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# Algorithm and evaluation of generating pseudo-datasets for integrated circuit power analysis

**Key words:** Graph computation; Electronic design automation (EDA); Pseudo-dataset; Average power analysis

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# Motivation

1. Power analysis plays a pivotal role in the design of large-scale digital integrated circuits (ICs), where accurate and efficient power evaluation during the design phase can substantially improve the chip performance.
2. Despite the advancements in power analysis techniques, the requirement for extensive circuit data and diverse topological scenarios remains a significant challenge.
3. In response to the limitations of existing datasets, to support the needs of machine learning (ML)-driven average power analysis methods, we propose a novel pseudo-circuit dataset generation algorithm specifically tailored for power analysis.

# Main idea

1. Random directed acyclic graphs (DAGs) are created, followed by mapping DAG nodes to gate-level nodes to form combinational circuits.
2. By integrating register units, these combinational circuits are converted into sequential circuits, which are subsequently optimized using the Synopsys design compiler.

# Method

1. We propose an efficient and rapid algorithm for generating random DAG topologies and then generating random combinational circuit netlists.

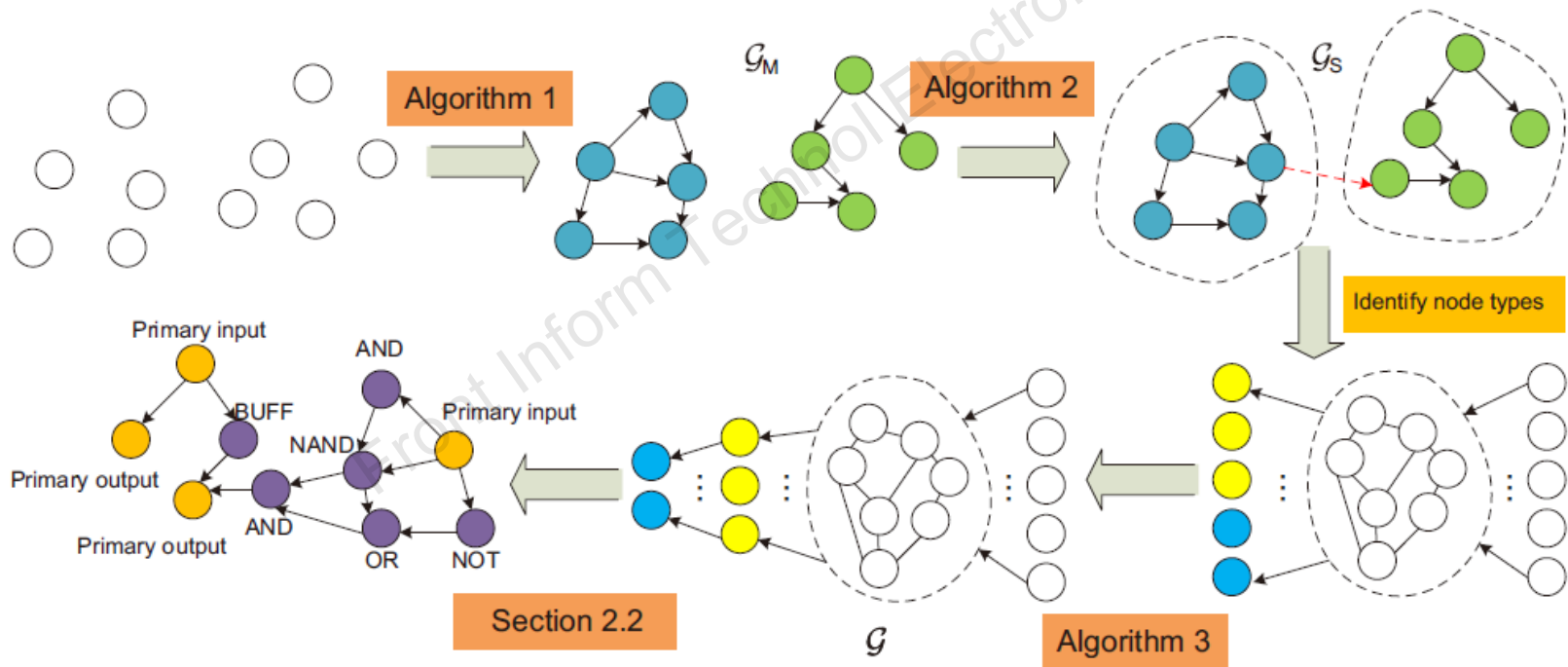


Fig. 2 Random combinational circuit netlist generation. Algorithm 1 processes the nodes into different connected components, Algorithm 2 transforms multi-connected components into a single-connected component, and Algorithm 3 adjusts the number of identified output pins. Finally, the generated DAG topology is converted into the combinational circuit netlist in Section 2.2

# Method (Cont'd)

1.1 We introduce the random multi-connected component DAG generation method in Algorithm 1, which efficiently establishes the initial connections within  $G$ .

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**Algorithm 1** Random multi-connected component DAG generation method

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**Require:** Graph  $\mathcal{G}$  defined only by nodes without edges

**Ensure:** Multi-connected DAG graph  $\mathcal{G}_M$

```
1:  $S \leftarrow \mathcal{W} + \mathcal{X}$ 
2: for all  $o \in \mathcal{O}'$  do
3:   Randomly select  $\gamma$  nodes from  $S$  as parent nodes
   for  $o$ , forming the set  $\mathcal{P}$ 
4:   for all  $p \in \mathcal{P}$  do
5:     Add edge  $\langle p, o \rangle$  to  $\mathcal{G}$ 
6:     if  $\mathcal{G}$  does not conform to DAG structure then
7:       Remove edge  $\langle p, o \rangle$ 
8:     end if
9:     Add  $p$  to  $S$ 
10:  end for
11: end for
```

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# Method (Cont'd)

1.2 Algorithm 2 enhances the graph structure by examining and connecting separate components, ensuring that the graph maintains weak connectivity and forms a single-connected component.

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**Algorithm 2** Single-connected component assurance

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**Require:**  $\mathcal{G}_M$   
**Ensure:**  $\mathcal{G}_S$

- 1:  $\mathcal{G}_S = \mathcal{G}_M$
- 2: **while**  $\mathcal{G}_S$  is not weakly connected **do**
- 3: List all connected components of  $\mathcal{G}_S$
- 4: Select different nodes from two different components
- 5: Connect these two nodes
- 6: Update  $\mathcal{G}_S$
- 7: **end while**

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# Method (Cont'd)

1.3 By post-processing with Algorithm 3, the resultant computational graph forms a single-connected DAG, which is suitable for implementation in combinational circuits.

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**Algorithm 3** Adjustment of the primary output nodes

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**Require:**  $\mathcal{G}_S$  and the expected output node number  $n$

**Ensure:** Computational graph  $\mathcal{G}$  with adjusted output

```
1: Let  $\mathcal{G} = \mathcal{G}_S$ 
2: while true do
3:    $\mathcal{O}_S \leftarrow \mathcal{G}$ 
4:    $\mathcal{O}_S^+, \mathcal{O}_S^- \leftarrow \mathcal{O}_S$ 
5:   for all  $\sigma \in \mathcal{O}_S^+$  do
6:     Select nodes from  $\mathcal{O}_S^-$  as parent  $\mathcal{P}_S$  for  $\sigma$ 
7:     for  $p \in \mathcal{P}_S$  do
8:       Add edge  $\langle p, \sigma \rangle$  to  $\mathcal{G}$ 
9:     end for
10:  end for
11:  if the number of output nodes in  $\mathcal{G}$  approximates  $n$  then
12:    Break loop
13:  end if
14: end while
```

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# Method (Cont'd)

2. The transformation from a combinational circuit netlist to a sequential circuit netlist can be facilitated by introducing registers. This method involves selecting a specific number of primary inputs and outputs from the existing gate-level combinational circuit and connecting them using predefined gate-level registers. This process effectively transforms the DAG combinational circuit into a directed cycle graph (DCG) structure pseudo-sequential circuit netlist.

# Major results

Pseudo-power datasets and comparison with state-of-the-art dataset methods

**Table 1 Overview of pseudo-power datasets**

Type	Metric	Number of input nodes	Number of output nodes	Number of wires	Number of logical gates	Number of registers
Combinational circuit	Mean	49	58	3311	3370	
	Min	22	35	887	939	
	Max	79	83	5638	5715	
Sequential circuit	Mean	254	256	4769	4918	107
	Min	90	98	686	1104	37
	Max	436	440	4950	7429	185

**Table 2 Comparison between the proposed power consumption dataset and the ML EDA dataset of application-specific integrated circuit (ASIC) and field programmable gate array (FPGA) in existing studies**

Work	Number of cases	Number of sources	Platform & level	Usage
CircuitNet (Chai et al., 2022)	20 000	6	ASIC PR design	DRC; IR drop
OpenABC-D (Chowdhury et al., 2021)	870 000	29	ASIC RTL	Synthesis
HLSDataset (Wei et al., 2023)	19 000	34	FPGA HLS	Power; timing
Spector (Gautier et al., 2016)	8000	9	FPGA HLS	NA
Proposed	Unlimited	NA	ASIC gate-level Verilog	Power

NA: not available; PR: placement & routing; HLS: high-level synthesis; DRC: design rule checking

# Major results (Cont'd)

## Power result

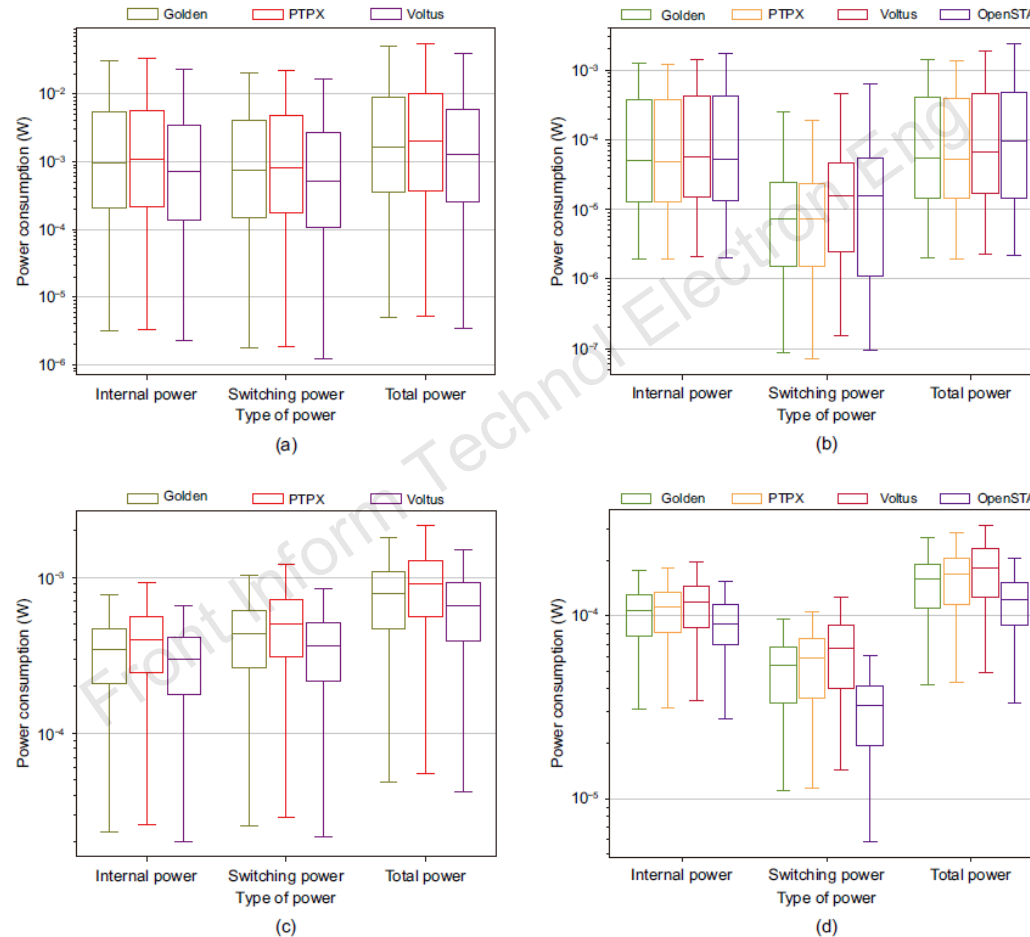
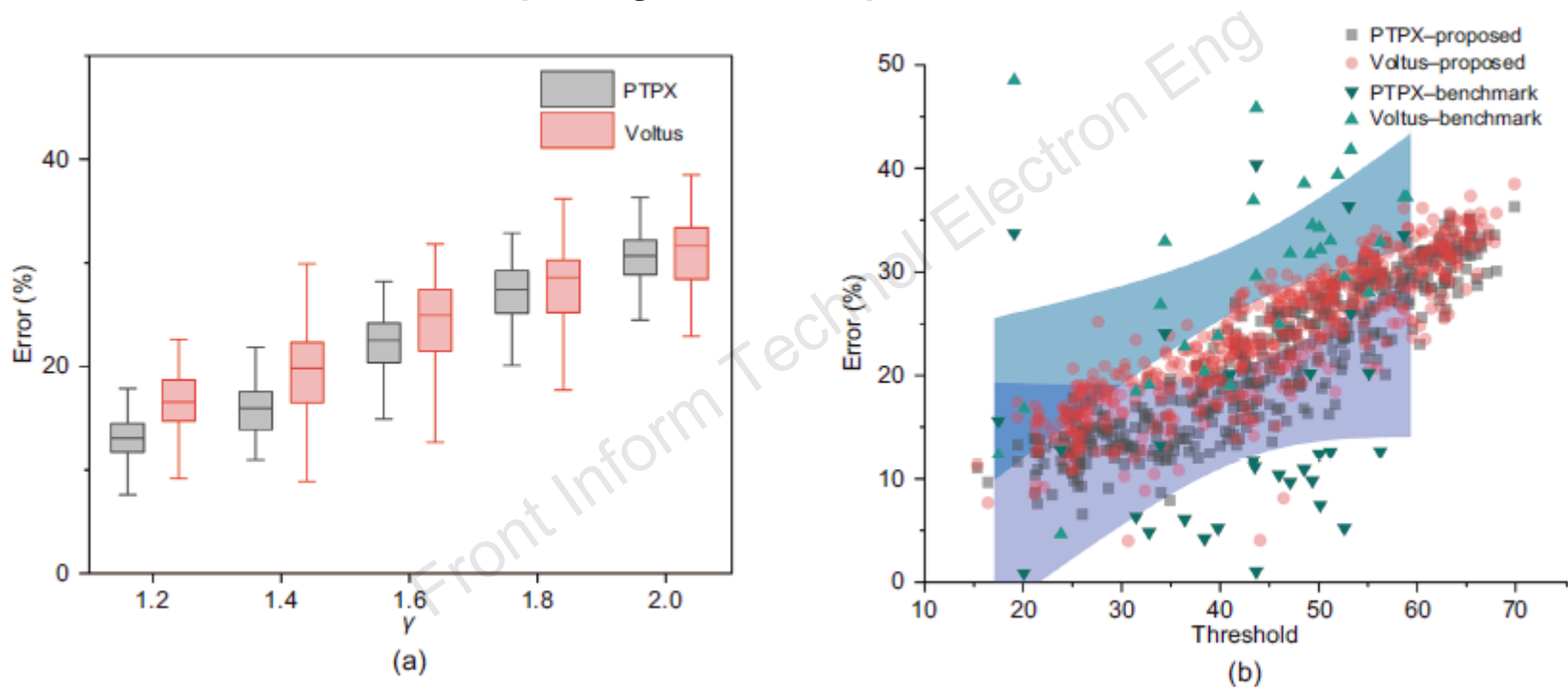


Fig. 4 Results of the three power consumptions for all samples shown on the left for combinational circuits and on the right for sequential circuits: (a) benchmark combinational circuit power consumption; (b) benchmark sequential circuit power consumption; (c) proposed combinational circuit power consumption; (d) proposed sequential circuit power consumption. References to color refer to the online version of this figure

# Major results (Cont'd)

Simulations on the topological complexities



**Fig. 5** Simulations on the topological complexities of the generated combinational circuits, where the vertical coordinates are all the total power consumption errors: (a) effect of  $\gamma$  value on the power consumption error; (b) threshold measures, where the upper blue region is the 95% confidence interval of the PTPX error for benchmark and the lower purple region is the 95% confidence interval of the Voltus error

# Conclusions

1. Unlike traditional approaches, the proposed method uses graph topology computation to efficiently generate random DAG structures.
2. These DAGs are transformed into pseudo-combinatorial circuit netlists, with registers added to convert them into pseudo-sequential circuit netlists.
3. We manage the complexity of these circuits by setting hyperparameters. By examining complexity and comparing it with that of the benchmark datasets, the results demonstrate and validate the effectiveness of the proposed dataset.



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