GUIDANCE DOCUMENT

This document guides how to run some examples in our manuscript.

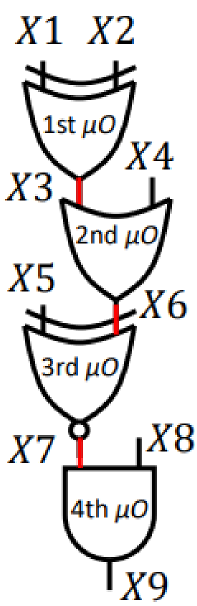
The following folders are different examples attached:

- Cascaded Gates Simple Example
- Image Processing
- Ripple Carry Complex Circuit Example
- XOR with NANDS

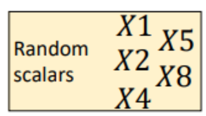
Each subfolder requires `CT.m`, which is the necessary file for simulations. Each folder constructs generic contingency table (CT) set-ups based on the examples; the depth of the circuit and the randomization procedure is important (e.g., *binomial distribution*)

- Cascaded Gates Simple Example

Please refer to the manuscript *Figure 5 (b)* for this example. This is a simple example of CT simulation. The main code file in the folder is: gates cascaded circuit.m



The circuit has four terminals to be assigned with random scalars: X1, X2, X4, X5, and X8. Using 1000-times random assignments, the circuit is simulated for the mean absolute error (`MAE`) calculations.



The probability of each input terminal is calculated considering the bitstream size, *N*.

$$P_{X1} = \frac{X1}{N} \qquad P_{X5} = \frac{X5}{N}$$

$$P_{X2} = \frac{X2}{N} \qquad P_{X8} = \frac{X8}{N}$$

$$P_{X4} = \frac{X4}{N}$$

On the other hand, the other terminals those are binding to the gate outputs: X3, X6, X7, and the final output X9 are calculated for the expected values:

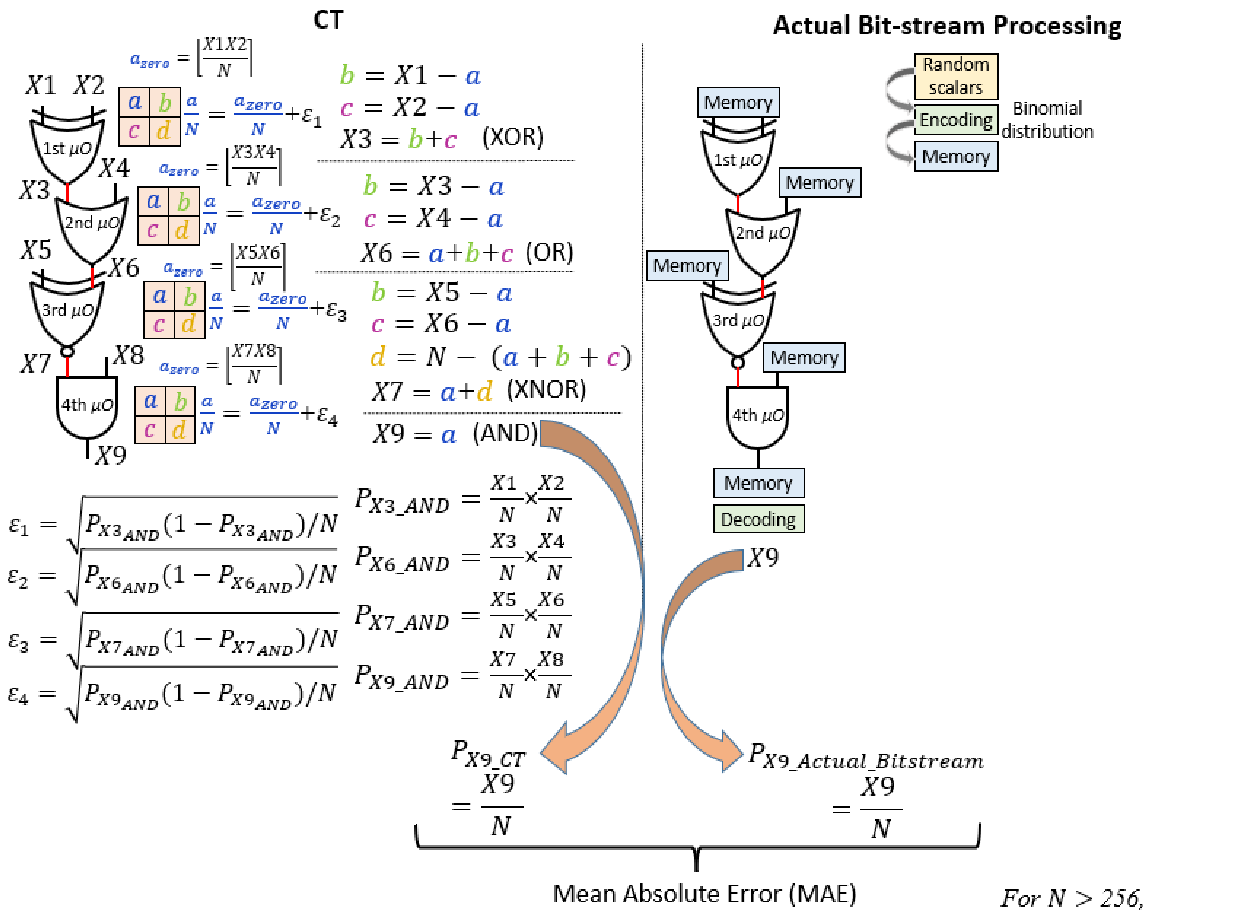
$$P_{X3} = P_{X1} + P_{X2} - 2P_{X1}P_{X1}$$

$$P_{X6} = P_{X3} + P_{X4} - P_{X3}P_{X4}$$

$$P_{X7} = 1 - (P_{X5} + P_{X6} - 2P_{X5}P_{X6})$$

$$P_{X9} = P_{X7}P_{X8}$$

CT-based and actual bitstream-based processing run simulations for the same logic structure. CT handles the model of binomial distributions:



N	8	16	32	64	128	256	512	1024
MAE	0.254	0.212	0.154	0.104	0.068	0.048	0.034	0.024

For $N > 256$, $MAE < 4\%$ which is quite acceptable for image processing applications

Image Processing

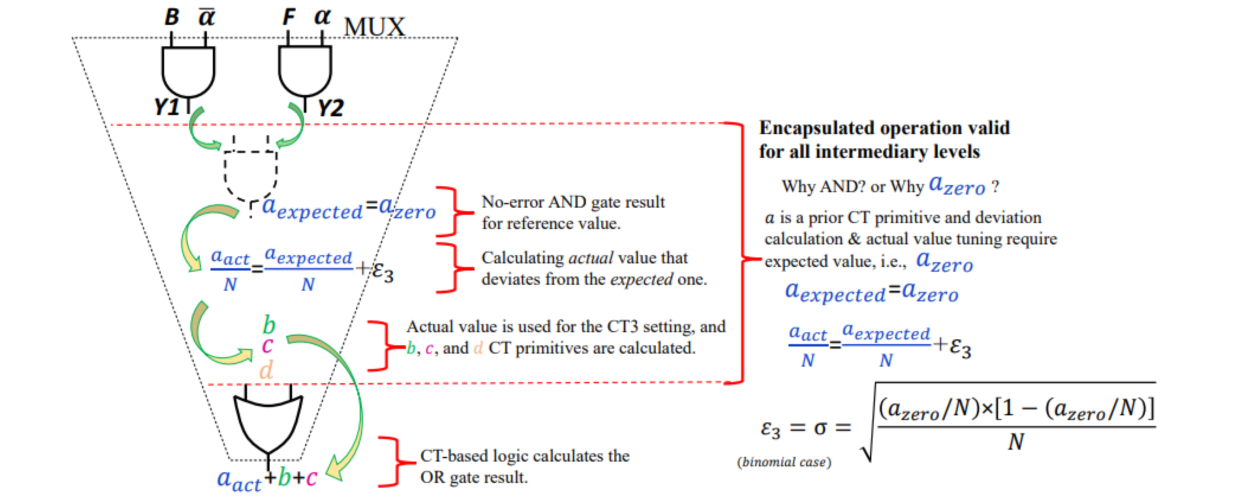
This folder exemplifies the image compositing in the paper. You can use background and foreground images to be composited. Do not forget to use a foreground image having the alpha values.

```
[image, ~, alpha] = imread('your_alpha_image.png');
```

```
background = imread('your_background_image.png');
```

These lines are required to be updated with the file names you use (or use the file names as you see above).

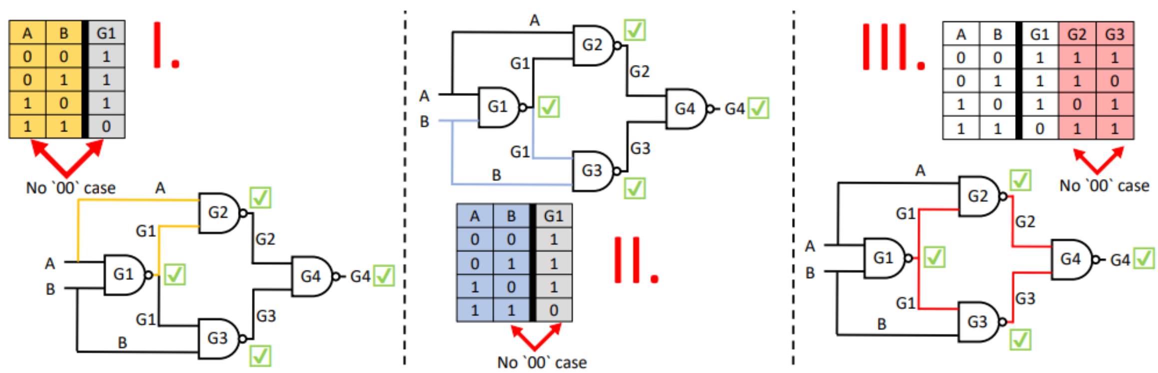
The imitation of random fluctuations is performed using the following approach:



Ripple Carry Complex Circuit Example

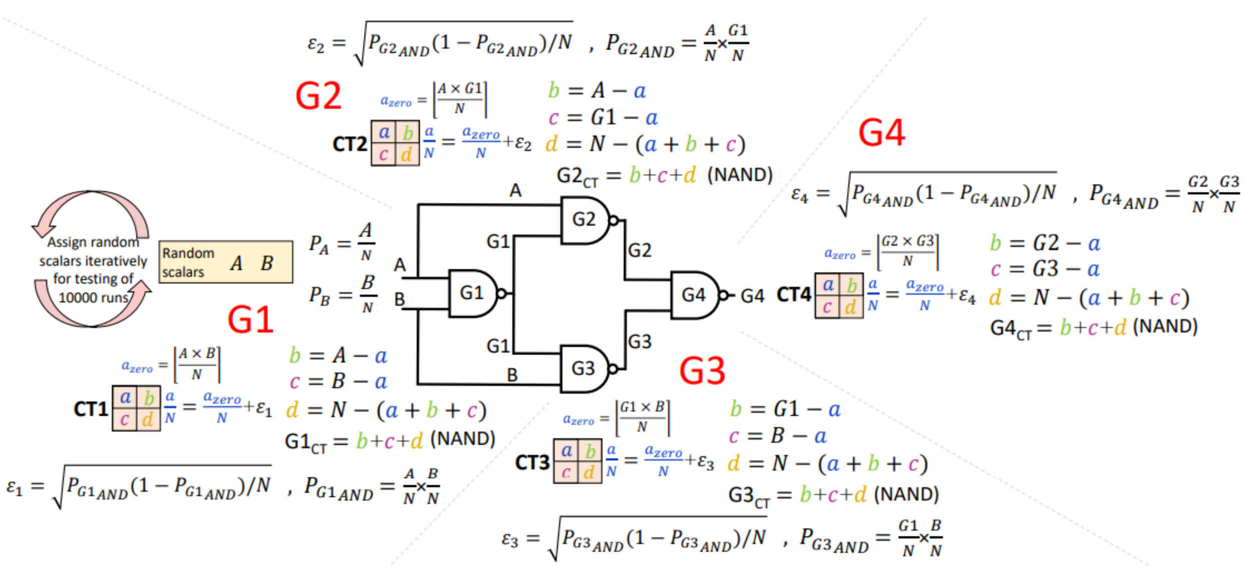
XOR with NANDS

These examples are for the imitation of reconvergent paths in a digital circuit simulation. The second example is simpler:

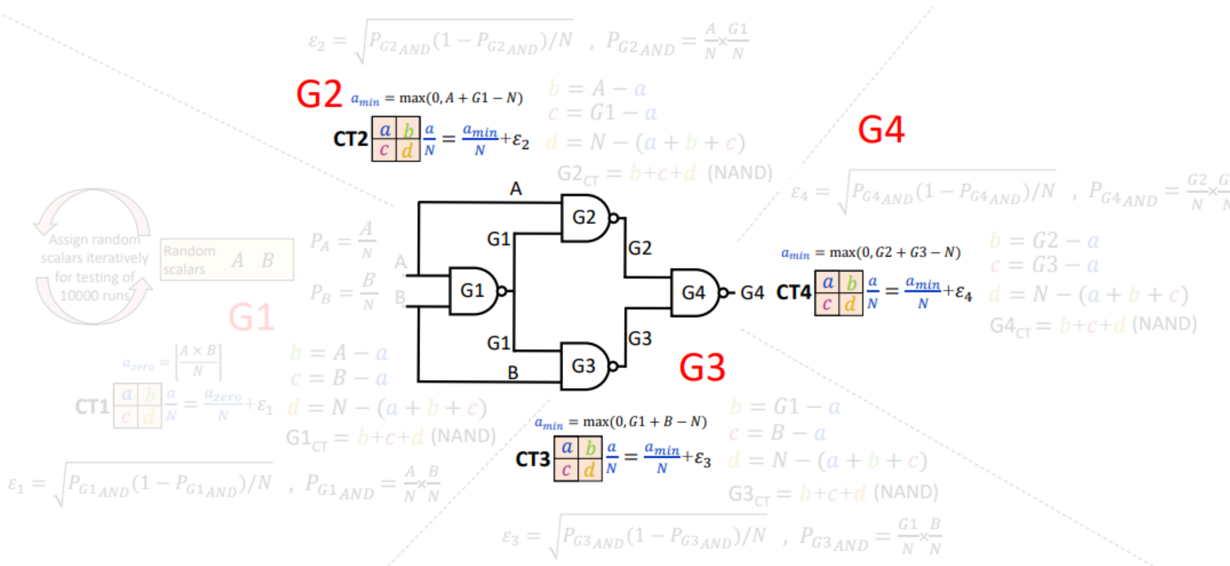


The CT can handle the reconvergent paths colored above. Without and with the awareness of reconvergence are considered:

- Without the reconvergence:



- With the reconvergence:



The error comparison:

<u>Without</u> the awareness of reconvergent paths

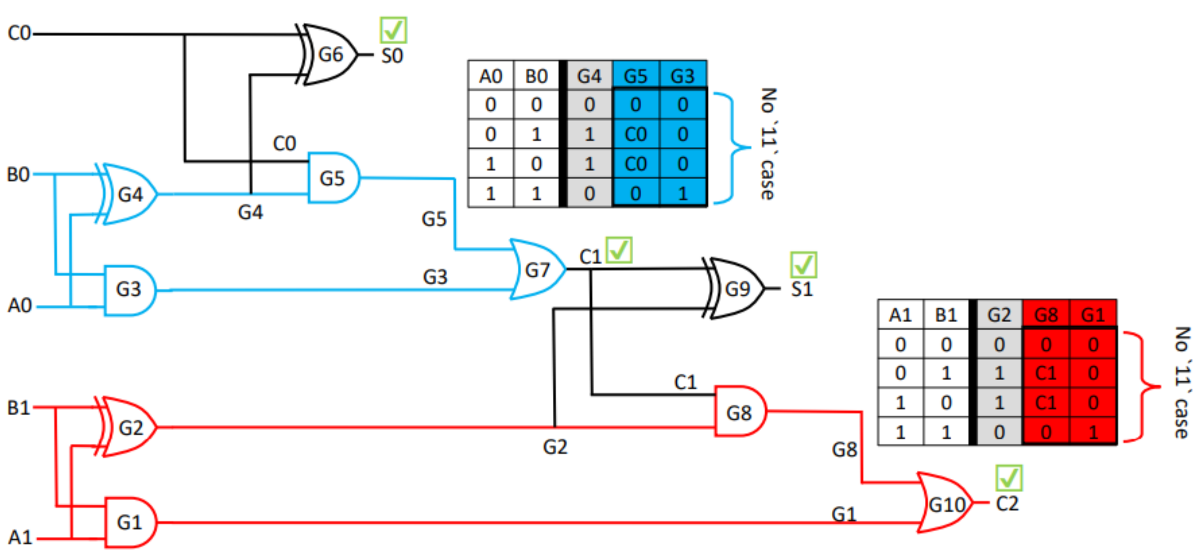
N	8	16	32	64	128	256	512	1024
MAE – G1	*0.124*	*0.102*	*0.072*	*0.051*	*0.036*	*0.025*	*0.017*	*0.012*
MAE – G2	*0.165*	*0.146*	*0.127*	*0.113*	*0.103*	*0.097*	*0.093*	*0.090*
MAE – G3	*0.168*	*0.147*	*0.126*	*0.113*	*0.103*	*0.097*	*0.093*	*0.091*
MAE – G4	***0.131***	***0.097***	***0.076***	*0.068*	*0.068*	*0.068*	*0.070*	*0.071*

<u>With</u> the awareness of reconvergent paths

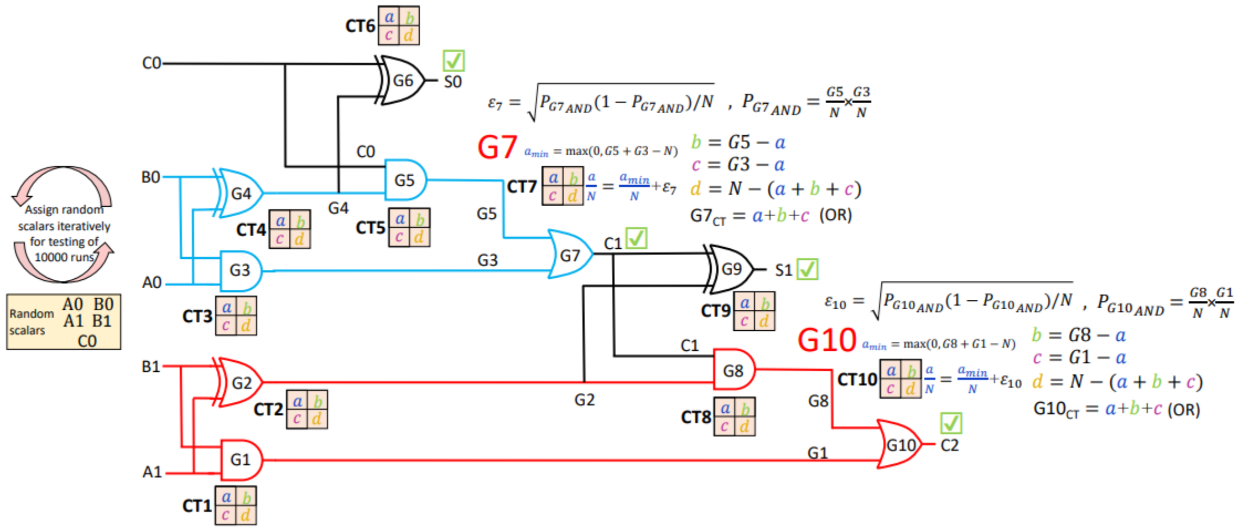
N	8	16	32	64	128	256	512	1024
MAE – G1	*0.124*	*0.101*	*0.072*	*0.051*	*0.036*	*0.025*	*0.017*	*0.012*
MAE – G2	*0.102*	*0.078*	*0.055*	*0.038*	*0.027*	*0.018*	*0.013*	*0.009*
MAE – G3	*0.104*	*0.078*	*0.055*	*0.039*	*0.027*	*0.018*	*0.013*	*0.009*
MAE – G4	***0.147***	***0.113***	***0.085***	*0.059*	*0.041*	*0.029*	*0.020*	*0.014*

Ripple Carry Complex Circuit Example

This is a relatively complex example with deeper network; two reconvergent paths are colored:



The CT-based modelling is as follows:



MAE results of the CT-based simulation with and without the reconvergence awareness:

N	8	16	32	64	128	256	512	1024
✓ *MAE – G6*	0.251	0.192	0.137	0.097	0.069	0.049	0.035	0.025
✓ *MAE – G7*	0.172	0.123	0.099	0.082	0.070	0.064	0.059	0.055
✓ *MAE – G9*	0.282	0.201	0.143	0.104	0.076	0.056	0.042	0.032
✓ *MAE – G10*	0.177	0.129	0.108	0.091	0.082	0.076	0.074	0.074

Without the awareness of reconvergent paths

N	8	16	32	64	128	256	512	1024
✓ *MAE – G6*	0.251	0.192	0.137	0.097	0.069	0.049	0.035	0.025
✓ *MAE – G7*	0.139	0.102	0.072	0.049	0.035	0.025	0.018	0.012
✓ *MAE – G9*	0.267	0.194	0.137	0.098	0.069	0.050	0.035	0.025
✓ *MAE – G10*	0.151	0.111	0.079	0.056	0.040	0.028	0.020	0.014

With the awareness of reconvergent paths