Semantic Filtering

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Content

Q: What is the aim of edge-preserving filters?

- Image smoothing
- Removing low-contrast details
- Maintaining strong edges and structures
- Computational feasibility

Q: What are the downsides of traditional and recent filtering techniques?

- User selected scale parameter to control texture smoothing
  - Scale-variant
- Not learning-based
  - ML based methods can help scale-invariance
- Computational Cost
  - RegCov (614 sec/Mp), TV(35 sec/Mp)
- Reliance on Image Gradients
  - No separation of meaningful structures from textures

Abstract

This paper proposes a **learning-based, scale-aware, edge-preserving filtering technique** :

- Smoothing without blurring the edges.
- Low computational cost, even real-time performance in certain cases.
- Efficient extraction of subjectively-meaningful structures from natural scenes containing multiple-scale objects.
- Preservation of edges between different-size objects/structures.

Abstract (cont.)

Main Structure of the proposed technique is a combination of

- DTF based Recursive Filter [1]
- Advanced edge detector [2]

[1] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011

[2] P. Dollar and C. L. Zitnick. Fast edge detection using structured forests. PAMI, 2015.

[2] P. Dollar and C. L. Zitnick. Fast edge detection using structured forests. PAMI, 2015.

Introduction

Edge-preserving filtering is an image smoothing technique that removes low-contrast details/textures while maintaining sharp edges/image structures.

Usage a specific filter kernel to measure the distance between two pixels in a local region.

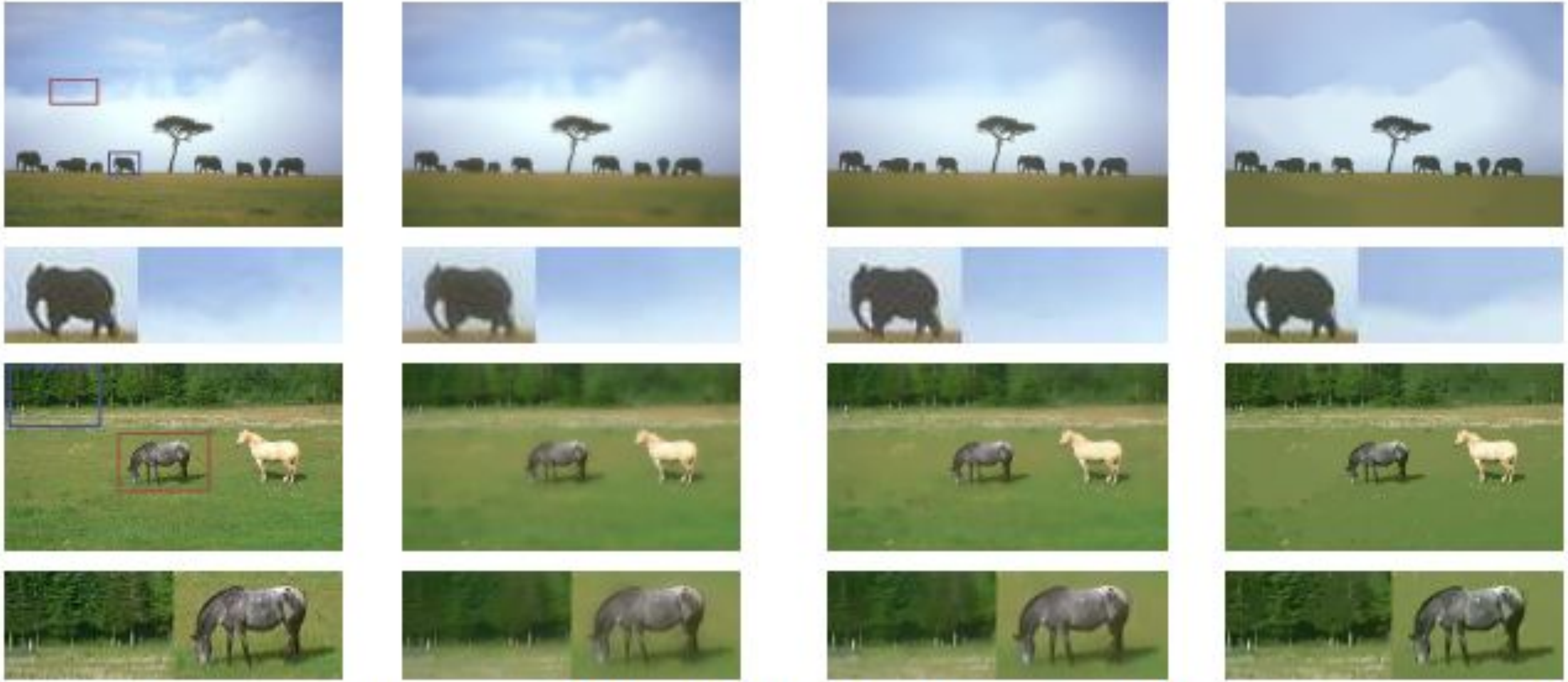
- The distance measurement is then converted to the confidence of an edge between the two pixels for edge-aware filtering.
- Very sensitive to noise/textures.

Introduction

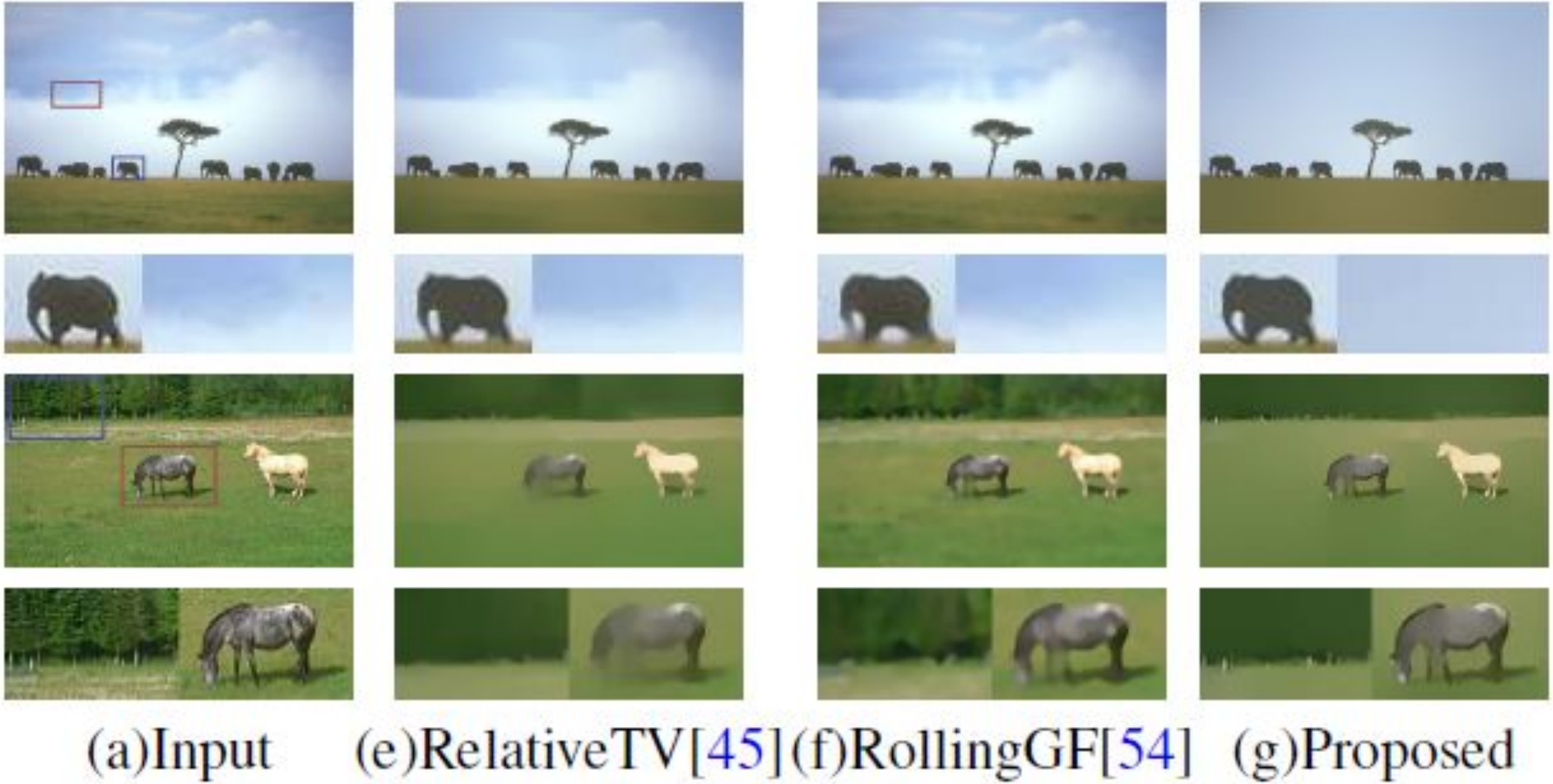
- What types of distance measurement have we seen so far?
    - Range distance, Intensity/Color distance
    - Vectoral distance between representations of two regions
    - Euclidean distance as combination of spatial and gray-level
    - Signal-induced distance (Rieman metric)
    - Mahalanobis distance
    - KL divergence as the statistical distance between two MV Gaussian

Examples

- P. Perona and J. Malik. Scale-space and edge detection using **anisotropic diffusion**. PAMI, 12:629–639, 1990.
- C. Tomasi and R. Manduchi. **Bilateral filtering** for gray and color images. In ICCV, pages 839–846, 1998.
- E. Gastal and M. Oliveira. **Domain transform** for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.
- L. Xu, C. Lu, Y. Xu, and J. Jia. Image **smoothing via l0** gradient minimization. ACM Transactions on Graphics (SIG-GRAPH Asia), 2011.
- L. Xu, Q. Yan, Y. Xia, and J. Jia. Structure extraction from **texture via natural variation** measure. ACM Transactions on Graphics (SIGGRAPH Asia), 2012.
- K. He, J. Sun, and X. Tang. **Guided image filtering**. PAMI,35:1397–1409, 2013.
- Q. Zhang, X. Shen, L. Xu, and J. Jia. **Rolling guidance filter**. In ECCV, 2014.



(a)Input (b)GuidedFilter[23] (c)D.T. Filter[20] (d)L0smooth[44]


(a)Input
(e)RelativeTV[45]
(f)RollingGF[54]
(g)Proposed

Introduction (cont.)

The main challenge in this category is accurately including scale measurement for filter design to distinguish textures/noise from image structure.

Learning-based edge-preserving image filter:

- build a model based on example inputs.
- use it to generate predictions or decisions.

Introduction (cont.)

For fast scale-aware edge-preserving filtering, this paper proposes a simple seamless combination of

- the recursive filtering technique
- the learning-based edge classification technique

Related Work

1. Edge preserving filtering:

Bilateral filters[1], joint bilateral filters[2], anisotropic[3] diffusion filters and DFT[4]

1 C. Tomasi and R. Manduchi. Bilateral filtering for gray and color images. In ICCV, pages 839–846, 1998.
2. G. Petschnigg, R. Szeliski, M. Agrawala, M. Cohen, H. Hoppe, and K. Toyama. Digital photography with flash and no-flash image pairs. Siggraph, 23(3):664–672, 2004.
3. P. Perona and J. Malik. Scale-space and edge detection using anisotropic diffusion. PAMI, 12:629–639, 1990.
4. E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.

Related Work

2. Structure-Preserving Filtering:

Total variation[1] (L1 norm), RegCov[2] (2nd order statistics), Rolling guidance[3] filters.

[1] L. I. Rudin, S. Osher, and E. Fatemi. Nonlinear total variation based noise removal algorithms. Phys. D, 60(1-4):259–268, 1992
[2] L. Karacan, E. Erdem, and A. Erdem. Structure-preserving image smoothing via region covariances. ToG, 32(6):176:1–176:11, 2013.
[3] Q. Zhang, X. Shen, L. Xu, and J. Jia. Rolling guidance filter. In ECCV, 2014.

Related Work

3. Edge Detectors:

Sobel[1], Canny[2], Deep neural networks based[3], Fast Edge Detectors using structured trees[4]

[1] R. O. Duda and P. E. Hart. Pattern Classification and Scene Analysis. New York: Wiley, 1973.
[2] J. Canny. A computational approach to edge detection. PAMI, 1986.
[3] J. J. Kivinen, C. K. Williams, and N. Heess. Visual boundary prediction: A deep neural prediction network and quality dissection. In AISTATS, 2014.
[4] P. Dollar and C. L. Zitnick. Fast edge detection using structured forests. PAMI, 2015.

Proposed Filter

Proposed filter is composed of three main approaches

1. Anisotropic Filtering: Based on DTF
2. Structure-Preserving Anisotropic Filtering: Use edge confidence to adjust distance measurement
3. Suppress small-scale textures around edges

Proposed Filter

Proposed filter is composed of three main approaches

1. **Anisotropic Filtering:** Proposed filter is based on DTF [1]

- DTF is a transformation that maintains the edge-preserving property of the filter
- DTF preserves geodesic distance between points on the curves
- Warping input signal for efficient performance of 1D edge-preserving in linear time
  - Use of 1D-filtering speeds-up the process and saves memory
  - Computational cost is independent of the choice of filter parameters
  - Works on arbitrary scales in real time without subsampling

[1] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.

Proposed Filter

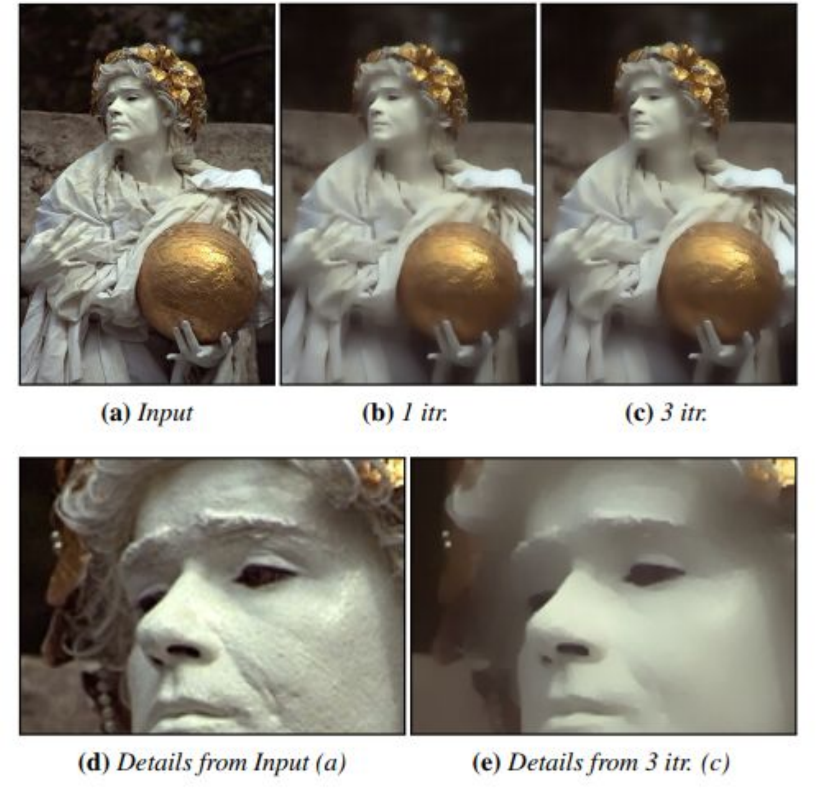
Proposed filter is composed of three main approaches

1. **Anisotropic Filtering:** Proposed filter is based on DTF [1]

- DTF : 3 realizations for 1D edge-preserving filters
  - Normalized convolution
  - Interpolated convolution
  - Recursion
- DTF: For 2D, iterate 1D operation along each dimension separately

[1] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.

Domain Transform Filter



Two-pass 1D filtering (σH = σs = 40 and σr = 0.77).
(a) Input image.
(b) One filtering iteration.
(c) Three filtering iterations.
(d) Details from (a).
(e) Details from (c).
The image content has been smoothed while its edges have been preserved.

Proposed Filter (cont.)

Domain Transform Filter [1]

$$t_i = x_0 + \sum_{j=1}^{i} (1 + |x_j - x_{j-1}|).$$

transformed signal

[1] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.

Proposed Filter

Proposed filter is composed of three main approaches

1. **Anisotropic Filtering:** Proposed filter is based on DTF [1]

Anisotropic filter is modeled using partial differential equations (PDEs) and implemented as an iterative process

- Fast and real time operation
- Distance-preserving transformation.
- Distance measurement in DTF adjusted using edge confidence computed from an edge classifier
- the proposed filter need to repeat iteratively until converge.

[1] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.

Proposed Filter (cont.)

Domain Transform Filter [1]

$$t_i = x_0 + \sum_{j=1}^{i} \left(1 + \frac{\sigma_s}{\sigma_r} |x_j - x_{j-1}|\right).$$

transformed signal — 1D input signal

σ_s size of the spatial neighborhood used to filter a pixel

σ_r how much an adjacent pixel is down-weighted because of the color difference

[1] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1−69:12, 2011.

Proposed Filter

Proposed filter is composed of three main approaches

1. Anisotropic Filtering: Based on DTF
2. **Structure-Preserving Anisotropic Filtering:** Use edge confidence to adjust distance measurement

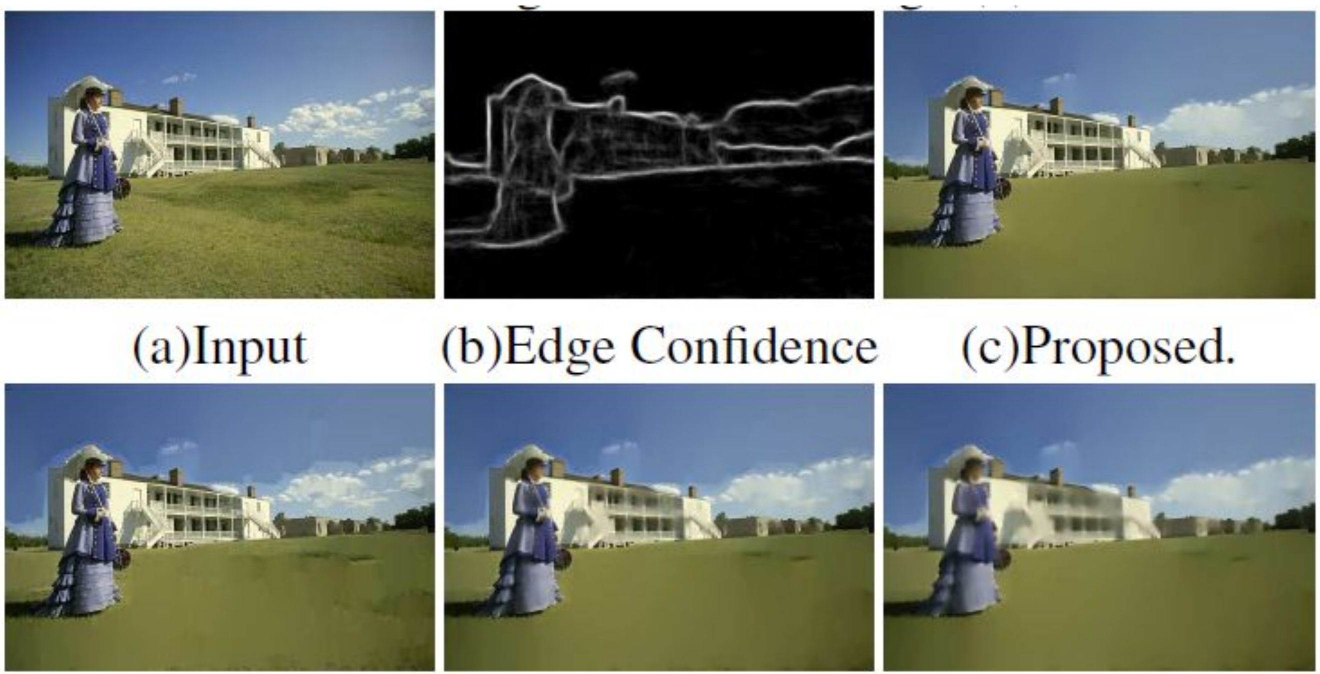
   An Edge detector trained with human-labelled data[1]

   Effective for objects of different sizes/scales

   Edge confidence computed from [1] used as the guidance in DTF for smoothing

[1].P. Dollar and C. L. Zitnick. Fast edge detection using structured forests. PAMI, 2015

Direct use of the edge confidence as the guidance may introduce visible artifacts or blur the image as shown in (d).



(a)Input (b)Edge Confidence (c)Proposed.

(d) Cross DTF (w.r.t. different parameters).

Proposed Filter

2. **Structure-Preserving Anisotropic Filtering:** Use edge confidence to adjust distance measurement

Using edge confidence as guidance iteratively to suppress textures:

$$t_i = x_0 + \sum_{j=1}^{i} (1 + \frac{\sigma_s}{\sigma_r} \cdot f_j |x_j - x_{j-1}|)$$

[1].P. Dollar and C. L. Zitnick. Fast edge detection using structured forests. PAMI, 2015

Proposed Filter

Proposed filter is composed of three main approaches

1. Anisotropic Filtering: Based on DTF
2. Structure-Preserving Anisotropic Filtering: Use edge confidence to adjust distance measurement

3. **Suppress small-scale textures around edges:**

- Imperfect confidence measurements around texture edges
- Apply a Median Filter[1] to the input image
- Won’t affect strong edges but textures close to edges will be removed

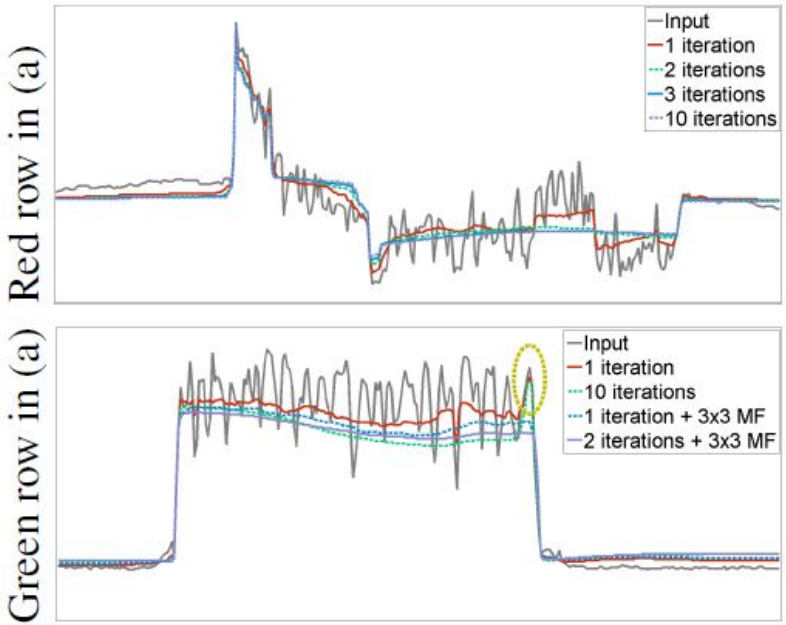
[1]. B. Weiss. Fast median and bilateral filtering. In Siggraph, volume 25, pages 519–526, 2006.

Proposed Filter

$$t_i = x_0 + \sum_{j=1}^{i} \left(1 + \frac{\sigma_s}{\sigma_r} f_j |x_j^{\mathbf{MF}} - x_{j-1}^{\mathbf{MF}}|\right)$$

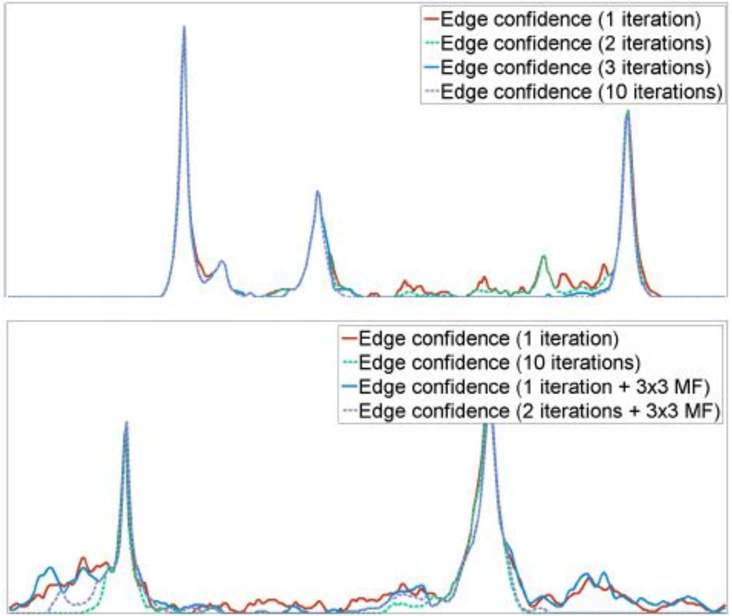
(a) Input (b) 1 Iter. (c) 10 Iter. (d)[54] + 2 Iter. (e)1 Iter.(MF) (f)2 Iter.(MF) (g)Our DTF[20]

Scale-Aware Structure-Preserving Filtering



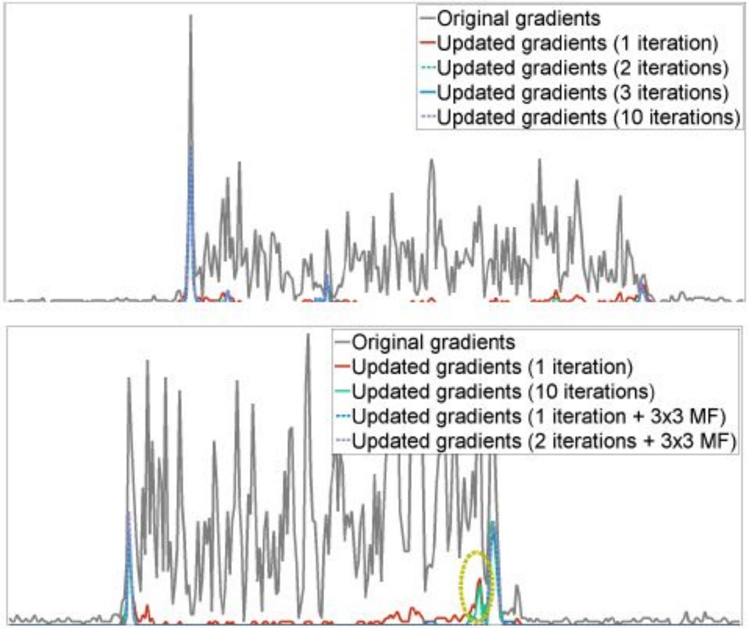
(i) Pixel values (on the red channel)

Scale-Aware Structure-Preserving Filtering



(j) Edge confidence

Scale-Aware Structure-Preserving Filtering



(k) Image gradients.

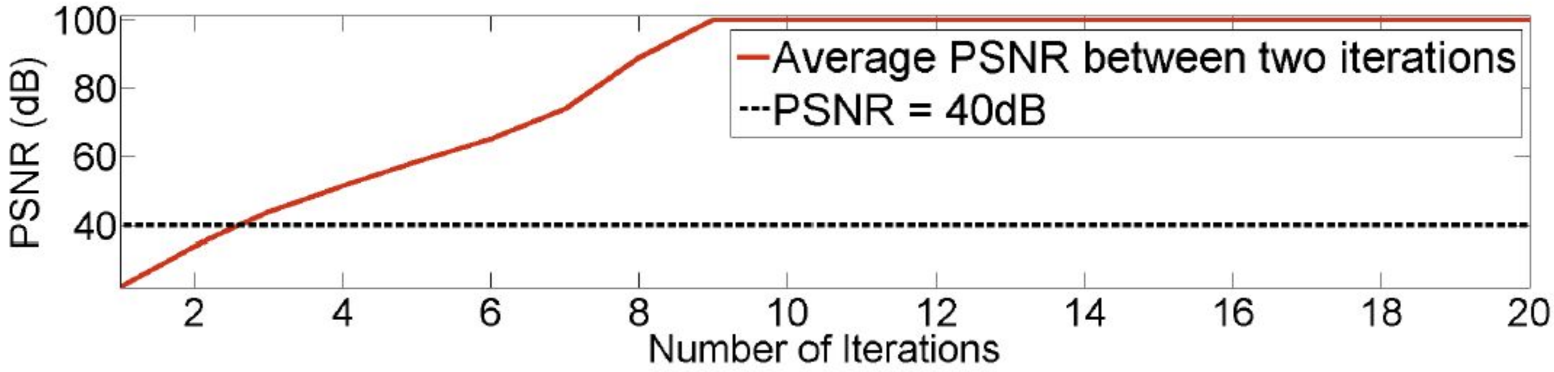
Computational Cost

Proposed filter's main blocks responsible for comp. Cost:

- Anisotropic Filter (DTF): Dominates computational cost
- Edge Detector: Down-sample version is enough
- Median Filter: Down-sample version is enough

[1]. B. Weiss. Fast median and bilateral filtering. In Siggraph, volume 25, pages 519–526, 2006.

Computational Cost:



- Average PSNR values computed from filtered images between every two iterations. PSNR values larger than 100 was shown as 100 for better visualization (as it can be infinity).
- 2 iterations is enough (< 40 dB)

Comparison with the state-of-the-art

(a)Input | $\{\sigma_s, \sigma_r\}=\{3, 0.05\}$. | $\{\sigma_s, \sigma_r\}=\{6, 0.05\}$. | $\{\sigma_s, \sigma_r\}=\{9, 0.05\}$.

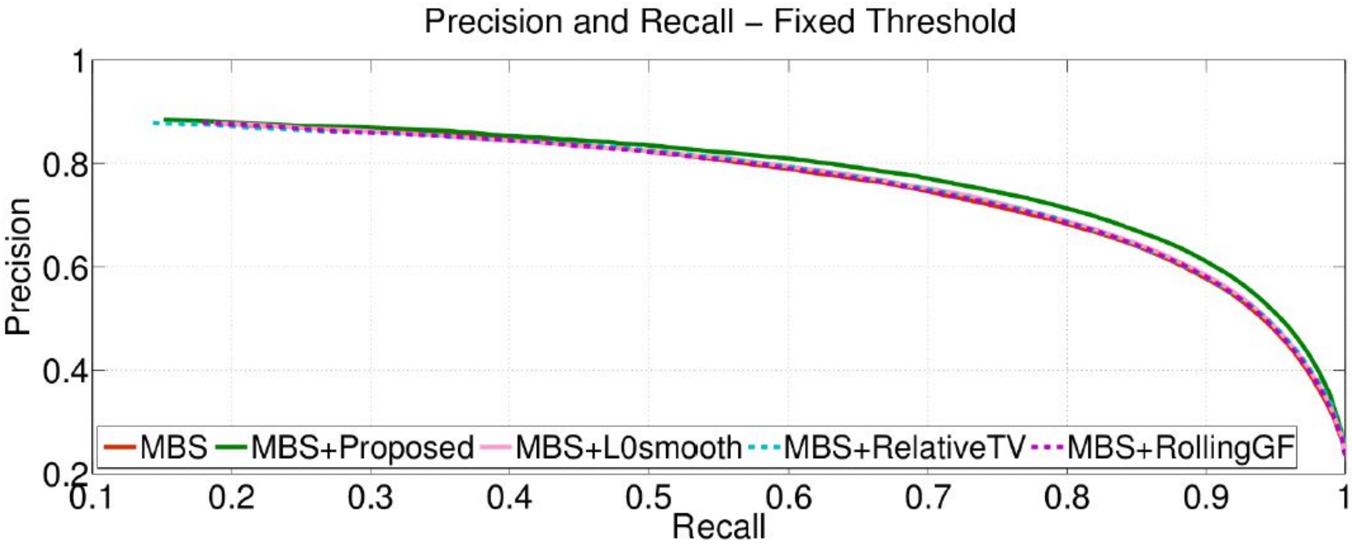
(b)Proposed | (c)$\{\sigma_s, \sigma_r\}=\{3, 0.15\}$. | (d)$\{\sigma_s, \sigma_r\}=\{6, 0.15\}$. | (e)$\{\sigma_s, \sigma_r\}=\{9, 0.15\}$.

Comparison with the state-of-the-art

Method	Runtime(Sec./Mp)
Relative TV[45]	35
L0 Smoothing[44]	18
WMF[55]	18
Covariance M2[24]	614
Rolling GF[54](with D.T. Filter[20])	0.15
Proposed (with D.T. Filter[20])	0.14
Proposed (with [54]+D.T. Filter[20])	0.27

Table 1. Exact runtime for processing a one megapixel color image on an Intel i7 3.4GHz CPU.

[20] E. Gastal and M. Oliveira. Domain transform for edge-aware image and video processing. TOG, 30(4):69:1–69:12, 2011.
[54] Q. Zhang, X. Shen, L. Xu, and J. Jia. Rolling guidance filter. In ECCV, 2014.



Precision-recall curves for saliency detection. Note that the combination of the structure-preserving filters can outperform the original Minimum Barrier Saliency (MBS) method on average and the proposed filter consistently outperforms the others.

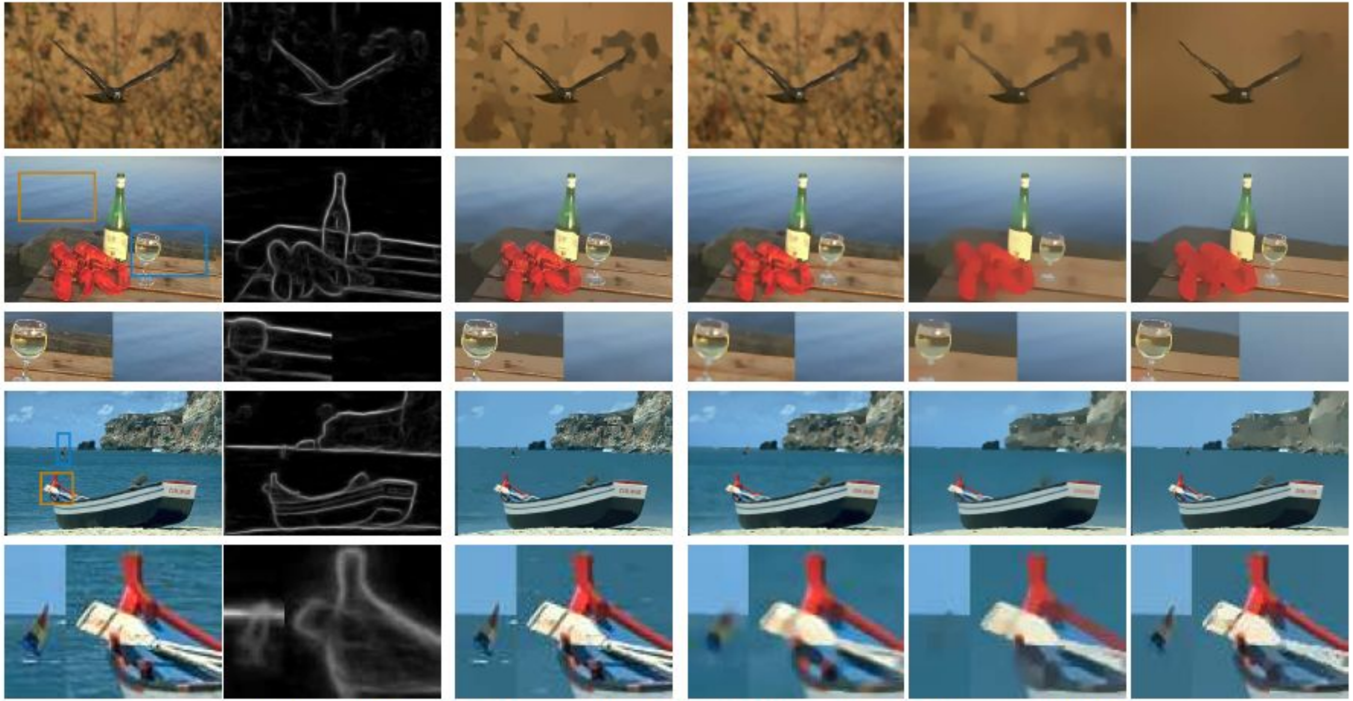
MAE and WFM

Mean absolute errors (MAE) and weighted-F-measure scores (WFM).

The proposed filter has the lowest error and the highest weighted-F-measure score.

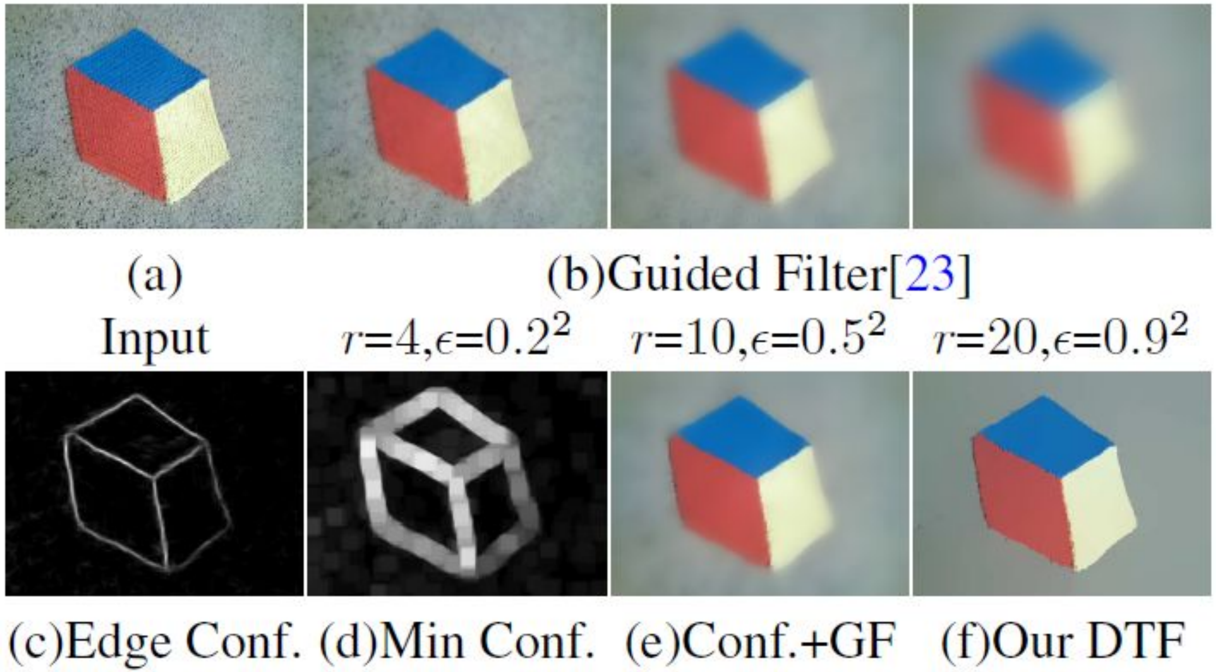
Method	MBS	MBS+ L0S[44]	MBS+ RTV[45]	MBS+ RGF[54]	MBS+ **Proposed**
MAE	0.1707	0.1674	0.1660	0.1698	**0.1578**
WFM	0.5612	0.5668	0.5630	0.5606	**0.5846**

Comparison with the state-of-the-art structure-preserving filters



(a)Input (b)Edge[13] (c)L0 smoothing[44] (d)Rolling GF[54] (e)Relative TV[45] (f)Proposed.

Conclusion



Guided filter is vulnerable to textures when a constant filter kernel is used.

Conclusion (cont.)

- An efficient structure-preserving filtering technique is proposed in the paper.
- The proposed technique is developed based on high-level understanding of the image structures.
- It is a seamless combination of the fast anisotropic filtering technique(s) with the structure learning based edge detector.
- It is more robust to objects/structures with different sizes/scales.
- The proposed technique cannot be directly applied to other edge-preserving filters like the guided filter and most of the quantization-based fast bilateral filters.

Pros & Cons

This paper uses image processing techniques which are already defined in literature. So it is not a new approach.

The techniques are selected based on their availability and simplicity. Other methods can be also utilized like sketch tokens.

The edge detection method is basically detects boundaries not edges. Therefore its bottleneck is using boundary detection algorithm.

Questions?

Thank you!