Bilateral Filters

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Overview

1. Introduction
2. Problems in Filtering
3. Bilateral Filtering
4. Algorithm
5. Results
6. Applications
7. Limitations
8. Conclusions

Introduction

- Fundemental process in CV

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- Pourquoi Bilateral Filter ?

Problems in Filtering

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Bilateral Filtering

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- Prefers near values to distant values

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- No phantom colors

Algorithm

The filter can be defined as:

$$I^{\text{filtered}}(x) = \frac{1}{W_p} \sum_{x_i \in \Omega} I(x_i) f_r(\|I(x_i) - I(x)\|) g_s(\|x_i - x\|) \tag{1}$$

where the normalization W_p is defined as:

$$W_p = \sum_{x_i \in \Omega} f_r(\|I(x_i) - I(x)\|) g_s(\|x_i - x\|) \tag{2}$$

x are coordinates of the current pixel to be filtered;
Ω is the window centered in x
f_r is the range kernel for smoothing differences in intensities
g_s is the spatial kernel for smoothing differences in coordinates

Algorithm

```
function outputImage = bilateralFilter(inputImage, w, sigma_d, sigma_r)
% Pre-compute Gaussian distance weights.
[X,Y] = meshgrid(-w : w, -w : w);
G = exp(-(X.^2 + Y.^2) / (2 * sigma_d ^ 2));
% Apply bilateral filter.
dim = size(inputImage);
outputImage = zeros(dim);
for i = 1:dim(1)
   for j = 1:dim(2)
         % Extract local region.
         iMin = max(i - w, 1);
         iMax = min(i + w, dim(1));
         jMin = max(j - w, 1);
         jMax = min(j + w,dim(2));
         I = A(iMin : iMax, jMin : jMax);
         % Compute Gaussian intensity weights.
         H = exp(-(I - A(i,j)).^2 / (2 * sigma_r ^ 2));
         % Calculate bilateral filter response.
         F = H .* G((iMin : iMax) -i + w + 1, (jMin : jMax) - j + w + 1);
         outputImage(i, j) = sum(F(:) .* I(:)) / sum(F(:));
   end
end
```

Algorithm

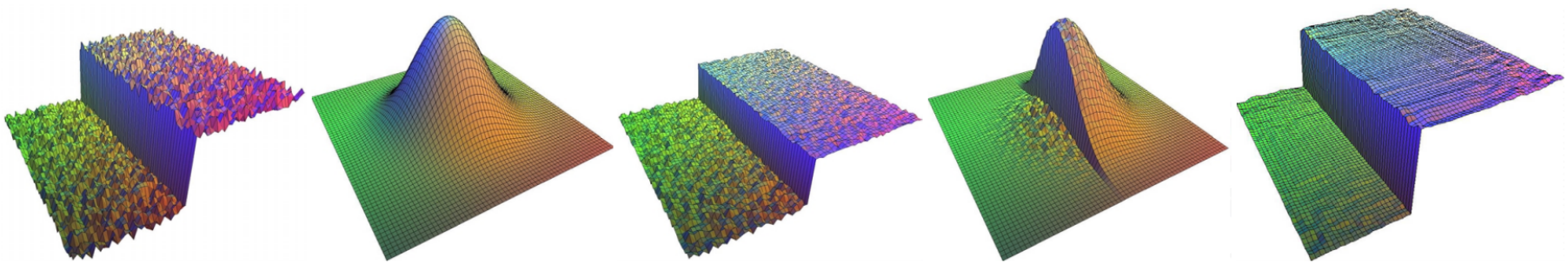

Figure : Overall

Algorithm

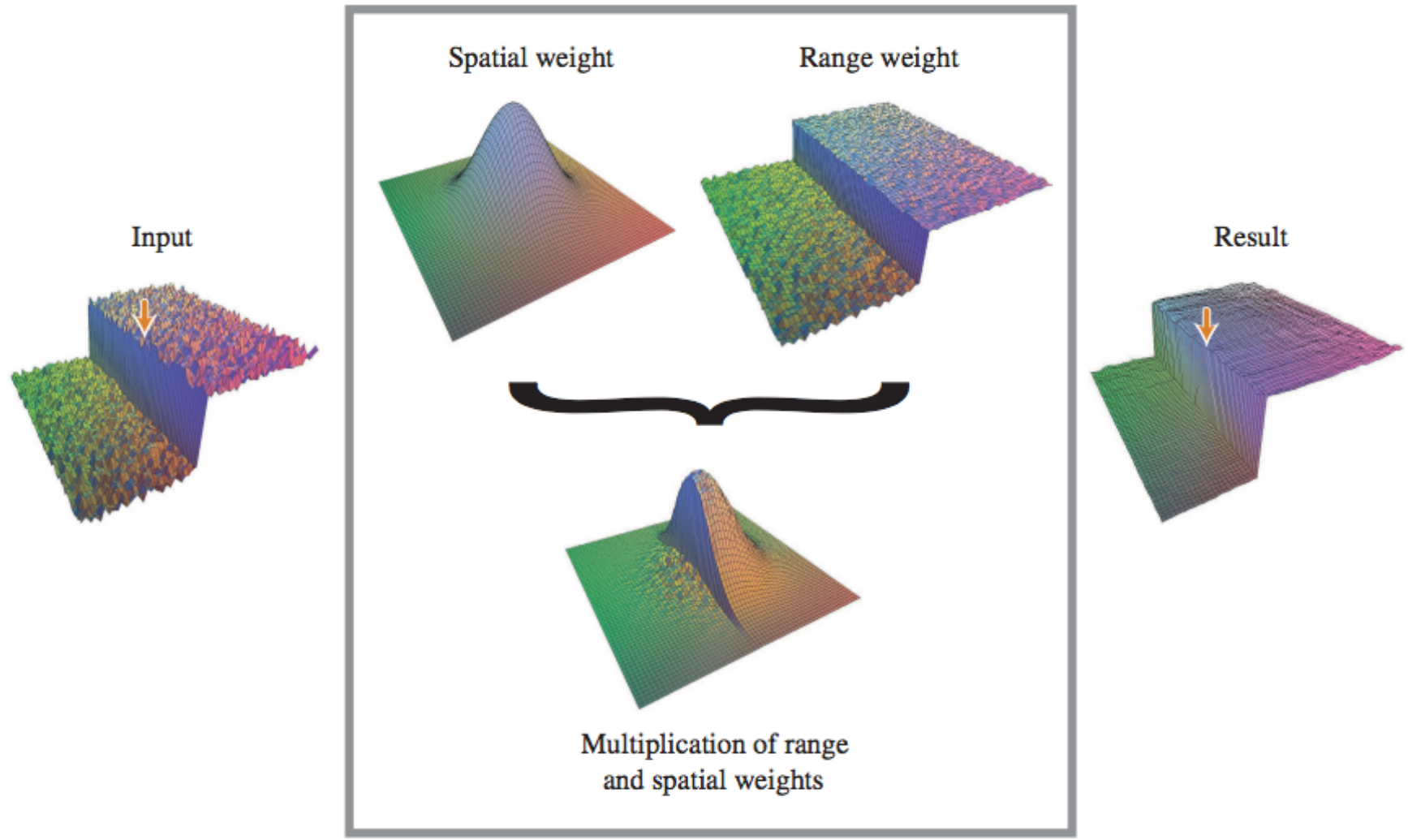

Figure : Overall Process

Results

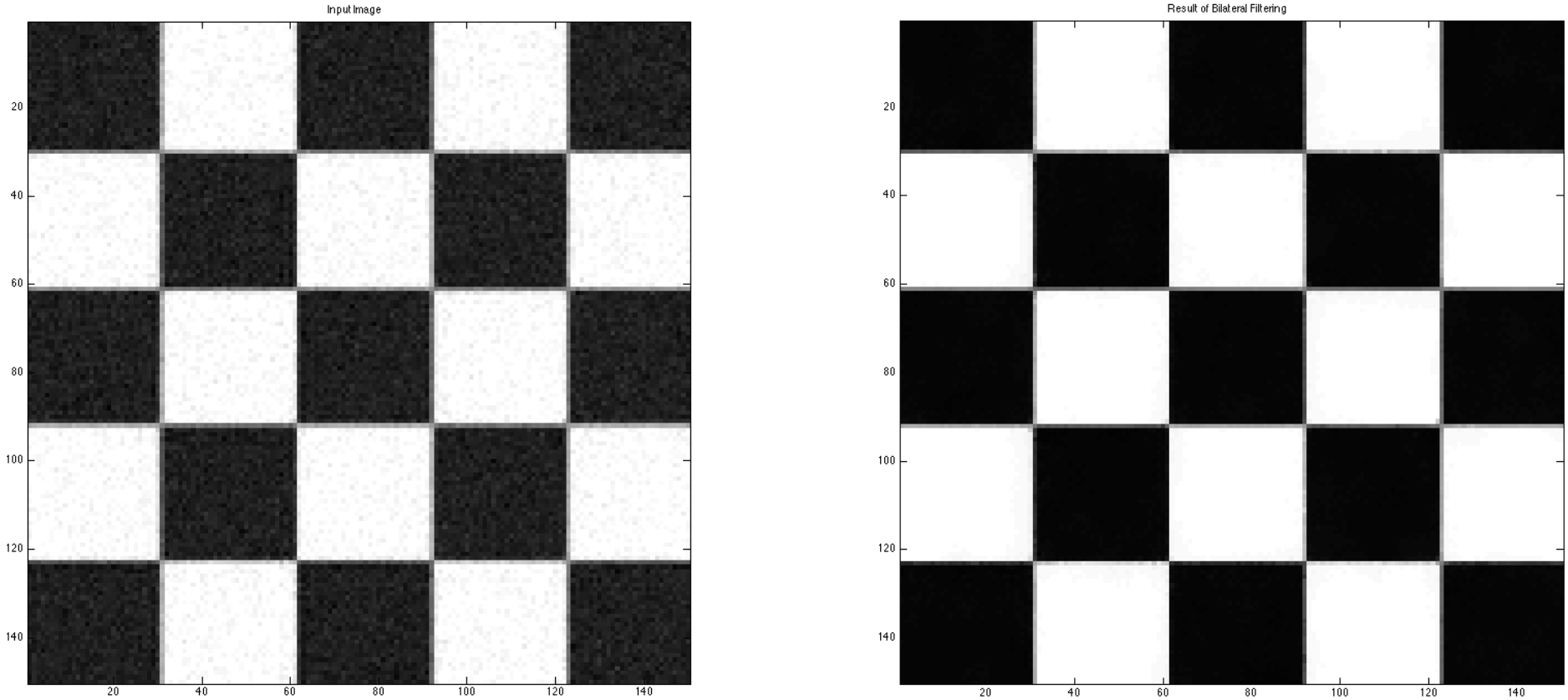

Figure : Denoising synthetic image

Results

Figure : Denoising gray-scale image

Results

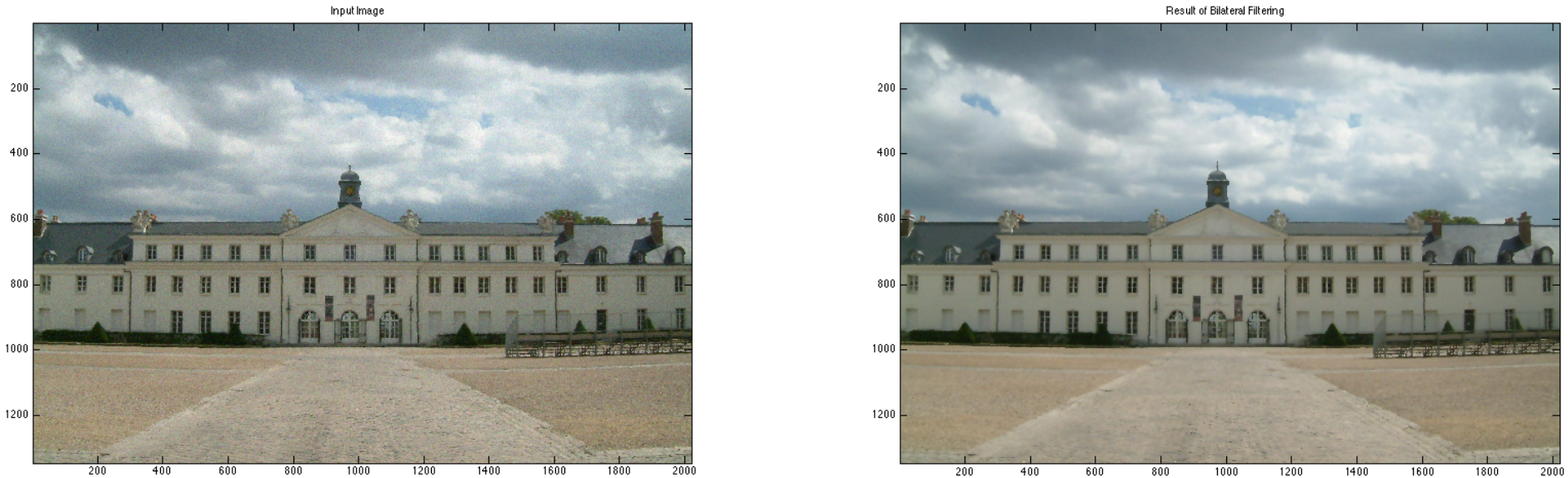

Figure : Denoising color image

Results

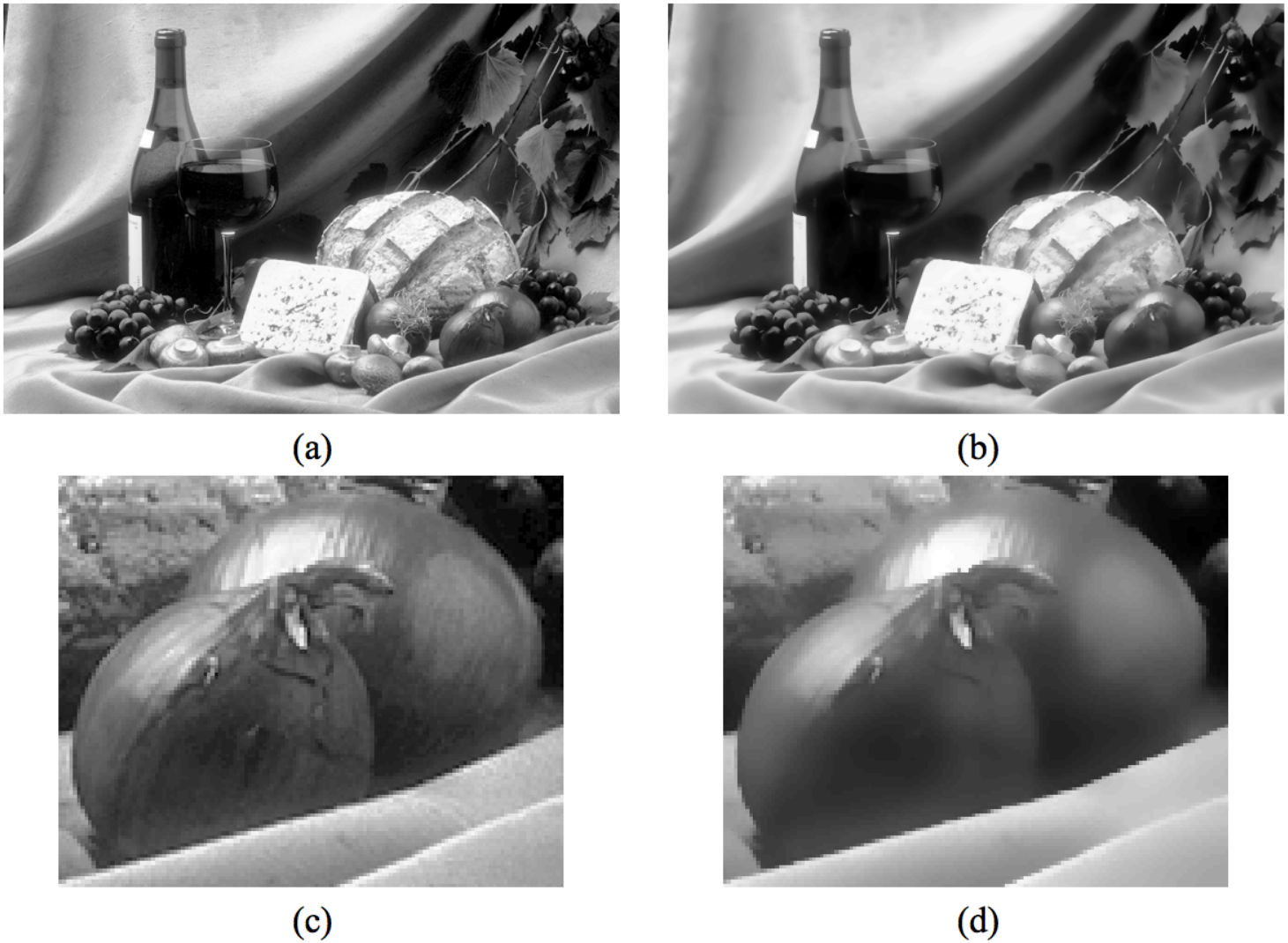

Figure 4: A picture before (a) and after (b) bilateral filtering. (c,d) are details from (a,b).

Results

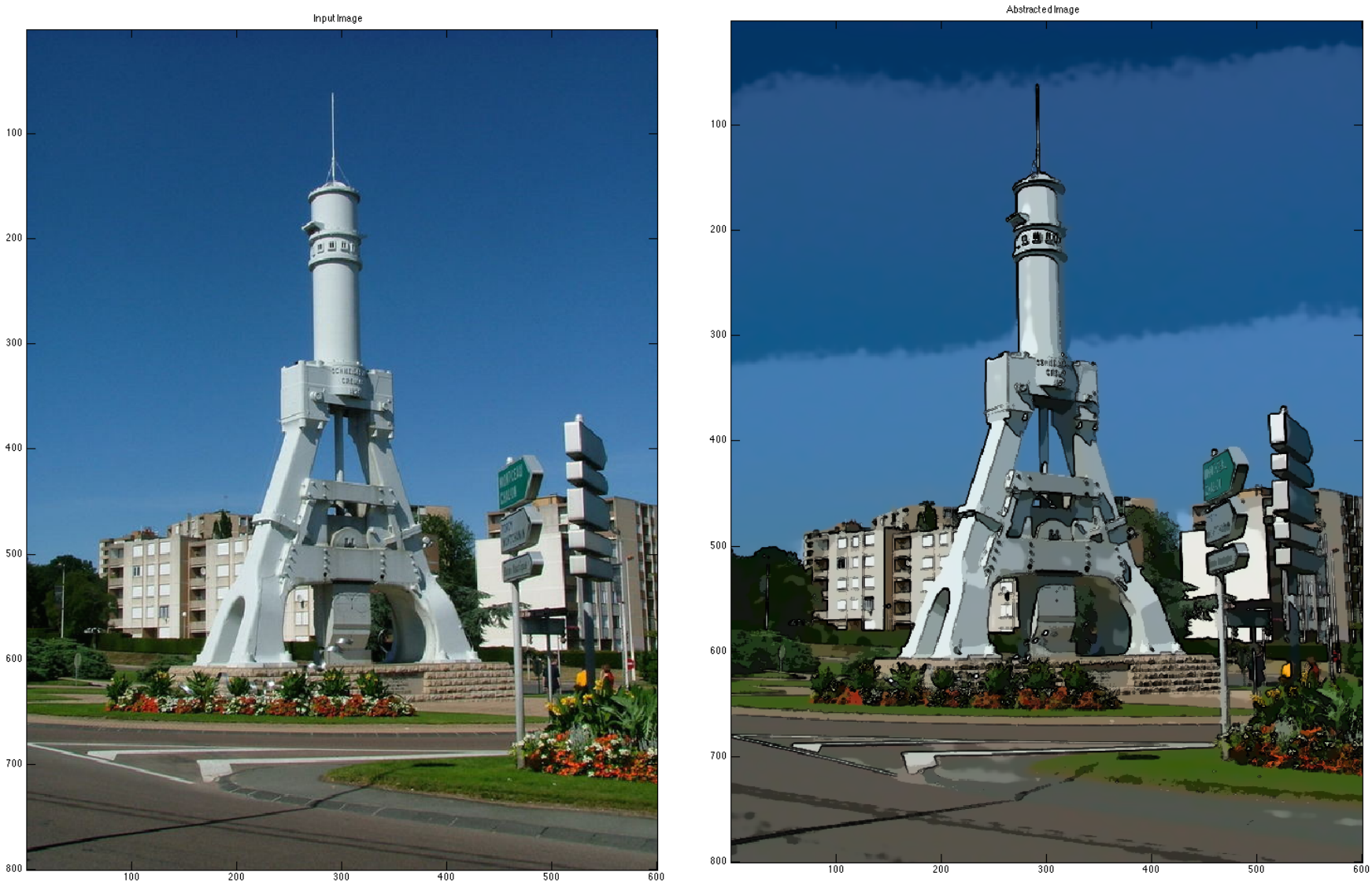

Figure : Image Abstraction

Results

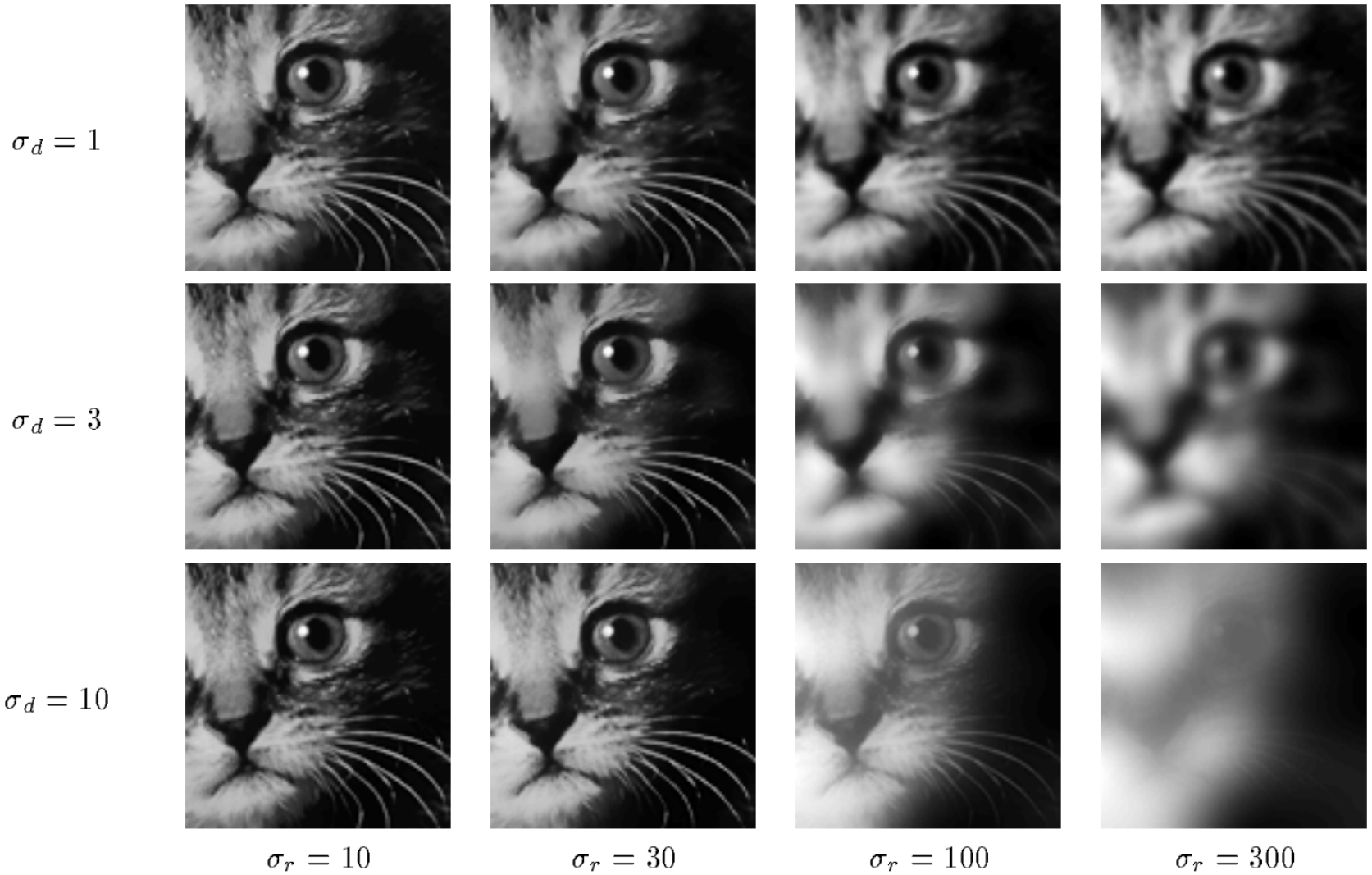

Figure : Cat Image: Range and Domain Parameters

Results

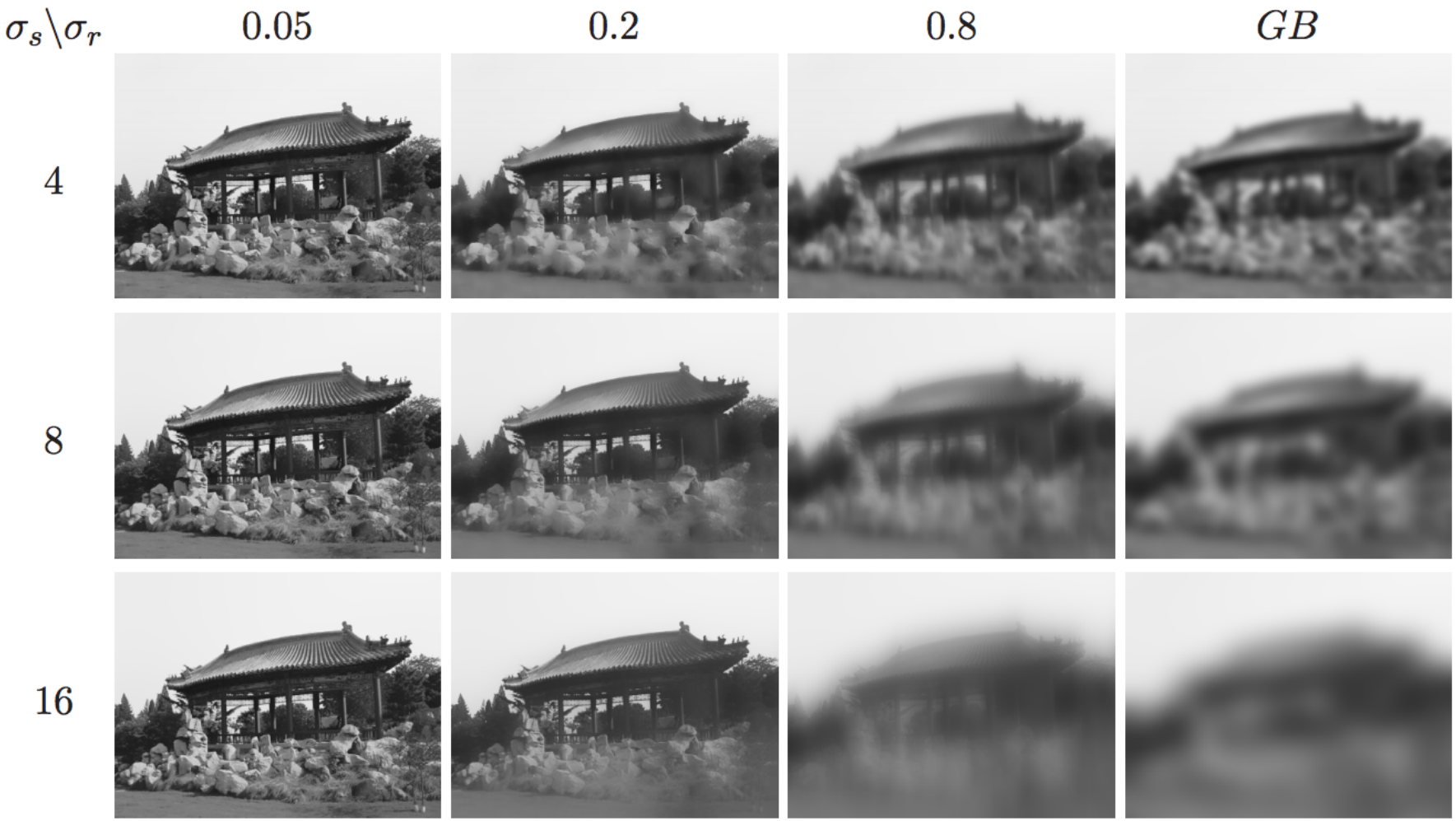

Figure : House Image: Range and Domain Parameters

Results

Parameters

The bilateral filter is controlled by two parameters: σ_s and σ_r.

Range

As the range parameter σ_r increases, the bilateral filter becomes closer to Gaussian blur because the range Gaussian is flatter i.e., almost a constant over the intensity interval covered by the image

Domain

Increasing the spatial parameter σ_s smooths larger features.

Applications

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- Cartoonizing applications

Limitations

The basic bilateral filter introduce several types of image artifacts:

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- Staircase effect - image appearing like cartoons and contours
- Gradient reversal - introduction of false edges

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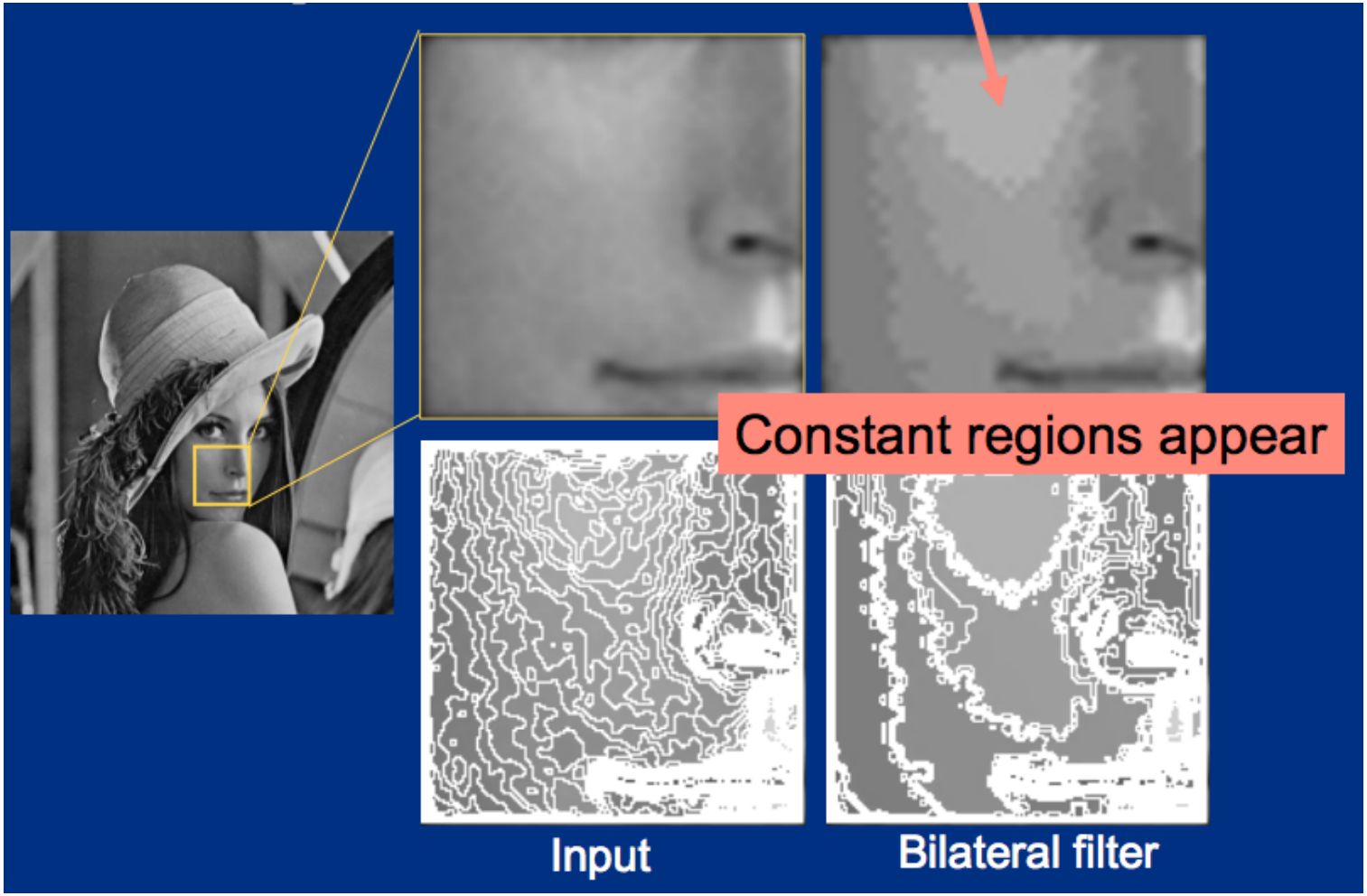

Figure : Staircase Effect

Limitations

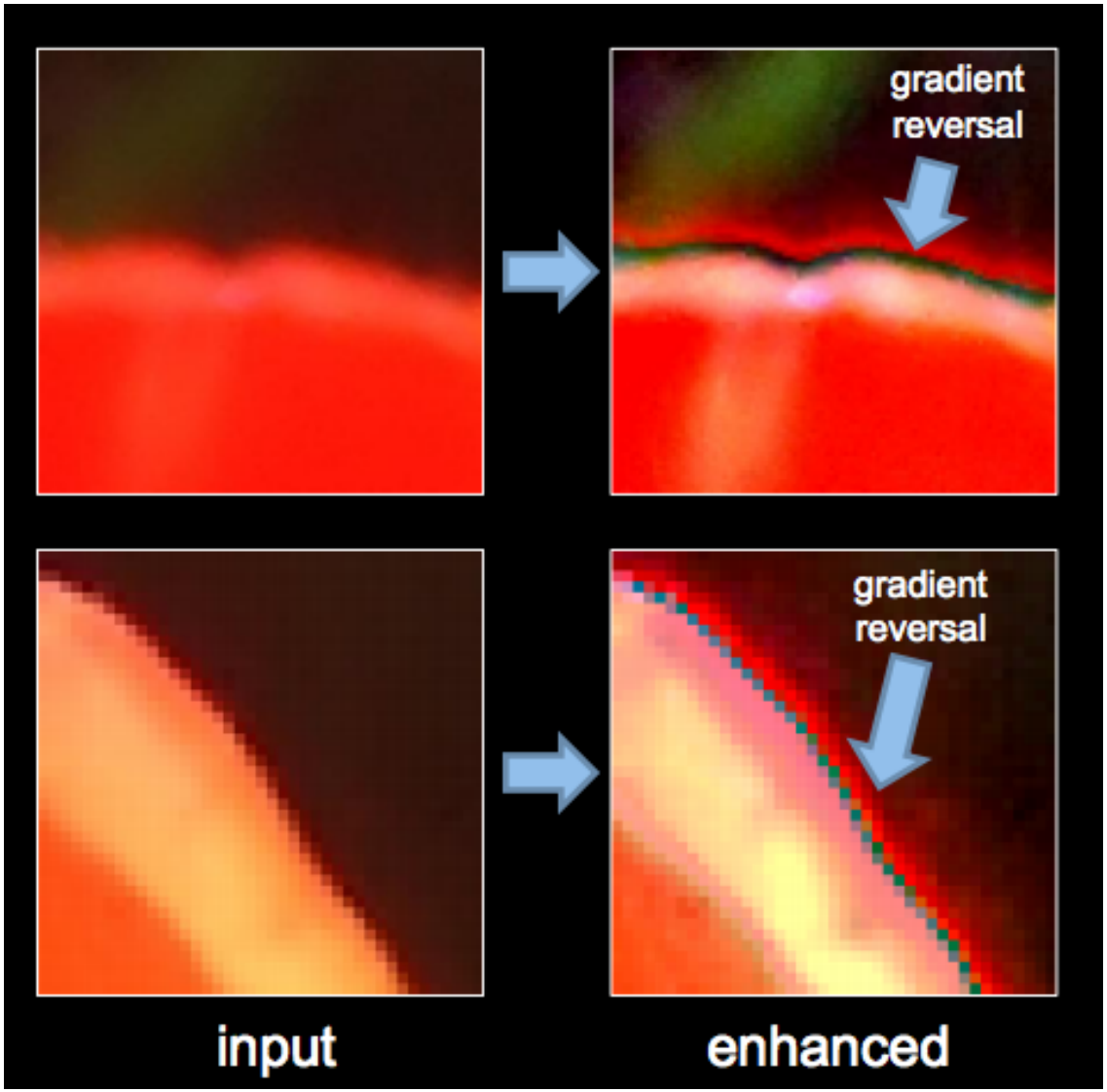

Figure : Gradient Reversal - False edges

Conclusions

- Good for preserving edges
- CIE-Lab color space gives better output
- Parameters depend of domain filter depends on image properties
- Details are lost with large range values but edges not
- It's nonlinear
- Complexity - $O(n^2)$

References

Wikipedia (2015)

Bilateral filter

C. Tomasi, R. Manduchi (1998)

Bilateral Filtering for Gray and Color Images

ICCV 1998

Thank you