text{TV-Norm}}$$

can be solved via gradient descent. We suggest the more efficient solution via the iterative numerical solving scheme *Successive Overrelaxation (SOR)*. This leads to faster convergence of up to a **speed up factor of** $\sim\mathbf{5}$.



Runtime Comparison (Seconds vs. Image Size)



Convergence Comparison (Energy vs. #Iterations)

Comparison for increasing Smoothness

Graph Cuts

TV

Metrication errors occur at the discrete Optimization via Graph Cuts when the regularization parameter ν is increased. This is not the case for the TV Minimization.

Convex TV based 3D Reconstruction

The optimal Surface $S \subseteq V$ is the minimum of the energy functional [3]

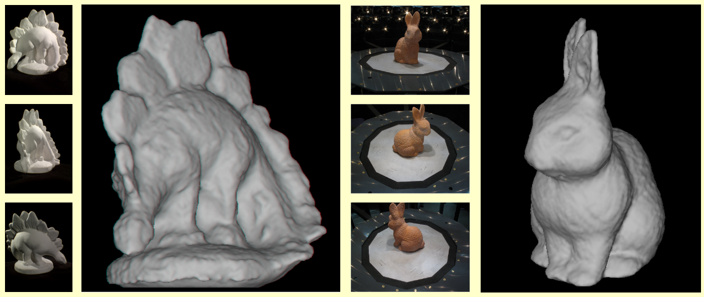
$$E(S) = -\int_{R^S_{obj}} \log P_{obj}(x)\,\mathrm{d}x - \int_{R^S_{bck}} \log P_{bck}(x)\,\mathrm{d}x + \nu \int_S \rho\,\mathrm{d}S$$

with the photoconsistency $\rho : V \to [0,1]$.
By introducing a binary variable $u : V \to \{0,1\}$ with $u = \mathbf{1}_{R^S_{obj}}$, E can be transformed into the following equivalent formulation

$$E(u) = \int_V (\log P_{obj} - \log P_{bck}) u\,\mathrm{d}x + \nu \underbrace{\int_V \rho\,|\nabla u|\,\mathrm{d}x}_{\text{weighted TV-Norm}}$$

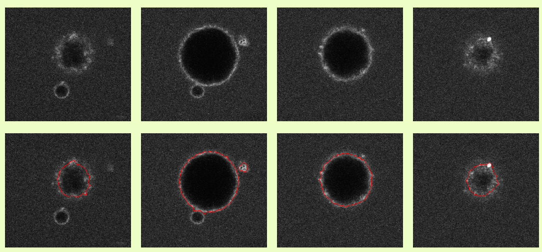
Relaxation to real-valued functions $u : V \to [0,1]$ results in a convex formulation allowing for global optimization. Thresholding the result yields the **global optimum** of the original problem.

Multiview 3D Reconstruction



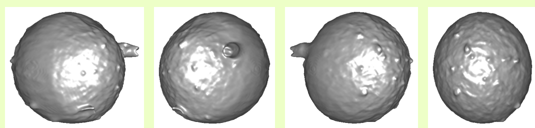
Input (3/48) | Reconstructed Object | Input (3/33) | Reconstructed Object

3D Segmentation



Slices of the 3D Input Volume.

Slices of the Reconstructed Surface (red).



Reconstruction of the Cell Surface.

(Thanks to IFF, Forschungszentrum Jülich for providing the data.)

Related Work

[1] Chan, Esedoglu, Nikolova: *Algorithms for finding Global Minimizers of Image Segmentation and Denoising Models*, SIAM J. Appl. Math. 2006.
[2] Boykov, Kolmogorov: *An experimental Comparison of Min-Cut/Max-Flow Algorithms for Energy Minimization in Vision*, EMMCVPR 2001.
[3] Kolev, Brox, Cremers: *Robust Variational Segmentation of 3D Objects from Multiple Views*, DAGM 2006.
[4] Kolev, Klodt, Brox, Esedoglu, Cremers: *Continuous Global Optimization in Multiview 3D Reconstruction*, EMMCVPR 2007.