Reconfigurable Stochastic Computing Architecture for Computationally Intensive Applications

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Outline

- Introduction
- Proposed Architecture
- Experimental Results
- Conclusion

Introduction - Motivation

- **Emerging Computationally intensive applications**

  Image recognition, Autonomous driving, AI Assistant ..

✓ **Efficient utilization of circuit area**

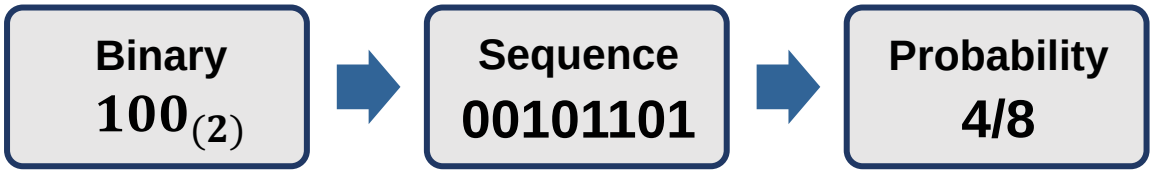
✓ **Lightweight logics with suitable accuracy**

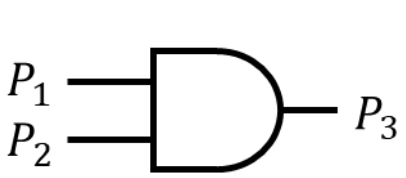
Introduction - Preliminaries

- **Stochastic Computing (SC)**

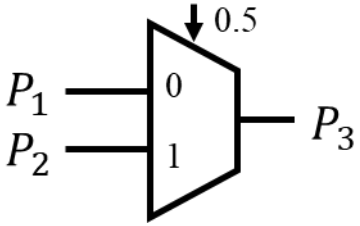
- The SC adapts probability value [0,1]

- The value is approximated to ratio of '1's in random bitstreams

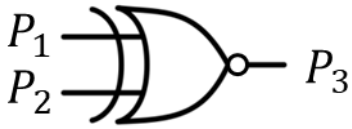




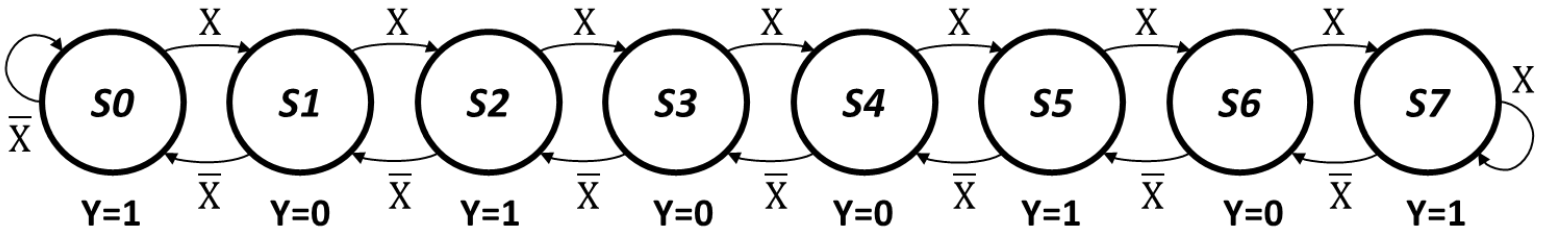
[Unipolar Multiplier]



[Adder]



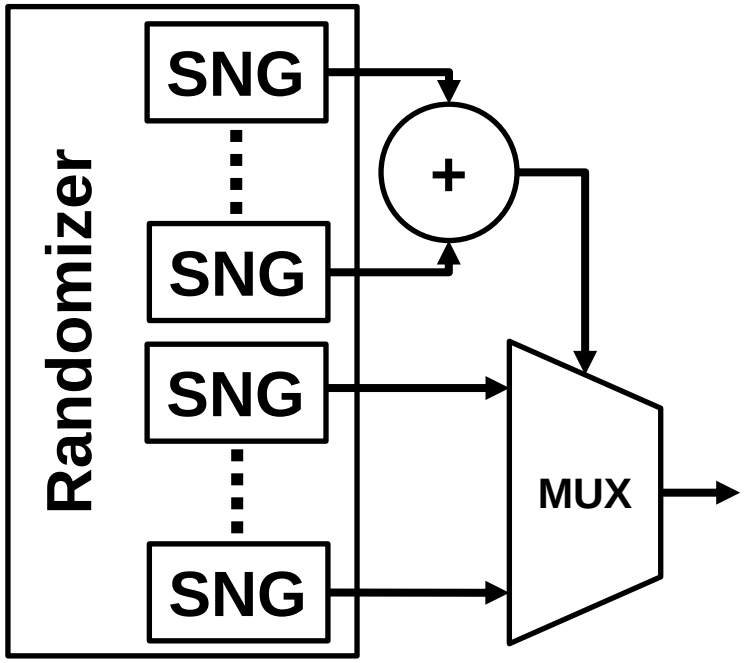
[Bipolar Multiplier]



[Absolute Function]

Introduction – Related works

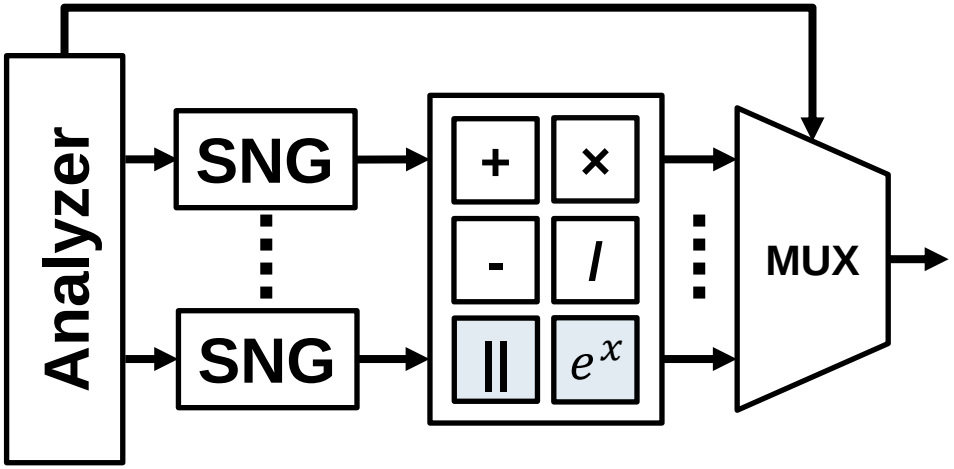
- **Reconfigurable SC Unit**



[Related works]

Bernstein polynomial

$$y = z_0 + z_1 x + z_2 x^2 + z_3 x^3$$



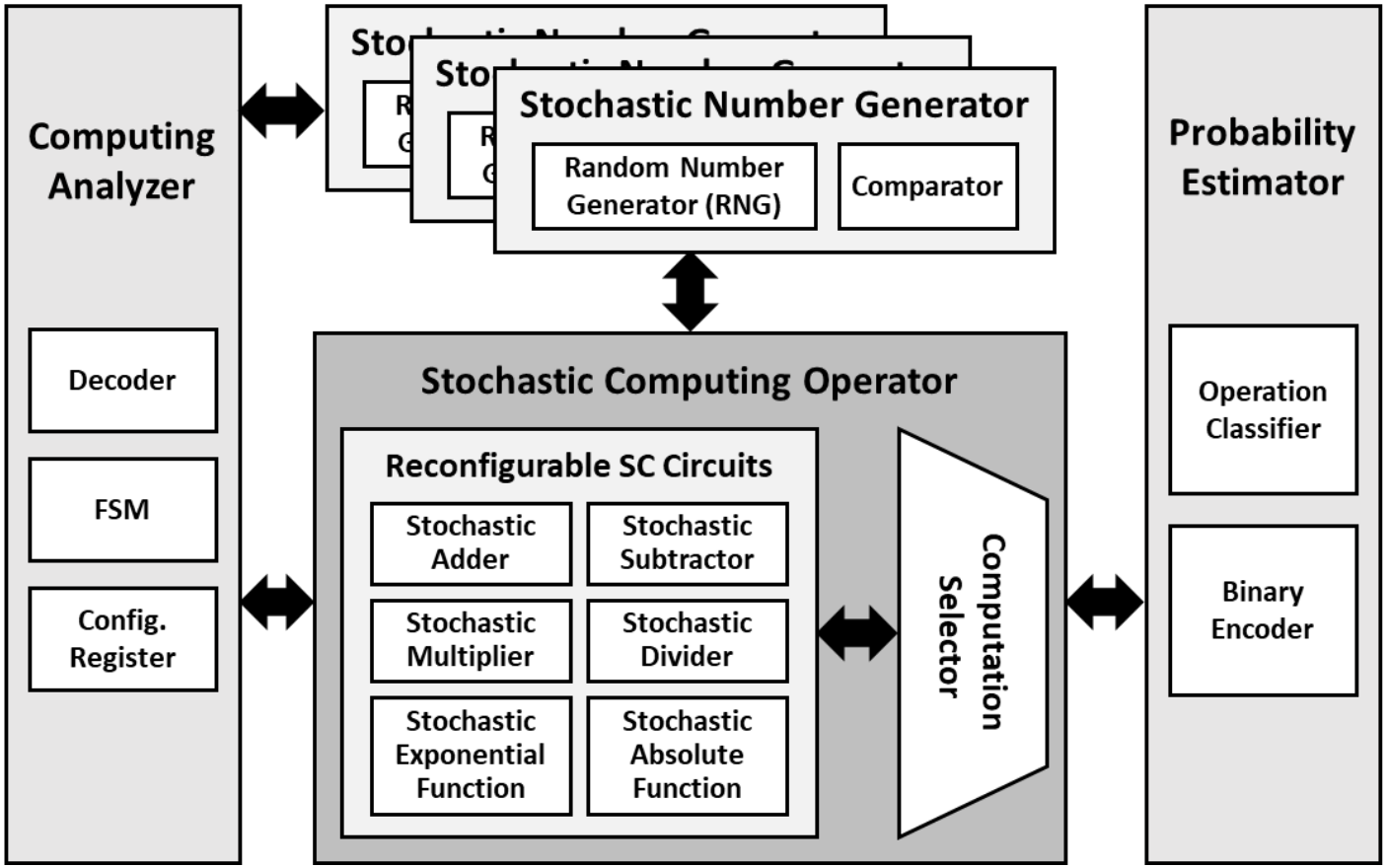
[Our work]

Arithmetic operation + Mathematical functions

$$y = |z_0 - z_1 x| + e^x + \frac{z_2}{z_3}$$

[1] H. El-Derhalli et.al, "OSCAR: An Optical Stochastic Computing AcceleRator for Polynomial Functions," DATE, 2020, pp. 1450-1455.
[2] W. Qian et.al, "An Architecture for Fault-Tolerant Computation with Stochastic Logic," in IEEE Transactions on Computers, vol. 60, no. 1, pp. 93-105.

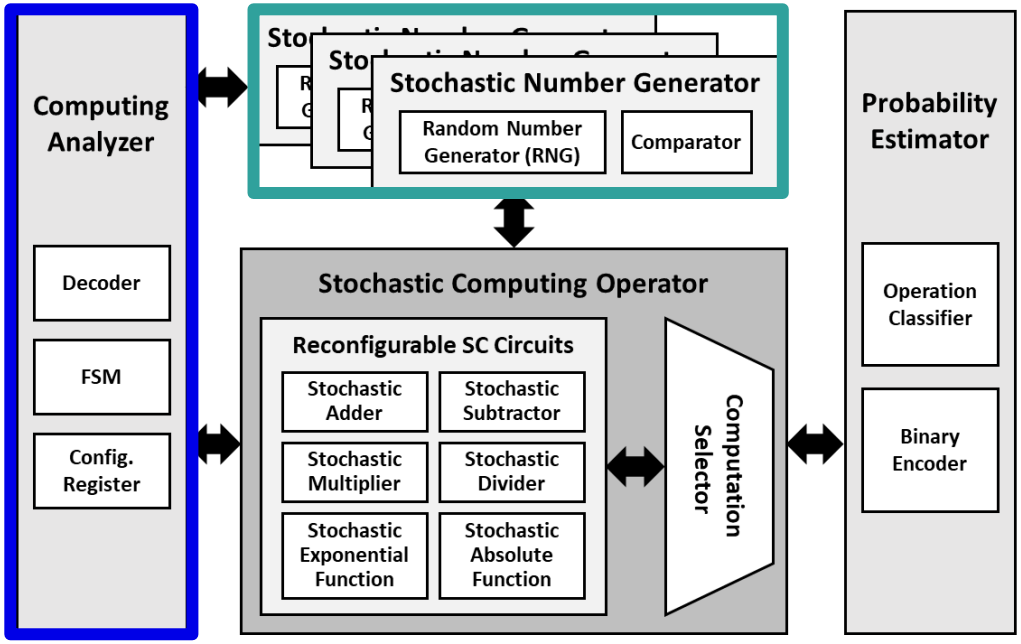
Proposed Architecture



[The proposed architecture of reconfigurable SC unit]

Proposed Architecture

- **Reconfigurable Stochastic Computing**

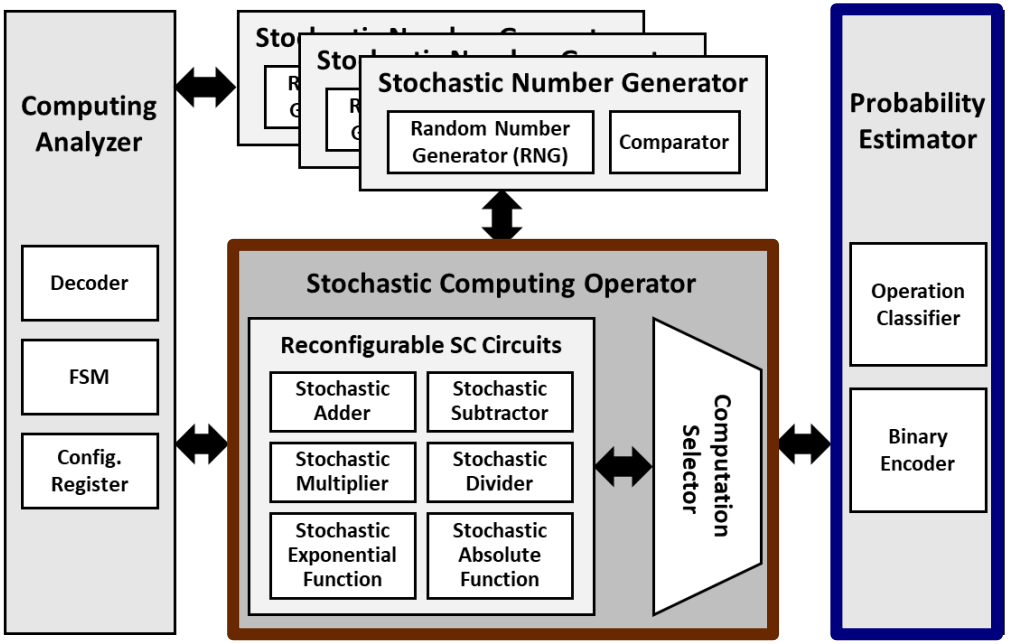


[The proposed architecture of reconfigurable SC unit]

- **Computing Analyzer**
  - Decode the input formula
  - Schedule each operation
- **Parallelized SNGs**
  - Include 8-bit linear feedback shift registers (LFSR)
  - Generate stochastic sequence

Proposed Architecture

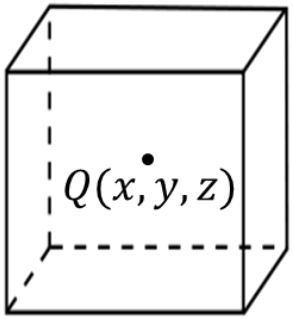
- **Reconfigurable Stochastic Computing**



[The proposed architecture of reconfigurable SC unit]

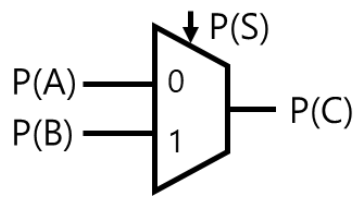
- **Stochastic Computing Operator**
  - Conduct stochastic computations
- **Probability Estimator**
  - Convert the resulting stochastic sequence to binary output

Experimental Results (1)



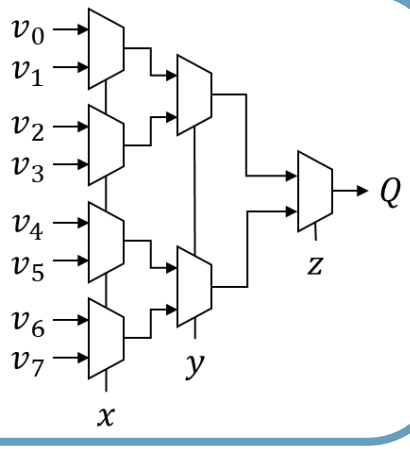
$$
\begin{aligned}
Q = {} & v_0(1-x)(1-y)(1-z) \\
& + v_1(1-x)y(1-z) \\
& + v_2(1-x)(1-y)z \\
& + v_3(1-x)yz \\
& + v_4x(1-y)(1-z) \\
& + v_5xy(1-z) \\
& + v_6x(1-y)z + v_7xy.
\end{aligned}
$$

[Arithmetic expression of Tri-linear interpolation [1]]

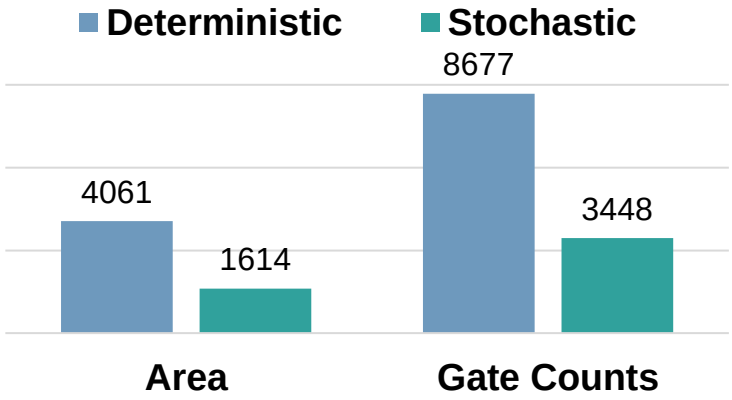


P(C) = (P(A)×(1-P(S)) +(P(B)×P(S))

In case of P(S)=0.5, P(C)=0.5(P(A)+P(B))



[Tri-linear interpolation operator based on SC [2,3]]



	Deterministic	Stochastic
Area	4,061μm^2	1,614μm^2
Gate counts	8,677	3,448

*** 8bit Operation**
***Samsung 28nm, Design Compiler**

[1] Y. Shicai et.al "An high efficient and speed algorithm of Ray Casting in volume rendering," ICCE, 2011, pp. 1027-1030.
[2] P. Li et.al, "Logical Computation on Stochastic Bit Streams with Linear Finite-State Machines," in IEEE Transactions on Computers, vol. 63, no. 6, pp.1474-1486, June 2014.
[3] Stochastic computing, Technology Trend column from IDEC

Experimental Results (2)

- **Image Processing**

[Original Image]

-1	0	+1
-2	0	+2
-1	0	+1

Gx

+1	+2	+1
0	0	0
-1	-2	-1

Gy

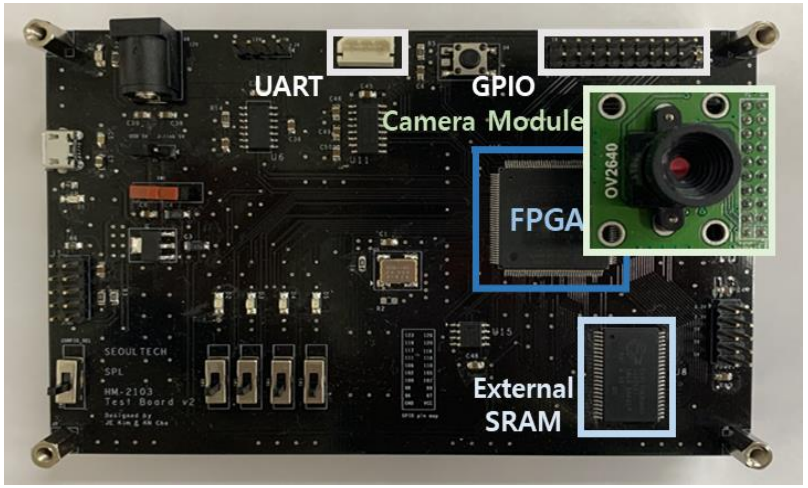
[Sobel Convolution Kernels]

$$|G| = |(P_1 + 2P_2 + P_3) - (P_7 + 2P_8 + 2P_9)| + |(P_3 + 2P_6 + P_9) - (P_1 + 2P_4 + P_7)|$$

[Approximate Gradient Magnitude]

[Deterministic Implementation]

[Stochastic Implementation, Accuracy(avg): 92.4%]



[Verification Prototype]

	Test Board Specifications
FPGA	Altera MAX10 10M50SCE144C8G
Input Voltage	5V / 12V
Operation Freq.	50MHz
Memory	off-chip 512KB SRAM
Camera Module	OV2640 CMOS
Peripheral	Camera I/F, Serial I/F, GPIO

Conclusion

- **Reconfigurable SC architecture**
  : targeting computationally intensive applications

- **39.7% of area reduction with lightweight circuits**
- **92.4% of accuracy on Image processing**

Thank You





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