Part I: Dataset Generation & Analysis

This section involves generating datasets from simulations to train regression-based machine learning models. Dataset generation comprises of two main parts, generating Process, Voltage and Temperature (PVT) combinations by sampling these variables from pre-decided distributions and using these values to simulate circuits. Static Leakage power and Propagation delay of the circuit will be measured and will be treated as target variables in the dataset.

PVT variations for all standard cells must be generated. It should contain 30k samples.

Technology nodes: 45nm MGK, 32nm MGK, 32nm HP, 22nm MGK, 22nm HP, 16nm HP.

Target Output: Leakage Power, Propagation Delay

Cells(choose 15): NOT, NAND2, NOR2, XOR2, NOR4, NOR3, NAND4, NAND3, MUX41, MUX31, MUX21, FA, LDHQ, DFPRQN, DFPQ, DFPHQ, AND4, AND3, AND2, A033, A032, A031, A022, A0222, A0212, A012, A0112

Netlist Simulator: NGSPICE

The range of PVT distributions must be decided accordingly. PVT values must be swept such that they satisfy the Monte-Carlo distribution. NGSPICE will be used to perform the simulations.

1. Generate PVT variation matrix of desirable size 30k.

PVT are:

Temp: Temperature range should be from -55 to 125 Celsius (uniform distribution).

Pvdd: ±10% variations from nominal must be considered (uniform distribution).

Cqload: For Delay consider cqload variations from 0.01f to 5f (uniform distribution).

Lmin: 22nm to 26nm (if tech=22nm MGK)

Wmin: 22nm to 440nm (if tech=22nm MGK)

For Process, consider the values in the PTM file as nominal standards and vary it with ±3σ variations satisfying Monte Carlo distribution, (i.e, mean = nominal, std = mean/30) :

toxe_n: electrical oxide thickness of nmos

toxm_n: physical oxide thickness of nmos

toxref_n: reference oxide thickness of nmos

toxe_p: ...of pmos

toxm_p: ... of pmos

toxref_p: ... of pmos

toxp_par: parasitic parameter

xj_n: junction depth of nmos

xj_p: junction depth of pmos

ndep_n: doping concentration of nmos

ndep_p:... of pmos

1. Distributions for variables:
   a. consider uniform random distributions for temperature, voltage and cload. Normal distributions for toxe, toxm, toxppar, toxref, xj, ndep
   b. lmin, wmin are channel dimensions say 22e-9 in 22nm.
   c. The ML model performance is dependent on the data quality and quantity.

2. The standard cell circuits will be provided to you.

3. Use them to design netlists - Reference netlists will be provided as well.

4. Include PVT variation matrix in the above netlist - Find reference PVT martrix in 'HSPICE PVT netlists for reference' folder

5. Launch the simulations in ngspice after checking the netlists thoroughly and save the generated performance matrix in csv/excel.

6. Once you have the dataset with you, you will perform **EDA(Exploratory Data Analysis)** to analyze the data, **find patterns** and report your observations. Eval 1 will be taken till this part. Along with Eval 1, you will be submitting a project proposal on the assigned theme. You will receive feedback on the approach you are considering to take for the next part.

Methodology:

Construct spice netlists for all standard gates.

• Generate 30k PVT distributions within the bounds mentioned above and store it in an input file. **CAUTION**: For each PVT there will be samples based on the input combination. For example, if an input gate has 4 combinations (00, 01, 10, 11), it will generate 4 samples for each PVT value. For reference, Table 1 of Assignment 1 has been provided.

• Use your constructed spice netlist to sweep across the generated PVT samples (input file) and generate leakage and delay dataset i.e output labels are leakage, delay lh nodea, delay hl nodea, delay hl nodeb, delay hl nodeb (for 2 i/p nodea & nodeb). **NOTE**: Spice directives for delay estimations are provided in the circuit images. For leakage drop cqload and perform DC analysis. For delay drop dc inputs and perform transient analysis (using PWL signals as input taking single PVT at a time).

• The final dataset would look like Table 1 in Assignment 1 (30**k pvt * 2^{no.of inputs}** total samples for leakage and 30k for delay) with additional leakage and delay columns concatenated into it.

Part II: Machine Learning

1. Develop ML models (**regression models**) to estimate leakage and delay of respective standard cells.

2. Based on the approach you have developed, you will perform leakage and delay estimation of standard cells with as little error as possible. Your approach will be scored based on **standard metrics (R2Score, MSE** etc)

3. Following are the tentative **themes** that you might receive:
   a. Meta-Learning: for eg. ensemble based approaches of classical machine learning models etc.
   b. Deep-Learning: for eg. Use of deep neural network etc.

and based on it and prior EDA, each team must propose **unique implementation/architecture designs** for their regression models before or during their Eval1.