An Accurate and Compact Hyperbolic Tangent and Sigmoid Computation Based Stochastic Logic

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Outline

- ❑ **Motivation & Background**
- ❑ **Existing Methods**
- ❑ **Stochastic Logic Implementation Based Bernstein Polynomial**
- ❑ **Proposed Architecture**
- ❑ **Experimental Results & Comparisons**
- ❑ **Conclusions**

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Motivation

Hyperbolic tangent and Sigmoid function are widely used, especially signal processing based application

- **High accuracy**
- **Reasonable hardware cost**
- **Fit to the stochastic end-to-end system**

Background

Stochastic computing

Generate a random sequence to represent a number based on fraction of the number 1's in bitstream

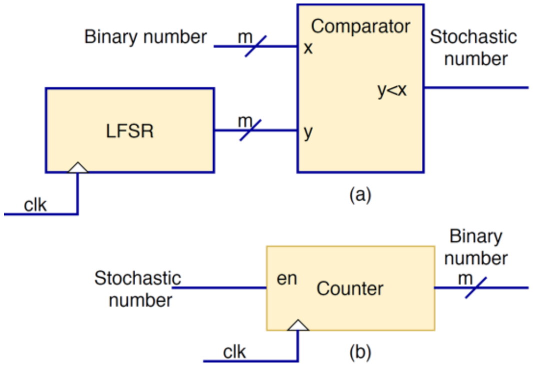
- **Unipolar format**

$$x = p(X = 1) = p(X)$$

- **Bipolar format**

$$x = p(X = 1) - 1 = 2p(X) - 1$$

Format conversion can be done the two format



(a) Stochastic number generator

(b) Converting stochastic number to binary number

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Existing Methods

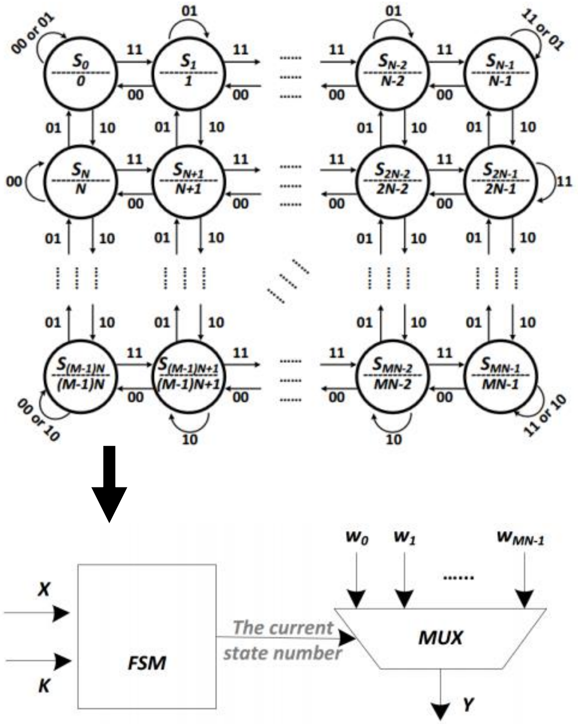
FSM based method

Pros

- Synthesize sophisticated funtions

Cons

- High hardware cost
- Low accuracy



Existing Methods

Series expansion and JK-FFs method

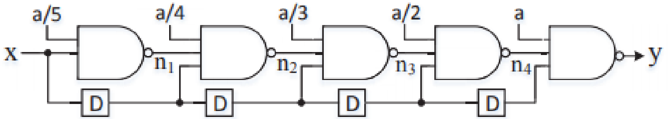
$$\tanh(ax) = \frac{e^{ax} - e^{-ax}}{e^{ax} + e^{-ax}} = \frac{1 - e^{-2ax}}{1 + e^{-2ax}}$$

Pros

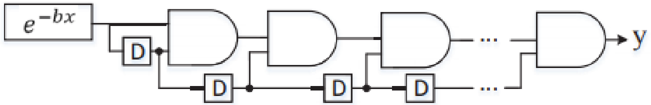
- End-to-end stochastic
- Reasonable hardware cost

Cons

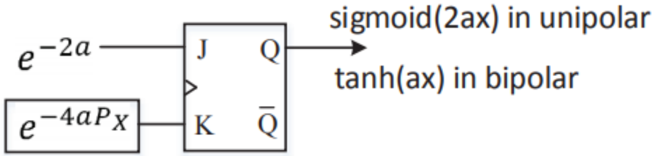
- Low accuracy



Stochastic implementation of e^{-ax} using Maclaurin polynomial



Stochastic implementation of e^{-ax} $(a > 1)$ using e^{-bx} cascaded



Stochastic implementation of $\tanh(ax)$ and $sigmoid(2ax)(a > 1)$ with bipolar input using format conversion

Existing Methods

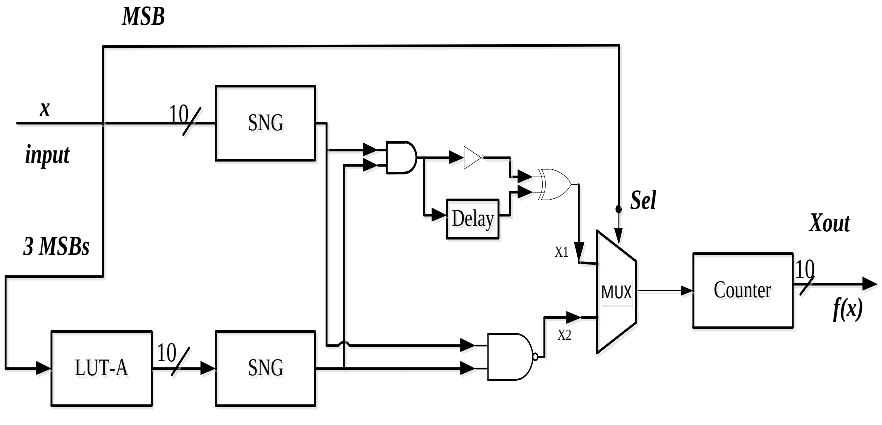
Piecewise linear approximation:

Pros

- Good accuracy
- Reasonable hardware cost

Cons

- Input format conversion from binary to stochastic



The architecture of stochastic implementation of the function e^{-2x}.

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SC based Bernstein Polynomials

- **Polynomial functions $f(x)$ are done by using multiplications and additions**
- **It fails to compute the polynomial functions which computation range is outside [0, 1], e.g $1.2x - 1.2x^2$**
- **For any polynomial functions, transforming a power-form polynomial to a Bernstein polynomial:**

$$B(x) = \sum_{i=0}^{n} b_i B_{i,n}(x)$$

Where $B_{i,n}(x) = \binom{n}{i} x^i (1-x)^{n-i}$.

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Proposed Architecture

Implementing hyperbolic tangent and sigmoid function in the bipolar format

- $tanh(ax) = \frac{1 - e^{-2ax}}{1 + e^{-2ax}} \quad a > 0$
- $sigmoid(2ax) = \frac{1}{1 + e^{-2ax}}$

$\Rightarrow tanh(ax) = 2\frac{1}{1+ e^{-2ax}} - 1$

$= 2sigmoid(2ax) - 1$ [1]

Proposed Architecture

Bipolar format: $\boldsymbol{x = 2P_x - 1}$

- $\boldsymbol{x \in [-1, 1]}$
- $\boldsymbol{P_x \in [0, 1]}$

$\Rightarrow$ **Format conversion between bipolar and unipolar format**

$\boldsymbol{sigmoid(2ax) \in [0, 1]}$ **=> output is unipolar format**

Applying format conversion to equation (1) to same

bitstream of $\boldsymbol{sigmoid(2ax) \Rightarrow tanh(ax)}$

Proposed Architecture

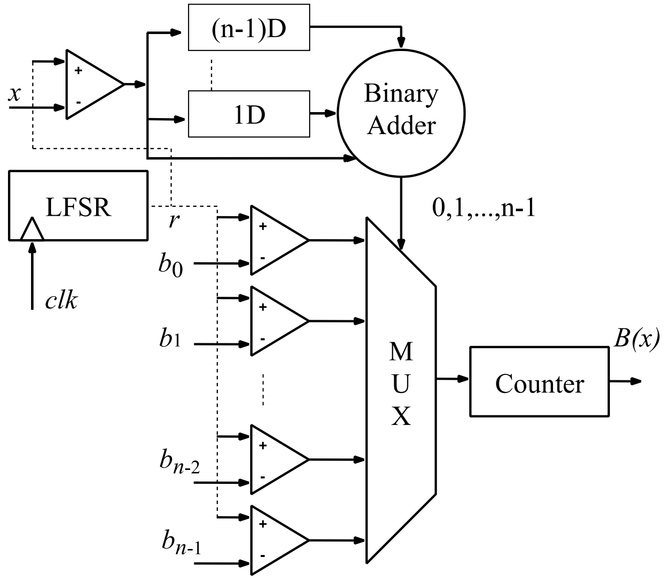
Impmentation of $sigmoid(2ax)$

- $$sigmoid(2ax) = \frac{1}{1+e^{-2ax}}$$

$$= \frac{1}{1+e^{-2a(2P_x-1)}} = \frac{1}{1+e^{-4aP_x}e^{-2a}}$$

$$= \frac{e^{-2a}}{e^{-2a}+e^{-4aP_x}}$$

- **The approximation can now be made by using Bernstein computations.**



Stochastic implementation of $Sigmoid(2ax)$ based Bernstein computation

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Simulations & Experiments Set-up

<u>Design</u>

- $\boldsymbol{Sigmoid(2x), Sigmoid(4x), tanh(x), tanh(2x)}$
- **5th order Bernstein polynomial**

<u>Simulation</u>

- **Matlab**
- **10 bit LFSR**
- **Mean Absolute Error (MAE) results of approximated and target functions**
- **Monte Carlo experiments**

Implementation

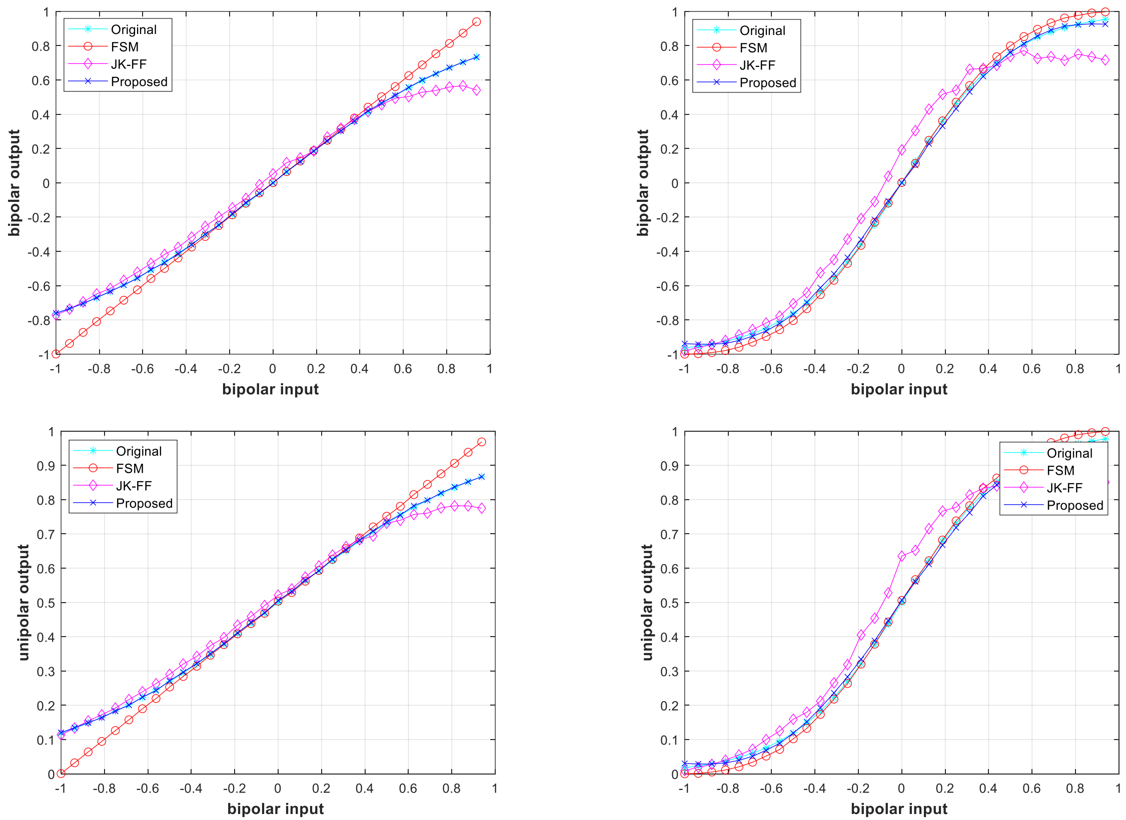
- **Synopsys DC using TSMC 180 nm**

Results & Comparison

Matlab simulation results

Function	Tanh(x) and sigmoid(2x)			
Method	Proposed		FSM [4]	JK-FF [6]
	n=3	n=5	2 states	-
MAE	0.003	0.001	0.06	0.02
Function	Tanh(2x) and sigmoid(4x)			
Method	Proposed		FSM [4]	JK-FF [6]
	n=3	n=5	2 states	-
MAE	0.007	0.003	0.03	0.05

Results & Comparison



Simulation results compared different approaches with target functions: $\mathbf{tanh}(\boldsymbol{x})$, $\mathbf{tanh}(\mathbf{2}\boldsymbol{x})$, $\mathbf{sigmoid}(\mathbf{2}\boldsymbol{x})$, $\mathbf{sigmoid}(\mathbf{4}\boldsymbol{x})$ **respectively**

Results & Comparison

Synopsys DC simulation results

Function	Tanh(x) and sigmoid(2x)			
Method	Proposed		FSM [4]	JK-FF [6]
	n=3	n=5	2 states	-
Area ($(\mu m)^2$)	1554	1777	1345	10121
Latency (ns)	2.25	2.33	2.38	3.42
Power (mW)	0.07	0.08	0.06	0.4

Results & Comparison

Synopsys DC simulation results

Function	Tanh(2x) and sigmoid(4x)			
Method	Proposed		FSM [4]	JK-FF [6]
	n=3	n=5	2 states	-
Area ($(\mu m)^2$)	1777	2106	1551	10476
Latency (ns)	2.33	3.3	3.07	3.07
Power (mW)	0.11	0.11	0.08	0.08

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Conclusions

$sigmoid(2ax)$ **and** $tanh(ax)$ **based Bernstein polynomial in bipolar format:**

- **Comparable hardware complexity**
- **Improvement of accuracy**

Reference

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