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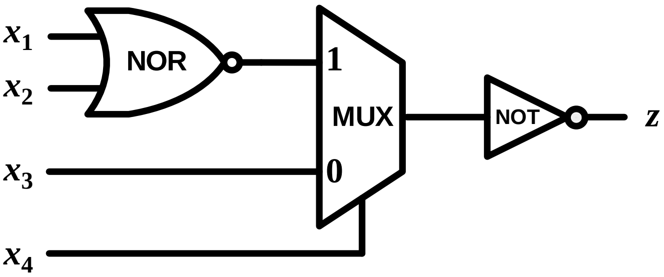
# ELE523E Computational Nanoelectronics
# Homework 3

Deadline: 29.11.2021, before 13:30

## 1. STOCHASTIC COMPUTING

Consider the stochastic circuit shown below.




**a)** Derive a **stochastic** expression of $\boldsymbol{z}$ in terms of the inputs $\boldsymbol{x_1}, \boldsymbol{x_2}, \boldsymbol{x_3}$, and $\boldsymbol{x_4}$. Note that $z, x_1, x_2, x_3$, and $x_4$ all represent probability values.

**b)** Suppose that a bit stream with a probability $p = \frac{1}{2}$ is applied to each of the inputs, i.e., $x_1 = x_2 = x_3 = x_4 = \frac{1}{2}$. Each input should have its own separate stream (each stream is randomly shuffled). For example, 1,0,0,1,0,1,1,0 for $x_1$ and 0,1,0,0,1,1,1,0 for $x_2$. Using the expression found in **a)**, find the value of $\boldsymbol{z}$, and name this value $\boldsymbol{z_{exp}}$. For different sizes of random bit streams, find the error at the output (using a **program** such as Matlab or C). Start with a stream of **8 bits** and increase the number of stream bits until the error is approximately **5%**. Sketch “number of bits in a stream” versus “error”. Error at the output is defined: $\boldsymbol{Error} = \frac{|z - z_{exp}|}{z_{exp}}$.

## 2. IMAGE SHARPENING WITH STOCHASTIC COMPUTING

In this question, a stochastic mean filter is to be realized. A conventional mean filter operates such that each pixel is used around the 9 pixels to do the mean operation. For example:

| unfiltered values | | |
|---|---|---|
| 5 | 3 | 6 |
| 2 | 1 | 9 |
| 8 | 4 | 7 |

5 + 3 + 6 + 2 + 1 + 9 + 8 + 4 + 7 = 45 45 / 9 = 5.

| mean filtered | | |
|---|---|---|
| * | * | * |
| * | 5 | * |
| * | * | * |

Center value (previously 1) is replaced by the mean of all nine values (5).

A renowned image "LENA" is used for evaluations; click here to download. The image has a size of 350×275 and its each pixel has a value between 0 and 255 (binary $11111111_2$). Add **Gaussian noise** with a mean of 0 and variance of 0.008 to the image. Corresponding Matlab function is **imnoise(I,'gaussian',M,V)**. The image and its noisy version are shown below.

**a)** Apply a **conventional mean filter** to the noisy image by directly averaging pixel values and round the averaged values to the nearest integers. Obtain the sharpened image.

**b)** Apply a **stochastic mean filter** to the noisy image with bit streams having ***n*** bits. Each pixel has an independent Binomial distribution with a mean as the pixel's value over 255. Note that ***n*** is the number of trials in binomial distribution. For example, ***n***=255 and a pixel value of 124 correspond to a bit stream such that each of its 255 bits is 1 with a probability of 124/255. Obtain a sharpened image with selecting ***n*=510**. Calculate peak signal-to-noise ratio (**PSNR**) in comparison with the image obtained in **a)**.

- **Hint**: For averaging operation, multiplexers with stochastic select inputs can be used such that the inputs are bit streams representing pixels and the select inputs are bit streams generally having 0.5 probabilities.

**c)** Repeat b) with selecting ***n*=5100**. Obtain the sharpened image. Calculate **PSNR** in comparison with the image obtained in **a)**.

**d)** Compare the realized conventional and stochastic mean filters in terms of **circuit size** (and scalability), **computing time**, and **accuracy**. Justify your answers.

*Grading: 1a)10%, 1b)30%*
*2a)15%, 2b)-c) 30%, 2d)15%*

Note: return harcopies of your homeworks before the lecture