Edge-Preserving Image Decomposition Based on Guided Upper/Lower Envelopes

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Outlines

- **Motivations**
- **Our method**
  - **Guided Envelopes Construction**
  - **Edge-Preserving Image Decomposition**
- **Experimental Results**
  - **High-Dynamic-Range Rendering**
  - **Image Abstraction/Stylization**
- **Conclusions**

Motivations

- **Image decomposition can offer many applications in the related field, such as computer vision, computer graphics, image processing and computational photography.**

- **We propose a systematic method for IC Design and increase more functions for digital cameras and displays.**

Our Method

- **In our work, we first pursuit a guided upper envelope using a quadratic function with the constrained around strong edges.**
- **Second, we reverse the original image and apply the previous process to have the guided lower envelope.**
- **Third, we obtain the base layer and the corresponding detail layer.**
- **Plenty of applications bloom.**

Guided Upper Envelope Estimator

- **We transfer the original R,G,B signals to H,S,V color space and only enhance on V-Channel, that is,** $I(x,y)$**.**
- **We deduce the upper envelope** $U(x,y)$ **using the quadratic cost function:**

$$F(U(x,y)) = \int_{\Omega} (\|\nabla U(x,y)\|^2 + \alpha \|U(x,y) - I(x,y)\|^2) dxdy$$

where ∇ **is the first-order differential operation.**

- **The prior term prefers a smooth result while the data term forces** $I(x,y)$ **close to** $U(x,y)$**.**

Guided Upper Envelope Estimator

- **To solve the quadratic cost function, we adopt the gradient-descent algorithm:**

$$U_j(x,y) = U_{j-1}(x,y) - \beta \cdot G_F(x,y)$$

- $U_j(x,y)$ **and** $U_{j-1}(x,y)$ **are the signals of upper envelop at step j and (j-1), respectively.**
- β **is the linear-search step size**
- $G_F(x,y)$ **can be regarded as the gradient of** $F(U(x,y))$

Guided Upper Envelope Estimator

- **Similar to Kimmel et al.'s work, we can have**

$$G_F(x,y) = \frac{\partial F(U)}{\partial U}$$

$$= -\Delta U(x,y) + \alpha \cdot (U(x,y) - I(x,y))$$

$$\approx -U(x,y) * K_{lap}(x,y) + \alpha \cdot (U(x,y) - I(x,y))$$

  - Δ **is the second-order Laplacian differential operator and can be approximated to a spatial filter**

$$K_{lap} = \begin{pmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

Guided Upper Envelope Estimator

- **In each step, we constrain the behavior around edges and obtain the guided upper envelope:**

$$U_j(x,y) \leftarrow \max\{w(x,y)\cdot I(x,y) + (1-w(x,y))\cdot U_j(x,y), I(x,y)\}$$

  - $w(x,y)$ **is our gradient-guided weighting function:**

    $w(x,y) = w_0$ **,if** $\nabla I(x,y) \geq TH$**;** $w(x,y) = 0$ **, otherwise**

    $$\nabla I(x,y) \approx \|I(x,y) * D_x(x,y)\| + \|I(x,y) * D_y(x,y)\|$$

    where $D_x(x,y)$ **and** $D_y(x,y)$ **are first derivative of Gaussian(FDOG) in x- and y- direction.**

- **Finally, the upper envelope converges:** $U_\infty(x,y)$

Guided Lower Envelope Estimator

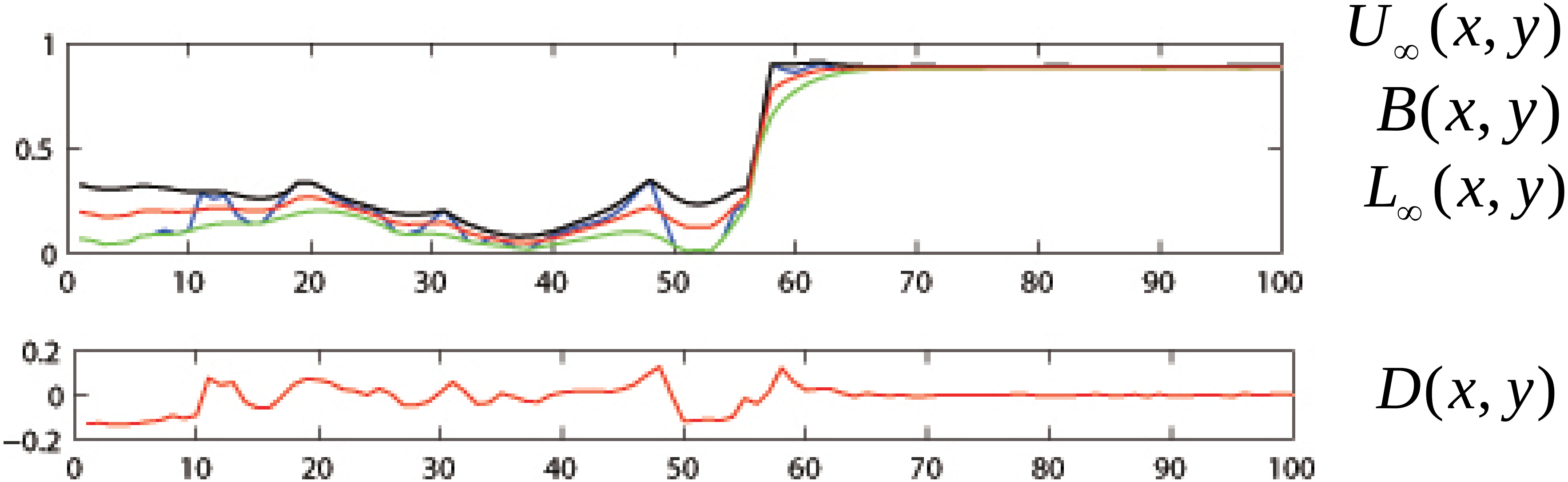
- **For lower envelope estimator, we adopt the same upper envelope estimator by substituting**
  $I(x,y)$ **by its reverse signal:** $\tilde{I}(x,y) = W - I(x,y)$
  where W **is 255 for 8-bit image.**
- **Using the same upper envelope estimator:**

$$F(\tilde{U}(x,y)) = \int_{\Omega} (\left\|\nabla \tilde{U}(x,y)\right\|^2 + \alpha \left\|\tilde{U}(x,y) - \tilde{I}(x,y)\right\|^2) dxdy$$

- **Having the final convergent signal:** $\tilde{U}_{\infty}(x,y)$
- **We can obtain the final lower envelope:**

$$L_{\infty}(x,y) = W - \tilde{U}_{\infty}(x,y)$$

Edge-Preserving Image Decomposition



- **Since we have upper envelope** $U_\infty(x,y)$ **and lower envelope** $L_\infty(x,y)$ **, we can easily obtain the base layer** $B(x,y)$ **and the detail layer** $D(x,y)$ **:**

$$B(x,y) = \frac{1}{2}(U_\infty(x,y) + L_\infty(x,y))$$

$$D(x,y) = I(x,y) - B(x,y)$$

Experimental Results

- **High Dynamic Range Rendering**
  - **We enhance the base layer using gamma correction and enhance detail layer using a JND-profile:**

$$JND(x,y) = \mu + \sigma \cdot (B(x,y) * M(x,y))$$

$$M = \frac{1}{32}\begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 2 & 2 & 2 & 1 \\ 1 & 2 & 0 & 2 & 1 \\ 1 & 2 & 2 & 2 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

μ **=4**

σ **=0.123**

$M(x,y)$ **is related to its surrounding.**

Experimental Results

- **Enhance the base layer and detail layer:**

$$B_{EN}(x,y) = W \cdot \left(\frac{B(x,y)}{W}\right)^{1/\gamma}$$

$$D_{EN}(x,y) = D(x,y) \cdot \left(\frac{W + JND(x,y)}{W}\right)^{\tau(x,y)}$$

W **=255**

$\tau(x,y)$ **could be uniform or spatially-varying. Besides, we can introduce saliency into** $\tau(x,y)$ **.**

- **Merge the enhanced signals:**

$$I_{EN}(x,y) = B_{EN}(x,y) + D_{EN}(x,y)$$

Experimental Results

Original

Tomasi et al.

Farbman et al.

He et al.

Our Base Layer

Our Enhancement

Experimental Results

Original

Kimmel et al.(IJCV04)

Meylan et al. (TIP06)

Ours

Experimental Results

Original

Kimmel et al.(IJCV04)

Meylan et al. (TIP06)

Ours

Experimental Results

Original

Jobson et al.(TIP97)

Meylan et al. (TIP06)

Ours

Experimental Results

- **Image Abstraction/Stylization**
  - **We only adopt the base layer and remove the detail layer**
  - **We can enhance the strong edges into different styles**

Experimental Results

Original **Winnemolle et al.(SIGGRAPH06)**

Experimental Results

Farbman et al. (SIGGRAPH08)

Ours

Experimental Results

Original

Ours

Conclusions and Future Works

- **Guided Upper/Lower Envelopes**
- **Edge-Preserving Image Decomposition**
- **Base/Detail layers**
- **High Dynamic Range Rendering**
- **Image Stylization**

- **Future work**
  - **Backlight of Displays**