GPU Based Bilateral Filtering for Images

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*Abstract*—A Bilateral filter smooths images while preserving edges, this is accomplished through nonlinear combination of a neighborhood of image values. The method combines colors or intensities based on geometric closeness and photometric similarities. Bilateral filters can enforce the perception metric of the CIE-Lab color space to smooth colors and preserve edges tuned to human perception. Bilateral filtering has the added benefit of an absence of phantom colors along the edges of a color image. A naïve, iterative solution to Bilateral filtering will iterates over all the input image’s pixels. The iterative and local nature of this algorithm has tremendous potential for parallel GPU implementations. (LENGTHEN)

Keywords—bilateral; parallel; filtering; GPU

# Introduction

One of the most fundamental operations of computer vision and image processing is filtering. Broadly defined, a value of a filtered image at some location is a function of color or intensity values in a neighborhood about the location. For example, a Gaussian low-pass filter, one of the most commonly used filters, computes a weighted average value for the location in question. The weights are computed to have a higher weight for values nearby the location and lower weights for values further away. A more formal explanation of the weight fall-off can be found [1], intuitively an image varies little over a small space, thus nearby pixels are going to be similar. By averaging these pixels together, the image function is smoothed and noise is removed.

The assumption of a slow spatial variation fails at edge cases, a pure Gaussian filter will blur image edges as it does not consider legitimate variations in pixel intensities or color values. This is a major issue for computer vision applications, cameras inherently introduce noise which could negatively alter feature matching techniques however if a standard Gaussian filter is applied to the image edge information can be completely lost. Edge based segmentation for example look for abrupt changes in intensity. However, if an image is not smoothed than false edges can be detected. There have been attempts to reduce the effect of smoothing as well as do without smoothing altogether [2] [3].

One popular answer to this problem is anisotropic diffusion [4]. In this approach, the local image variation is measured at every point with pixel values being averaged from neighborhoods with size and shape depending on local variation. Diffusion methods average over an extended region through solving partial differential equations and are thus iterative inherently. In addition to possible efficiency issues, iteration can raise issues of stability.

A scheme introduced by C. Tomasi and R. Manduchi [5] provides a non-iterative and simple scheme for smoothing that preserves edges. The basic idea of this approach is to do what traditional filters do in the image domain, in the image range. Two pixels can either be spatially near each other or have values near each other, in a perceptually meaningful way. Closeness is specific to the vicinity in the domain, while similarity refers to the vicinity in the range. A traditional filter is filters by domain, enforcing closeness by weighing pixel values with coefficients which fall off over a distance. Range filtering on the other hand, averages image values with weights decaying by similarity. A range filter is nonlinear as weights depend on intensity or color of the image.

In the scheme, spatial locality is not altogether disregarded. Range filtering alone will only distort the image’s color map. Thus, the scheme combines range and domain filtering. This is what is referred to as *bilateral* filtering [5].

As this *bilateral* filters have an explicit definition for distance in an image function’s domain and range, they can be applied to any function in which these distances can be defined. Applying this filter to a color image is just as simple as applying to black-and-white images. The CIE-Lab color space gives the color space a meaningful measure of color similarity which in short distances correlate with human color discrimination performance. A bilateral filter often uses this metric as it provides a smooth image with edges that are preserved in a way that is tuned to human performance. In other words, colors that are perceptually similar are averaged together and perceptually visible edges are preserved.

This scheme introduced by C. Tomasi and R. Manduchi [5] is non-iterative and so each pixel must only be evaluated once. This is a perfect candidate for implementation in a massively multi-threaded environment such as a GPU which is made up of hundreds if not thousands of computation units providing excellent throughput [6]. With no one output pixel depending on the output of another pixel and a pixel’s output depending upon a single set of calculations, a GPU’s high throughput can be used to great effect.

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*a**b* 

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* The subscript for the permeability of vacuum **0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o”.
* In American English, commas, semi-/colons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
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* In your paper title, if the words “that uses” can accurately replace the word “using”, capitalize the “u”; if not, keep using lower-cased.
* Be aware of the different meanings of the homophones “affect” and “effect”, “complement” and “compliment”, “discreet” and “discrete”, “principal” and “principle”.
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* The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
* There is no period after the “et” in the Latin abbreviation “et al.”.
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1. Table Type Styles

| Table Head | Table Column Head | | |
| --- | --- | --- | --- |
| Table column subhead | Subhead | Subhead |
| copy | More table copya |  |  |

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2. Example of a figure caption. (*figure caption*)

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##### Acknowledgment *(Heading 5)*

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1. G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

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1. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
2. I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
3. K. Elissa, “Title of paper if known,” unpublished.
4. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
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6. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.