
Bilateral Filtering: Theory and Applications

Bilateral Filtering: Theory and Applications

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Bilateral Filtering: Theory and Applications

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Abstract

The bilateral filter is a non-linear technique that can blur an image while respecting strong edges. Its ability to decompose an image into different scales without causing haloes after modification has made it ubiquitous in computational photography applications such as tone mapping, style transfer, relighting, and denoising. This text provides a graphical, intuitive introduction to bilateral filtering, a practical guide for efficient implementation and an overview of its numerous applications, as well as mathematical analysis.

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1

Introduction

Bilateral filtering is a technique to smooth images while preserving edges. It can be traced back to 1995 with the work of Aurich and Weule [4] on nonlinear Gaussian filters. It was later rediscovered by Smith and Brady [59] as part of their SUSAN framework, and Tomasi and Manduchi [63] who gave it its current name. Since then, the use of bilateral filtering has grown rapidly and is now ubiquitous in image-processing applications Figure 1.1. It has been used in various contexts such as denoising [1, 10, 41], texture editing and relighting [48], tone management [5, 10, 21, 22, 24, 53], demosaicking [56], stylization [72], and optical-flow estimation [57, 74]. The bilateral filter has several qualities that explain its success:

- Its formulation is simple: each pixel is replaced by a weighted average of its neighbors. This aspect is important because it makes it easy to acquire intuition about its behavior, to adapt it to application-specific requirements, and to implement it.
- It depends only on two parameters that indicate the size and contrast of the features to preserve.
- It can be used in a non-iterative manner. This makes the parameters easy to set since their effect is not cumulative over several iterations.

2 Introduction

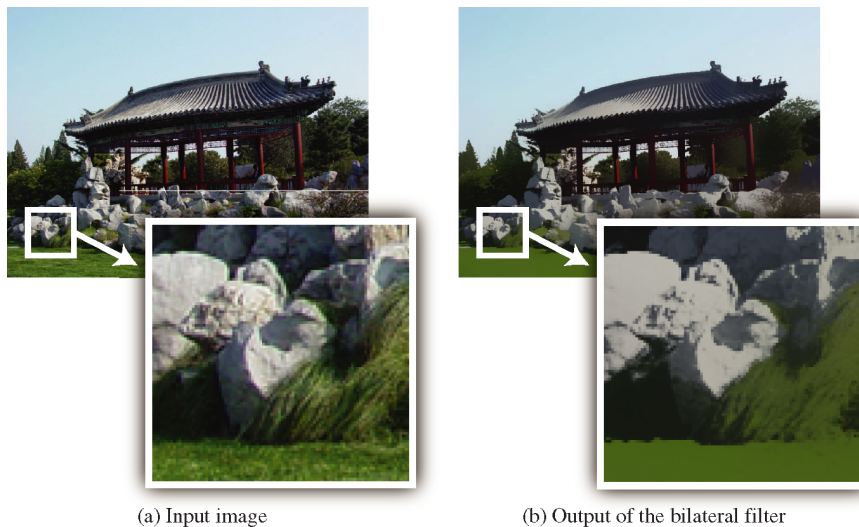


Fig. 1.1 The bilateral filter converts any input image (a) to a smoothed version (b). It removes most texture, noise, and fine details, but preserves large sharp edges without blurring.

- It can be computed at interactive speed even on large images, thanks to efficient numerical schemes [21, 23, 55, 54, 50, 71], and even in real time if graphics hardware is available [16].

In parallel to applications, a wealth of theoretical studies [6, 7, 13, 21, 23, 46, 50, 60, 65, 66] explain and characterize the bilateral filter's behavior. The strengths and limitations of bilateral filtering are now fairly well understood. As a consequence, several extensions have been proposed [14, 19, 23].

This paper is organized as follows. Section 2 presents linear Gaussian filtering and the nonlinear extension to the bilateral filter. Section 3 revisits several recent, novel and challenging applications of bilateral filtering. Section 4 compares different ways to implement the bilateral filter efficiently. Section 5 presents several links of bilateral filtering with other frameworks and also different ways to interpret it. Section 6 exposes extensions and variants of the bilateral filter. We also provide a website with code and relevant pointers (http://people.csail.mit.edu/sparis/bf_survey/).

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