Error-Tolerant Image Processing Application Based on Stochastic Logic

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Introduction & Motivation

- An error-tolerant system is in urgent need to eliminate various external factors that can cause errors in modern techniques. A single transient fault may cause the whole system to perform erroneously. Unreliability in systems can lead to huge loss.
- Stochastic logic can create analog signal states in digital-based systems. It can be regarded as “bit-level” redundancy in some sense.
- Stochastic arithmetic can be adapted to computing such as image processing due to a number of features
  - + Tolerant transient fault
  - + Simple hardware in some computing
  - + Low silicon area and faster clock period
  - + progressive precision
  - - More clock cycles to compute

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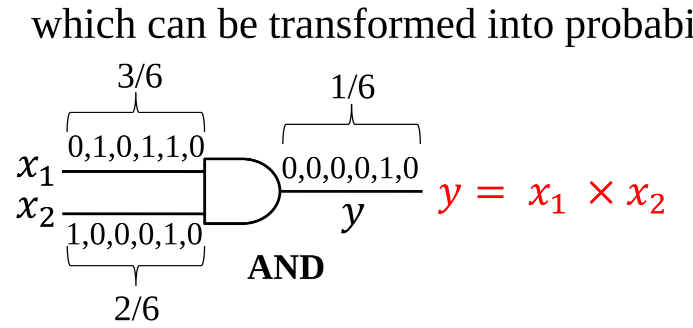
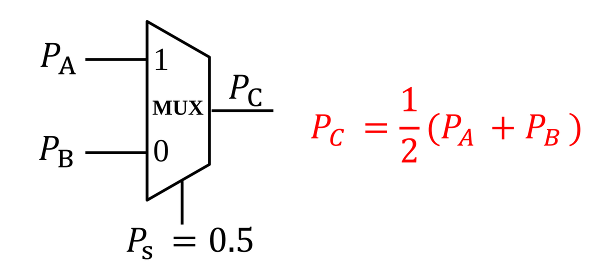
Solution - Stochastic Logic

- In stochastic logic, a normal input will take advantage of randomness and be transformed to a bit stream. The bit streams or wire bundles are digital, carrying zeros and ones, and the signal is conveyed through the statistical distribution of the logical values.
  - For example, 1010, 0101, and 0101011011000011 are possible stochastic representations of 1/2 = 0.5
- Stochastic logic represents values by random sequence of a bit stream which can be transformed into probabilities.



Stochastic Multiplier



Stochastic Adder

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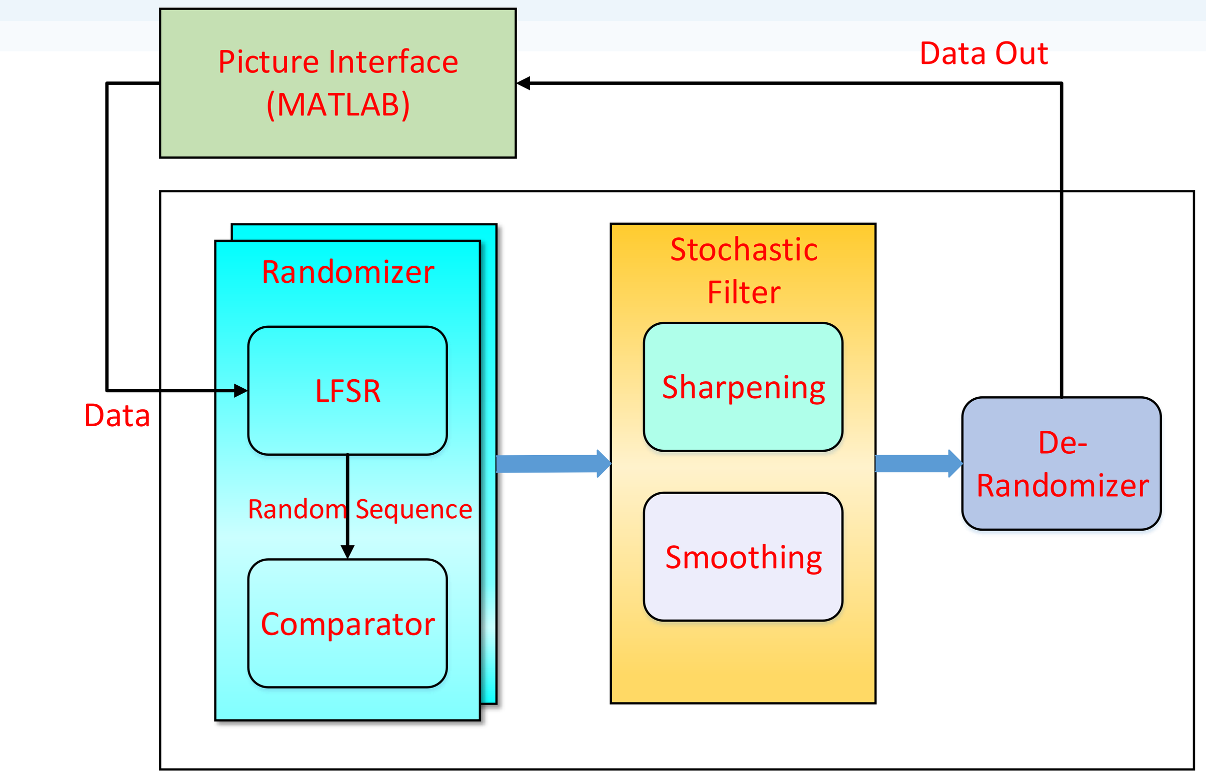
Solution - Architecture



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Filter Design

- The image sharpening and smoothing are implemented by high-pass and low-pass filter masks.

-1	-1	-1
-1	8	-1
-1	-1	-1

High pass mask

1	1	1
1	1	1
1	1	1

Low pass mask

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Error Tolerance

- We randomly flipped the input of the filters at different error rates to see the behavior.
- We use SSIM (Structural SIMilarity) and PSNR(the peak signal-to-noise ratio) to measure the similarity of pictures quantitatively.
- Data shown below is the average results of ten different pictures.

	SSIM			PSNR (dB)		
	Baseline	Stochastic	Difference	Baseline	Stochastic	Difference
High-Pass Filter						
1%	0.407	0.447	9.83%	0.945	4.046	3.101
5%	0.174	0.205	17.82%	-5.504	-3.728	1.776
10%	0.106	0.146	37.74%	-7.859	-6.245	1.614
15%	0.076	0.118	55.26%	-8.854	-7.476	1.378
Low-Pass Filter						
1%	0.794	0.926	16.62%	25.732	33.273	7.541
5%	0.497	0.781	57.14%	17.482	21.497	4.015
10%	0.368	0.686	86.41%	13.310	15.871	2.561
15%	0.308	0.621	101.62%	10.960	12.894	1.934

Original 8-bit, grayscale

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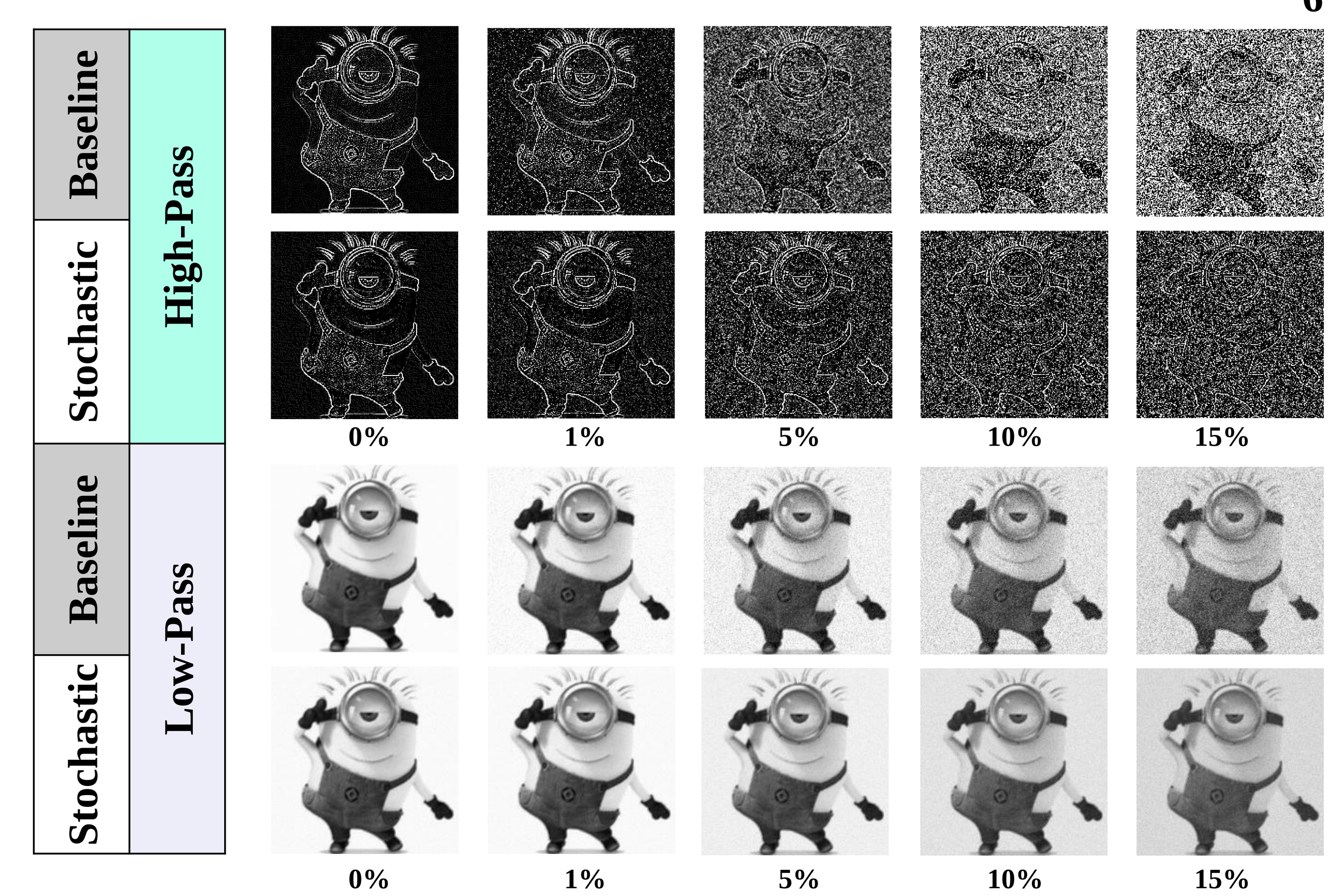

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Performance and Area

- We synthesized and evaluated speed/area of conventional and stochastic designs. The clock period and area of stochastic design are both smaller than baseline design.
- The stochastic logic itself is only a small portion of the area. The most area is used to covert between regular number and stochastic number.
- The stochastic design will need more cycles to execute.
- The $Period * Area * \#Cycle$ is roughly the same magnitude for baseline and stochastic design (if we only consider the core module).

	Baseline	Stochastic Low-Pass	Stochastic (core only) Low-Pass	Stochastic High-Pass	Stochastic (core only) High-Pass
Clock Period (ns)	7.8	1.8	1.8	1.8	1.8
Synthesis Area (μm^2)	49,687	26,796	1,063	31,222	1,461
Total Cycle	N	$N \cdot 2^8$	$N \cdot 2^8$	$N \cdot 2^8$	$N \cdot 2^8$
Period∗Area∗ #Cycle	387,559N	12,347,596N	489, 830N	14,387,097N	673,228N

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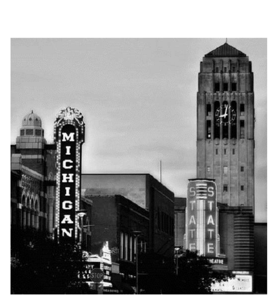
Discussion

- The high-pass filter is more prone to faults
  - Low-pass filter will smooth the picture and tolerant errors to some extents
- Progressive precision
  - Partial bit-stream provide a good estimate of the exact value
- Possible random number resource to reduce hardware cost



Original

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Conclusion

- The stochastic logic filter can be adapted to image processing filters to simplify the hardware design.
- It consumes less silicon area and can operate at a faster clock
- While it will take more cycle numbers than conventional filter to execute, stochastic logic takes advantage of randomness and outperforms the baseline filter in terms of the error-tolerance capability.

Acknowledgement

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