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M.S. Computer & Systems Engineering
Advanced VLSI Design
4/21/2025

Gaussian Filter Design

I. Introduction

Gaussian filtering is a technique typically used within Computer Vision, Medical Imaging, Remote Sensing, etc. It serves as a method for color balance, sharpening, and reducing image noise. Gaussian Filtering uses weighted moving average which provides weight to the central pixel. There is a gradual decrease in the weight as it moves away from the center. It creates a smoothing effect/slight blur within the image. Gaussian filters reduce high frequency noise by removing pixels. For single filters, the computational cost is negligible but the computational cost for multiple filters processes. The downside with Gaussian Filters is that larger computations (FIR Filters, etc) introduce cost due to numerous multiplications/additions needed. These computations happen with a kernel. Thus, the larger the kernel or higher the image resolution, the more processing power required and the slower the image processing algorithm[1].

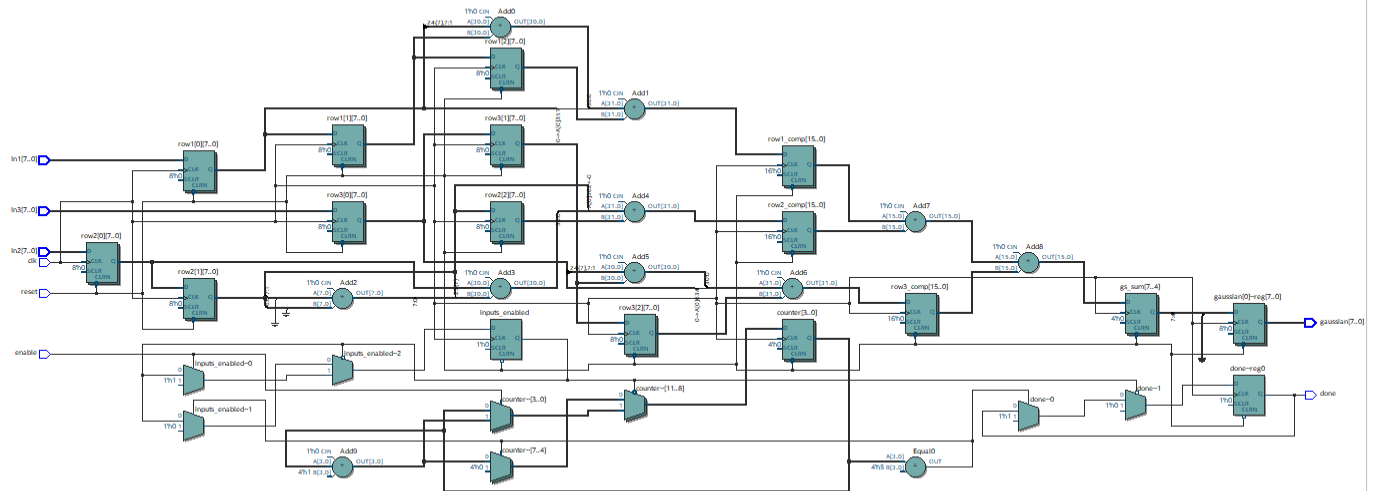
Gaussian Kernels are designed using the formula:

$$k(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right) \quad [2]$$

The x and y represent the spatial coordinates. The standard deviation represents the size of the bell curve-essentially how much area within the filter experiences increased smoothing with a higher weight. You can see a higher blur with a low standard deviation and lower blur with a high standard deviation.

II. 2D Direct Gaussian Implementation

RTL Viewer



Silicon Usage of Direct Gaussian Implementation:

Filter Resource Utilization by Entity										
<<Filter>>										
Compilation Hierarchy Node	Logic Cells	Dedicated Logic Registers	I/O Registers	Memory Bits	M9Ks	JFM Blocks	DSP Elements	DSP 9x9	DSP 18x18	Pins
1 Gaussian_Filter	128 (128)	110 (110)	0 (0)	0	0	1	0	0	0	36

Pins	Virtual Pins	LUT-Only LCs	Register-Only LCs	LUT/Register LCs	ADC blocks	ull Hierarchy Nam	Entity Name	Library Name
36	0	18 (18)	48 (48)	62 (62)	0	Gaussian_Filter	Gaussi...Filter	work

Maximum Frequency:

	Fmax	Restricted Fmax	Clock Name	Note
1	180.02 MHz	180.02 MHz	clk	

Power Analyzer Summary:

Power Analyzer Summary	
<<Filter>>	
Power Analyzer Status	Successful - Mon Apr 21 02:31:21 2025
Quartus Prime Version	23.1std.1 Build 993 05/14/2024 SC Standard Edition
Revision Name	Gaussian_Filter
Top-level Entity Name	Gaussian_Filter
Family	MAX 10
Device	10M08DAF484C8G
Power Models	Final
Total Thermal Power Dissipation	975.88 mW
Core Dynamic Thermal Power Dissipation	31.04 mW
Core Static Thermal Power Dissipation	40.62 mW
I/O Thermal Power Dissipation	904.22 mW
Power Estimation Confidence	Low: user provided insufficient toggle rate data

[1] L. Mazumder and V. Shah, "Fast Gaussian Filter Approximations Comparison on SIMD Computing Platforms," *Applied Sciences*, vol. 14, no. 11, 2024. [Online]. Available: <https://www.mdpi.com/2076-3417/14/11/4664>

[2] K. He, X. Zhang, S. Ren, and J. Sun, "Delving Deep into Rectifiers: Surpassing Human-Level Performance on ImageNet Classification," *Advances in Neural Information Processing Systems (NeurIPS)*, vol. 28, 2015. [Online]. Available: <https://proceedings.neurips.cc/paper/2020/file/f6a673f09493afcd8b129a0bcf1cd5bc-Paper.pdf>

[3] H. Gulati, "Understanding the Gaussian Filter," *Medium*, 2021. [Online]. Available: <https://himani-gulati.medium.com/understanding-the-gaussian-filter-c2cb4fb4f16b>

[4] StackOverflow, "What is meant by 1D Gaussian kernel vs 2D Gaussian kernel?", *Stack Overflow*, 2021. [Online]. Available: <https://stackoverflow.com/questions/66489348/what-is-meant-by-1d-gaussian-kernel-vs-2d-gaussian-kernel>