

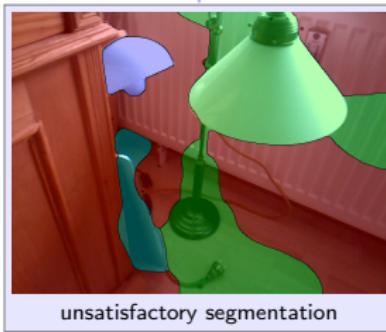
Total Variation Segmentation Incorporating Depth Information

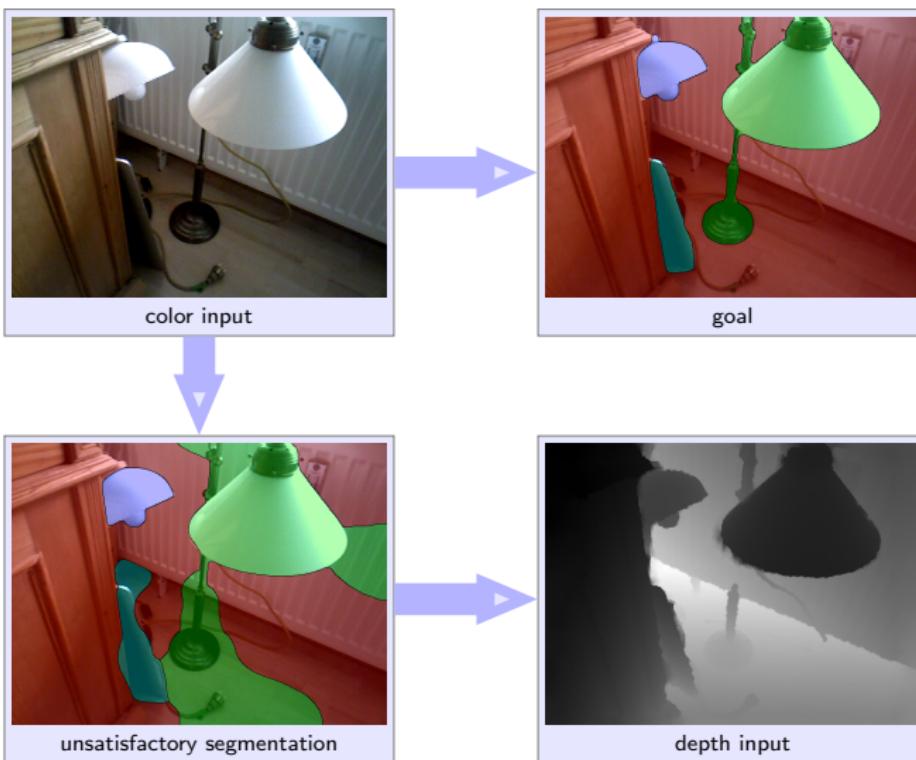
Nikolaus Demmel

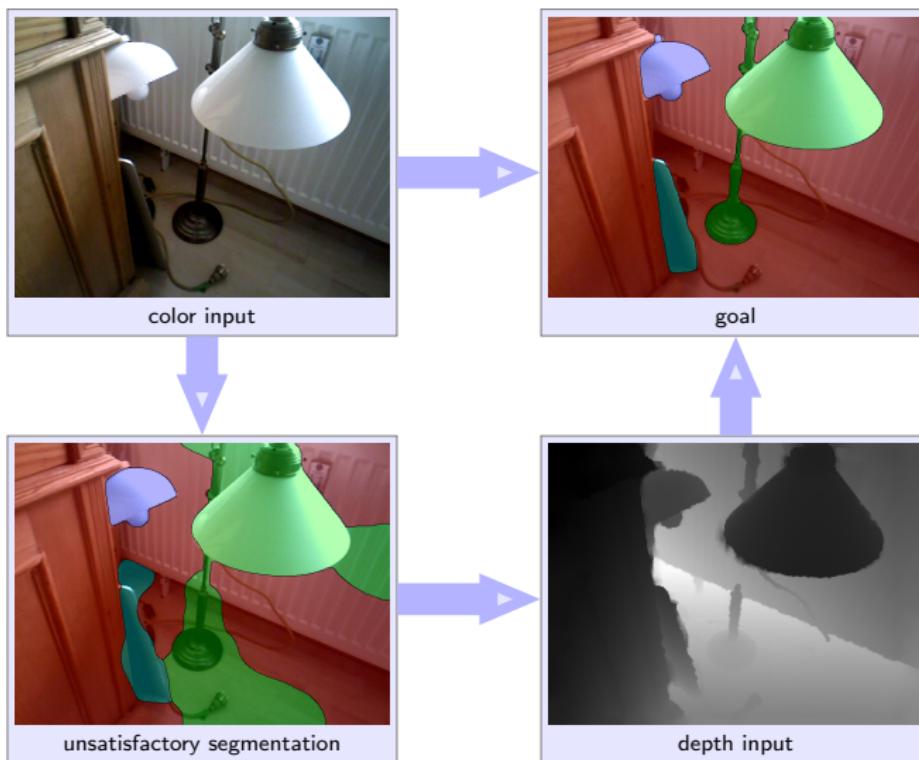
Technische Universität München

September 26, 2014









Variational multi-label segmentation

$$\mathcal{E}(\Omega_1, \dots, \Omega_n) = \underbrace{\sum_{i=1}^n \int_{\Omega_i} f_i(x) dx}_{\text{n = 4 regions}} + \lambda \underbrace{\frac{1}{2} \sum_{i=1}^n \text{Per}_g(\Omega_i)}_{\text{dataterm}} + \underbrace{\lambda \sum_{i=1}^n \text{Per}_g(\Omega_i)}_{\text{regularizer}}$$



segmentation

Variational multi-label segmentation

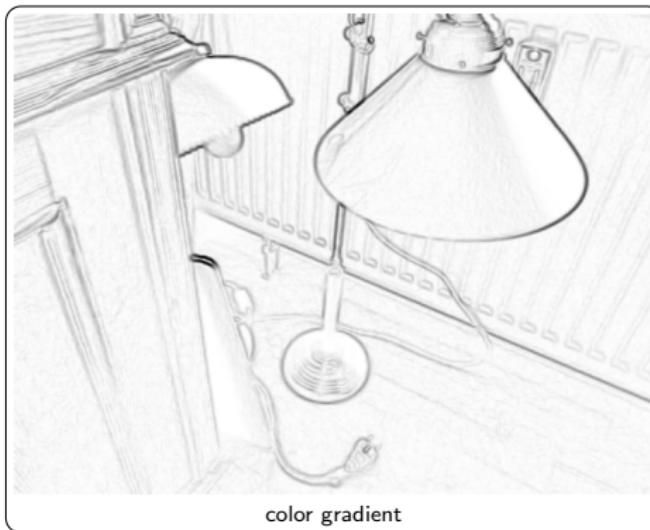
$$\mathcal{E}(\Omega_1, \dots, \Omega_n) = \sum_{i=1}^n \int_{\Omega_i} f_i(x) dx + \lambda \frac{1}{2} \sum_{i=1}^n \text{Per}_g(\Omega_i)$$



segmentation

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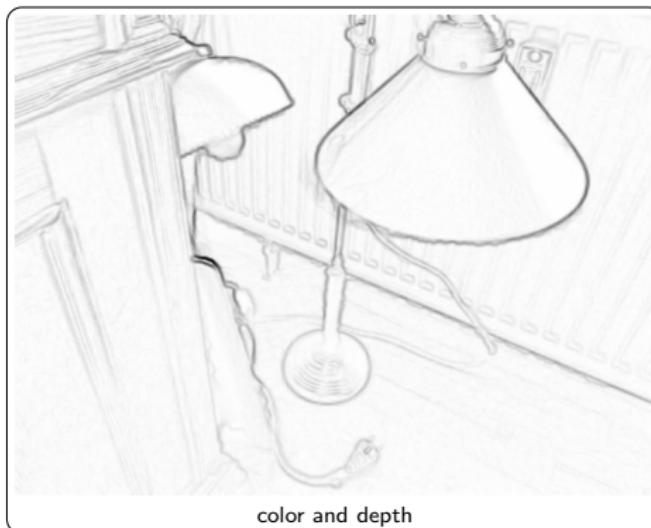
Variational multi-label segmentation

$$\mathcal{E}(\Omega_1, \dots, \Omega_n) = \sum_{i=1}^n \int_{\Omega_i} f_i(x) dx + \lambda \frac{1}{2} \sum_{i=1}^n \text{Per}_{\text{g}}(\Omega_i)$$



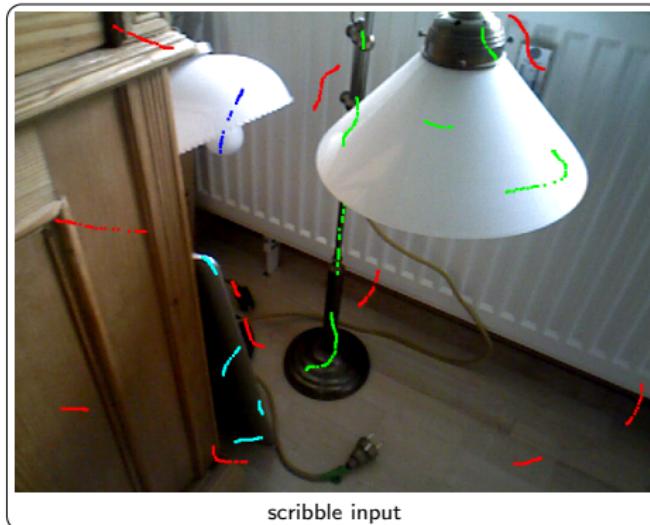
Variational multi-label segmentation

$$\mathcal{E}(\Omega_1, \dots, \Omega_n) = \sum_{i=1}^n \int_{\Omega_i} f_i(x) dx + \lambda \frac{1}{2} \sum_{i=1}^n \text{Per}_{\text{g}}(\Omega_i)$$



Variational multi-label segmentation

$$\mathcal{E}(\Omega_1, \dots, \Omega_n) = \sum_{i=1}^n \int_{\Omega_i} f_i(x) dx + \lambda \frac{1}{2} \sum_{i=1}^n \text{Per}_g(\Omega_i)$$



Spatially Varying Color Distributions

$$f_i(x) = -\log(\mathcal{P}(I(x), x \mid u(x) = i))$$

Spatially Varying Color Distributions

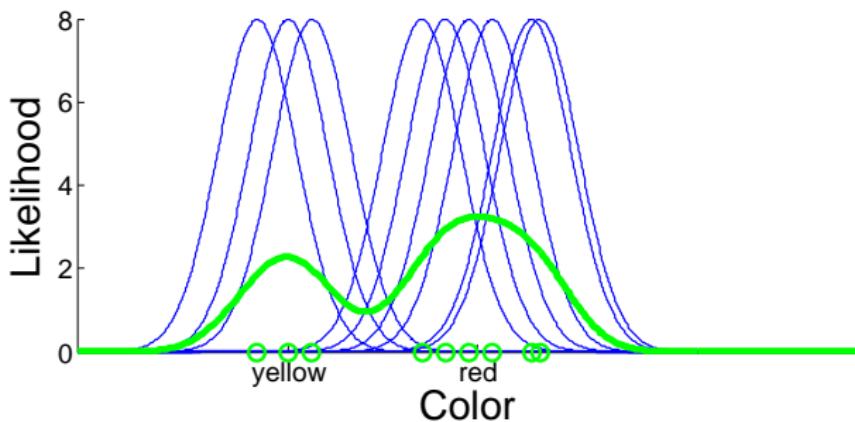
$$f_i(x) = -\log(\mathcal{P}(I(x), x \mid u(x) = i))$$

$$\mathcal{P}(I(x), x \mid u(x) = i) = \frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}}$$

Spatially Varying Color Distributions

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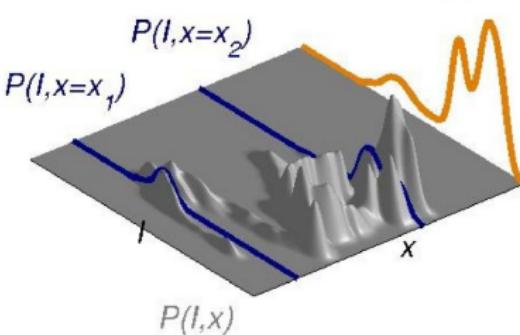
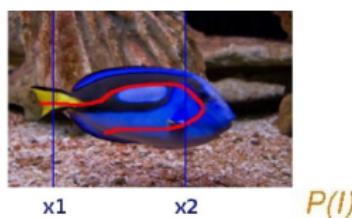
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Extension A — Depth Kernel

$$\frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}}$$



color input



color segmentation

Extension A — Depth Kernel

$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}} \underbrace{k_{\tau}(D - D_{ij})}_{\text{depth kernel}}$$



color input



depth input



color segmentation



depth segmentation

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$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) \underbrace{k_\sigma(I - I_{ij})}_{\text{color kernel}} \underbrace{k_\tau(D - D_{ij})}_{\text{depth kernel}}$$



color input



depth input



color segmentation



depth segmentation



combined segmentation

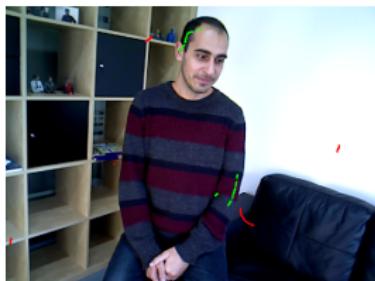
Extension A — Depth Kernel Bandwidth

$$\frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}} \underbrace{k_{\tau}(D - D_{ij})}_{\text{depth kernel}}$$

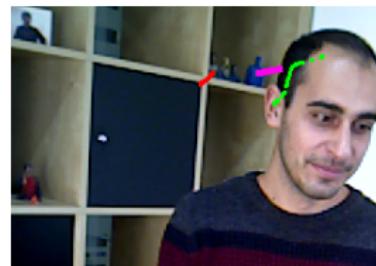
depth segmentation ($\tau = 0.5$)depth segmentation ($\tau = 0.2$)depth segmentation ($\tau = 0.05$)depth segmentation ($\tau = 0.01$)

Extension B — 3D Distance

$$\frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}}$$



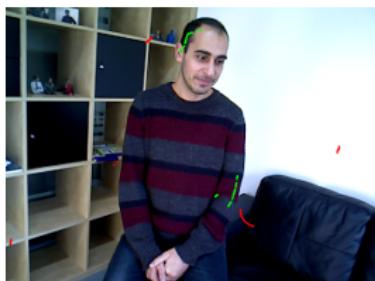
input with scribbles



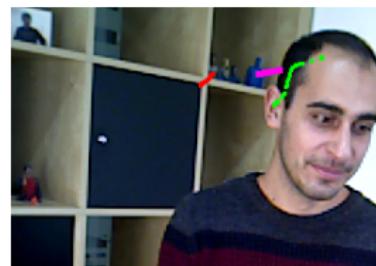
2d distance

Extension B — 3D Distance

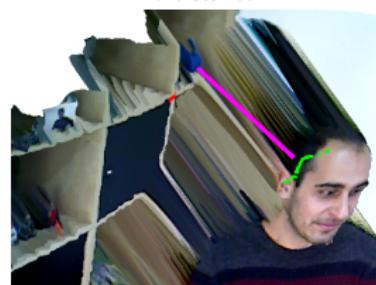
$$\frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}}$$



input with scribbles



2d distance

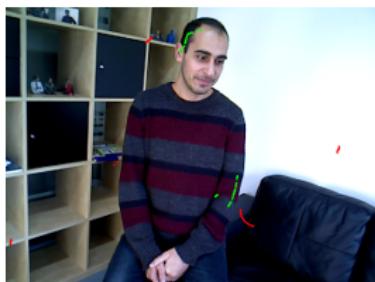


3d distance

back-projection

Extension B — 3D Distance

$$\frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}}$$



input with scribbles



2d distance



3d distance

Extension A and B — 3D Distance and Depth Kernel

$$\frac{1}{m_i} \sum_{j=1}^{m_i} \underbrace{k_{\rho_i}(x - x_{ij})}_{\text{distance kernel}} \underbrace{k_{\sigma}(I - I_{ij})}_{\text{color kernel}} \underbrace{k_{\tau}(D - D_{ij})}_{\text{depth kernel}}$$



2d distance, depth and color



3d distance, color



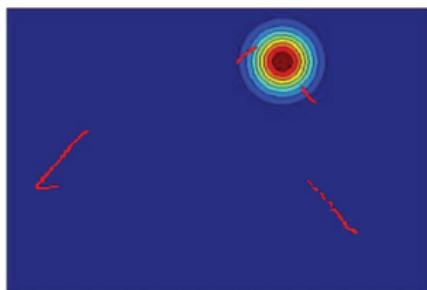
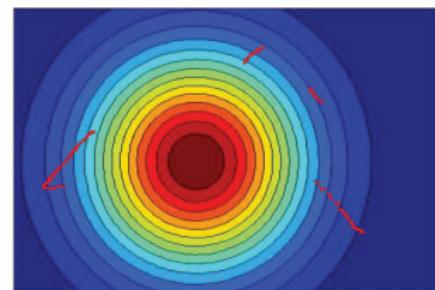
3d distance, depth and color

Extension C — Active Scribbles

$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) k_{\sigma}(I - I_{ij}) k_{\tau}(D - D_{ij})$$

distance kernel color kernel depth kernel

$\rho_i(x) = \alpha |x - x_{v_i}|_2$

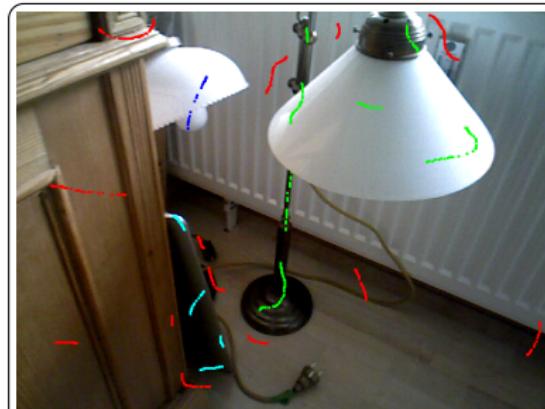
closest scribble v_i is nearclosest scribble v_i is far

Extension C — Active Scribbles

$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) k_{\sigma}(I - I_{ij}) k_{\tau}(D - D_{ij})$$

distance kernel color kernel depth kernel

$$\rho_i(x) = \alpha |x - x_{v_i}|_2$$



color input



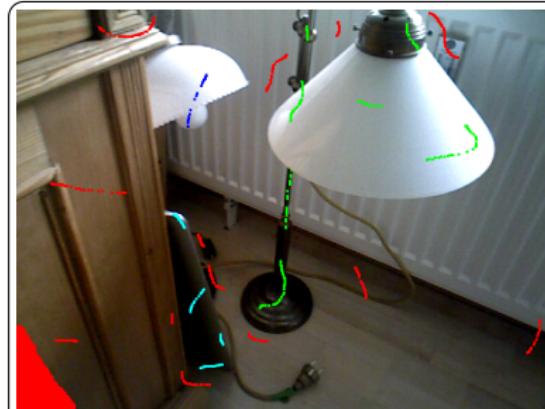
segmentation

Extension C — Active Scribbles

$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) k_{\sigma}(I - I_{ij}) k_{\tau}(D - D_{ij})$$

distance kernel color kernel depth kernel

$$\rho_i(x) = \alpha |x - x_{v_i}|_2$$



color input



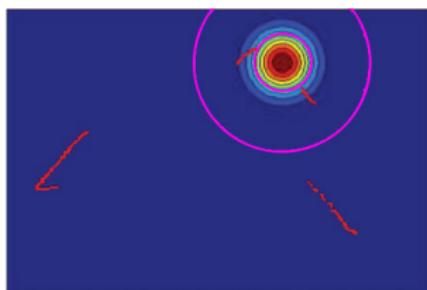
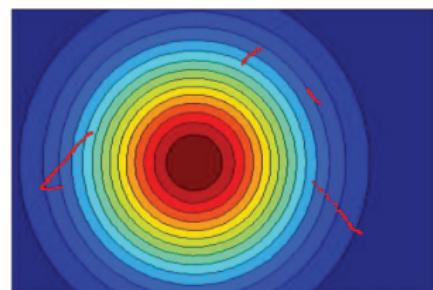
segmentation

Extension C — Active Scribbles

$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) k_{\sigma}(I - I_{ij}) k_{\tau}(D - D_{ij})$$

distance kernel color kernel depth kernel

$\rho_i(x) = \alpha |x - x_{v_i}|_2$

active scribbles within $3 |x - xv_i|$ 

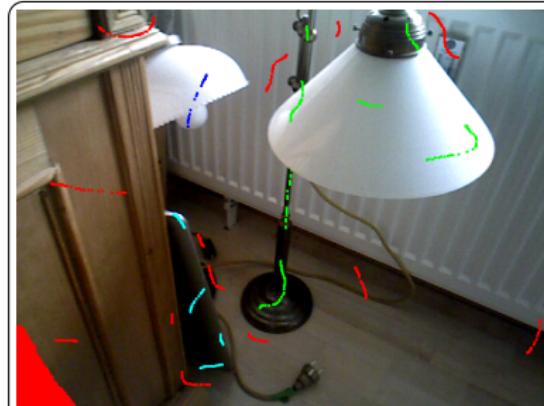
all scribbles active

Extension C — Active Scribbles

$$\frac{1}{m_i} \sum_{j=1}^{m_i} k_{\rho_i}(x - x_{ij}) k_{\sigma}(I - I_{ij}) k_{\tau}(D - D_{ij})$$

distance kernel color kernel depth kernel

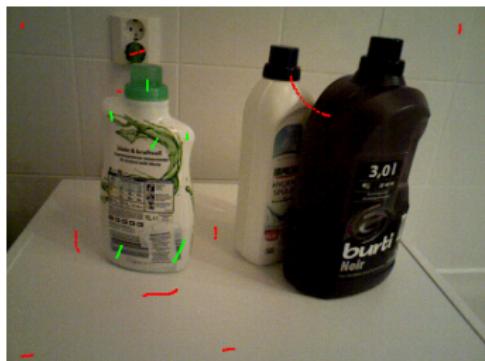
$$\rho_i(x) = \alpha |x - x_{v_i}|_2$$



color input



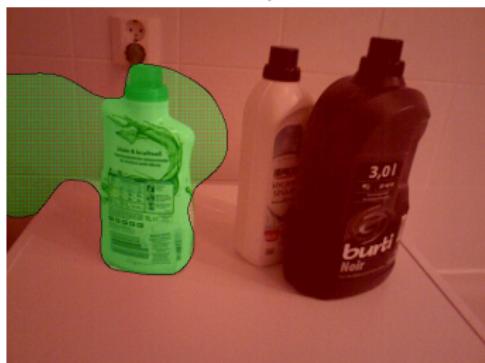
segmentation with active scribbles



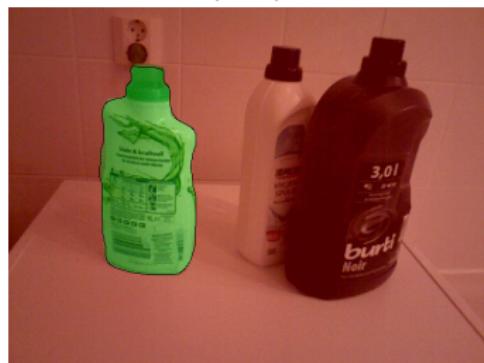
color input



depth input



no depth



our result



color input



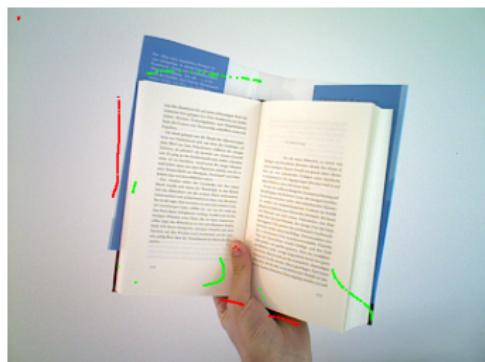
depth input



no depth



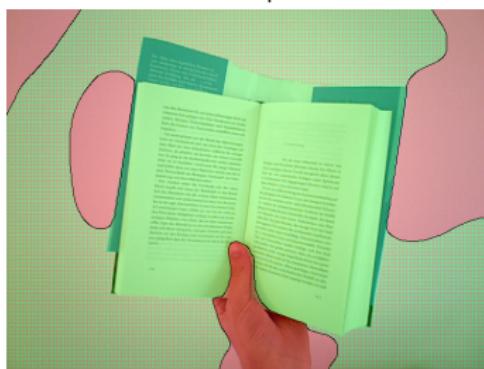
our result



color input



depth input

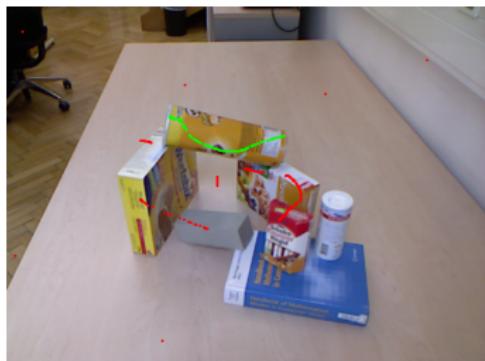


no depth



our result

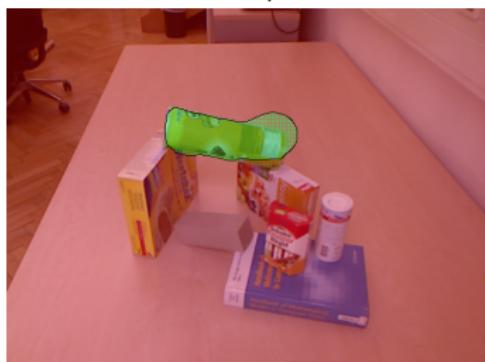
Examples



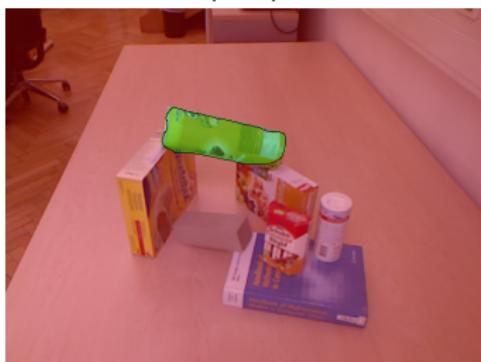
color input



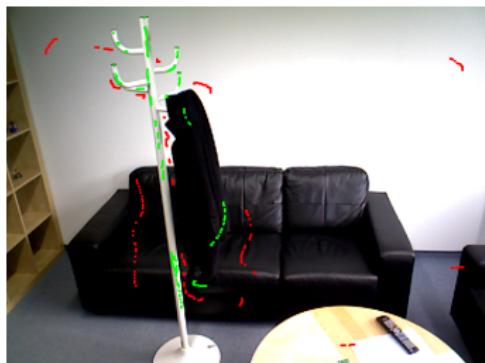
depth input



no depth



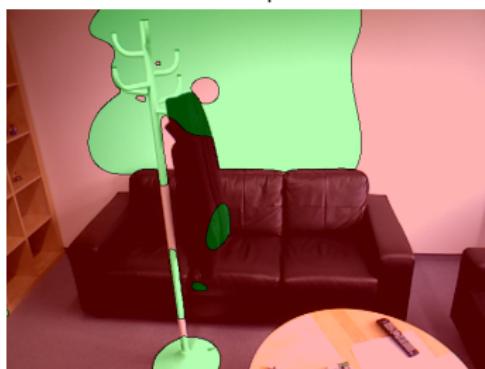
our result



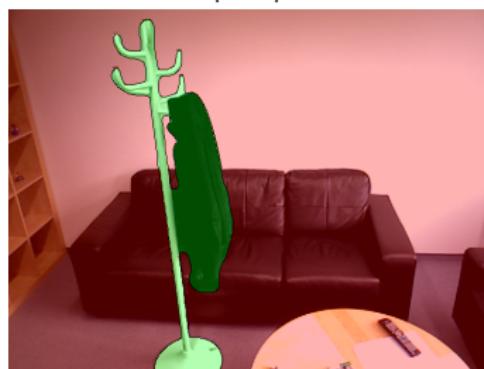
color input



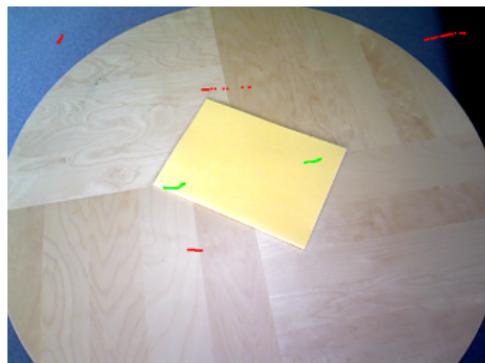
depth input



no depth



our result



color input



depth input



no depth



our result



color input



depth input



no depth



our result



our result, no depth kernel



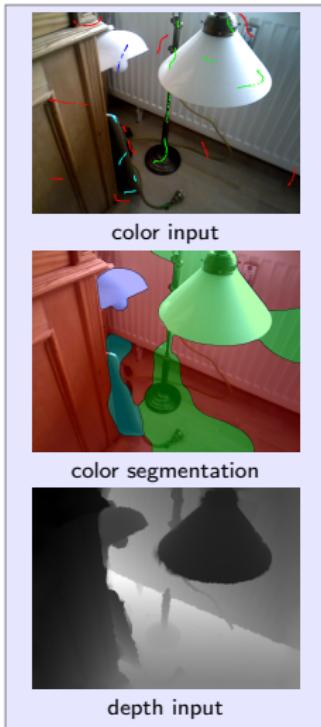
our result, no active scribbles

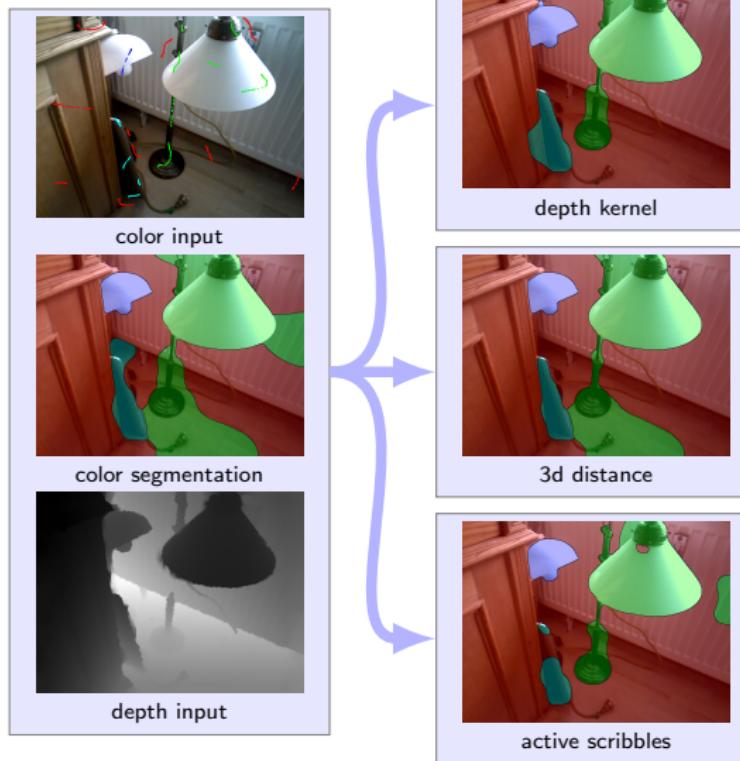


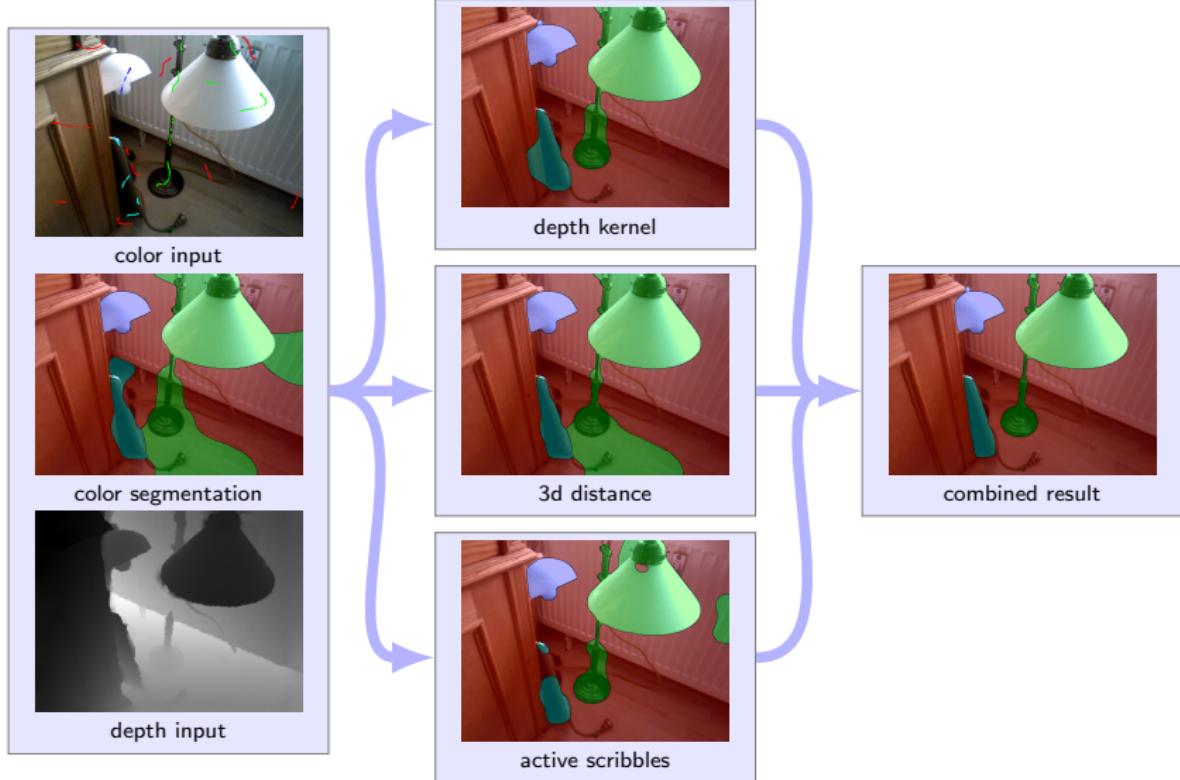
our result, not spatially varying



our result, no color







- quantitative evaluation (how to compare? accuracy, number of scribbles, user interaction time, ...)

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- other improvements of spatially-varying color distributions
 - other color spaces (including OLDA)
 - texture kernel
 - shape priors
 - automatic kernel bandwidth estimation

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- geometry, connectivity
- other input (bounding boxes, ...)

Demo

