Monte Carlo Algorithm for Leakage Optimization Based on Input Vector Control

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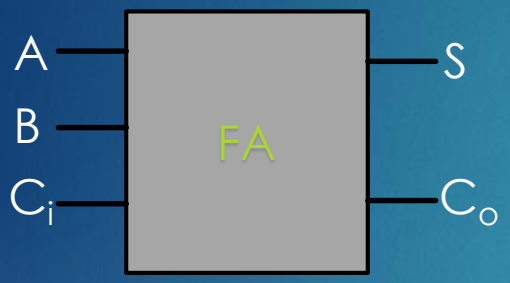
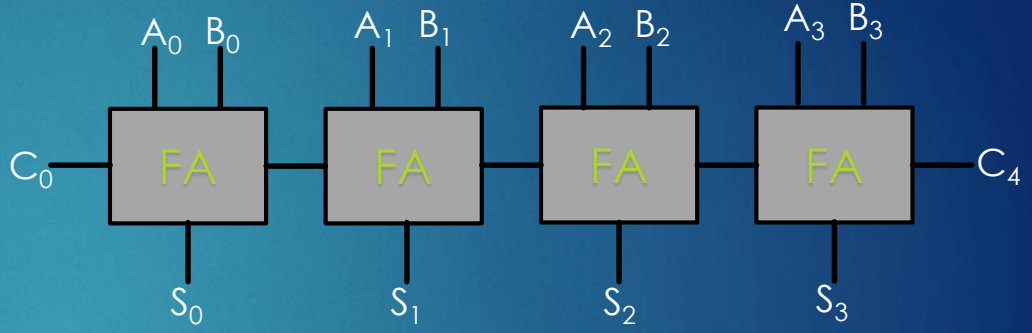
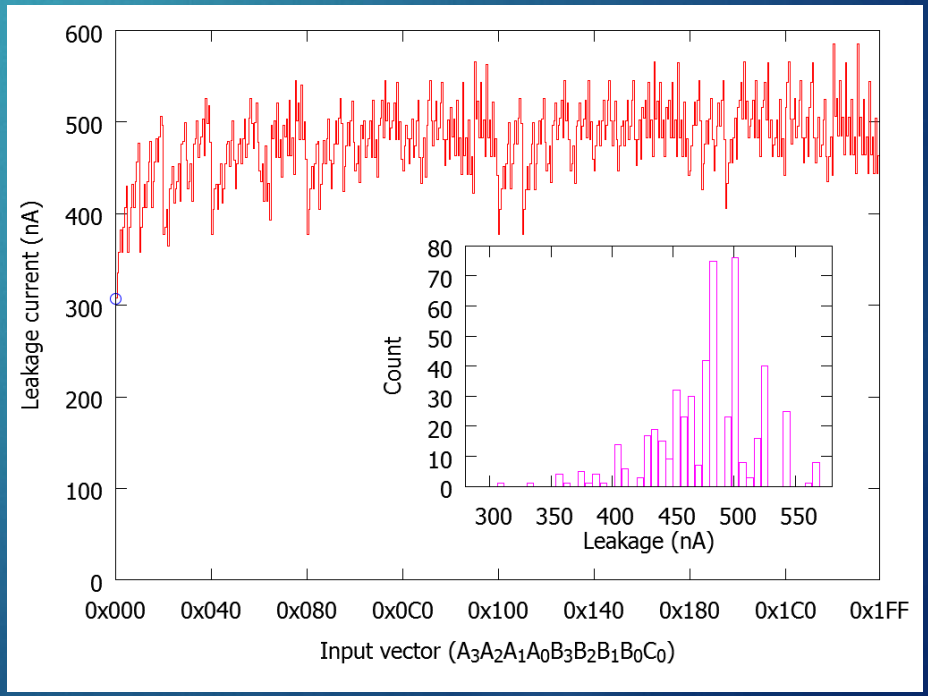
Input Vector Control

- A method for reducing leakage power consumption





Input vector(A,B,Ci)	Output(S ,Co)	Leakage/ nA
000	00	76.97
001	01	104.60
010	01	126.48
011	10	124.12
100	01	146.35
101	10	126.51
110	10	146.13
111	11	105.73



Extracted from Cadence GSCLIB090 ADDFXL

Finding the best input vector

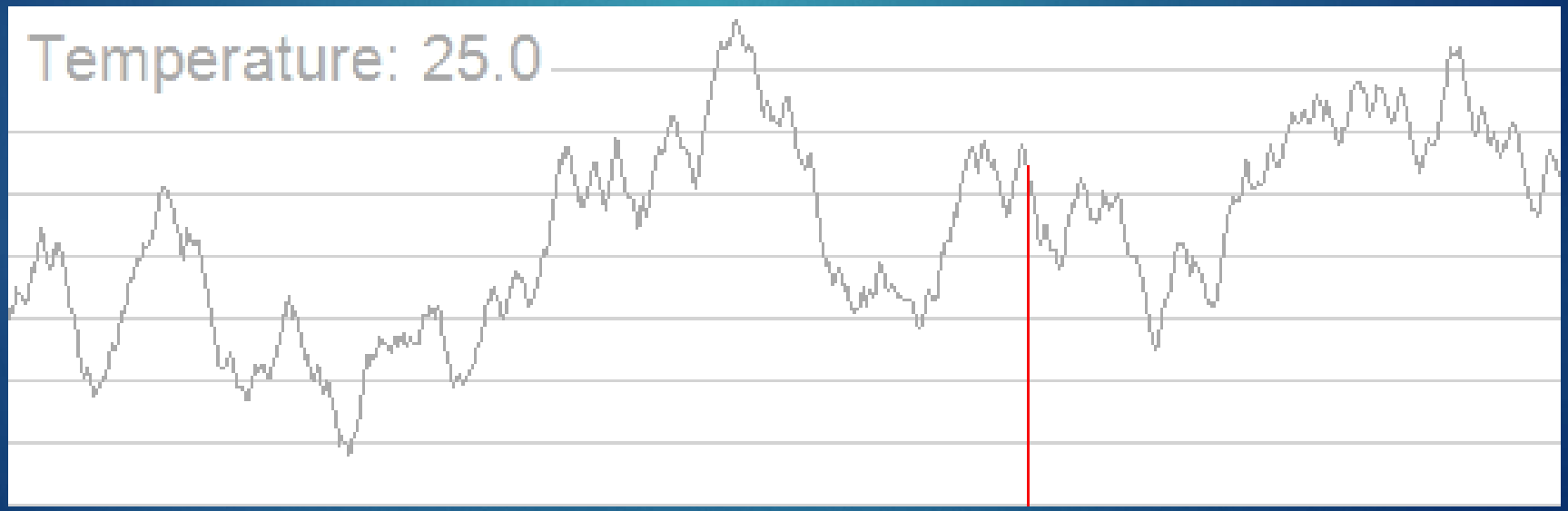
- NP-Complete problem
  - Heuristic algorithm
  - Random search
- Existing Algorithms
  - Linear programming
  - Dynamic programming
  - 2-SAT
  - Random searching
- Problems
  - Slow
  - Sub-optimal result

Random search

- A large class of algorithms based on random numbers
- Crude and simple, but can be sometimes effective
- Simplest random search:
  - n=64 inputs
  - Number of state $N=1.845\times10^{19}$
  - Random search ~10^{8} states

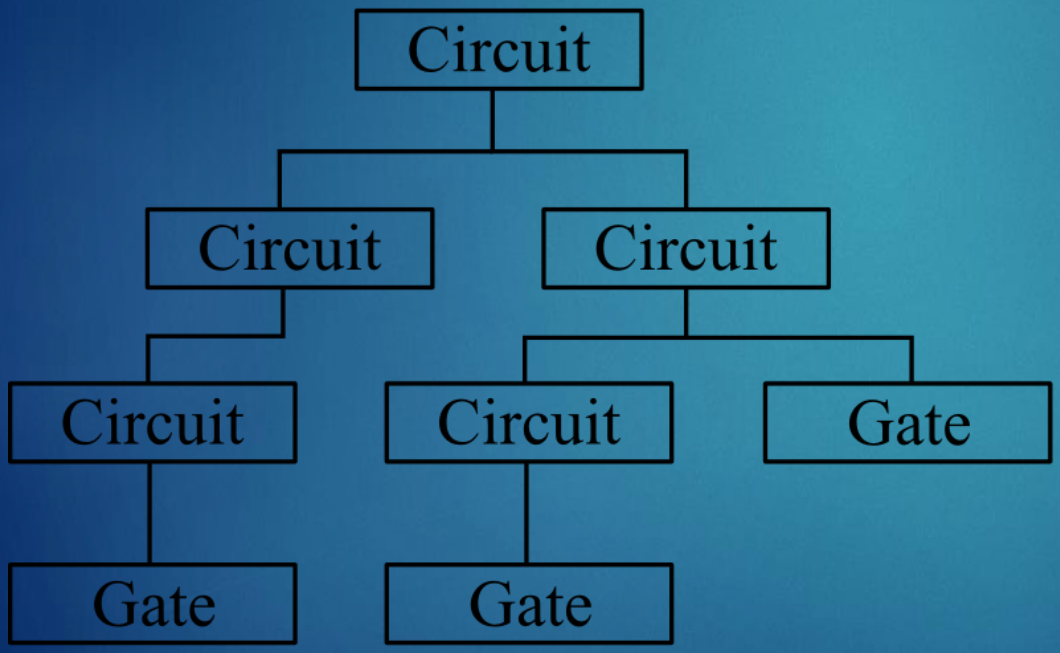
Improvement: Simulated Annealing

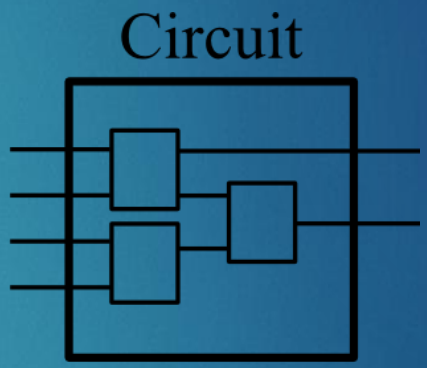
- Analogue of thermodynamics problem
- Temperature *T*: characterizes the randomness

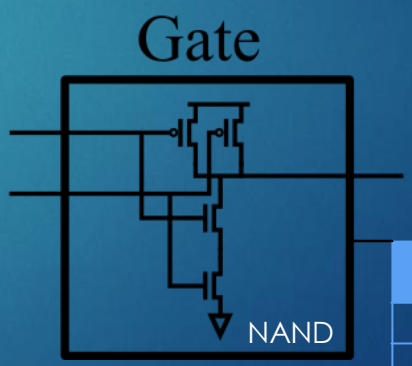


Simulation model

- Hierarchical model for simulating combinational logic

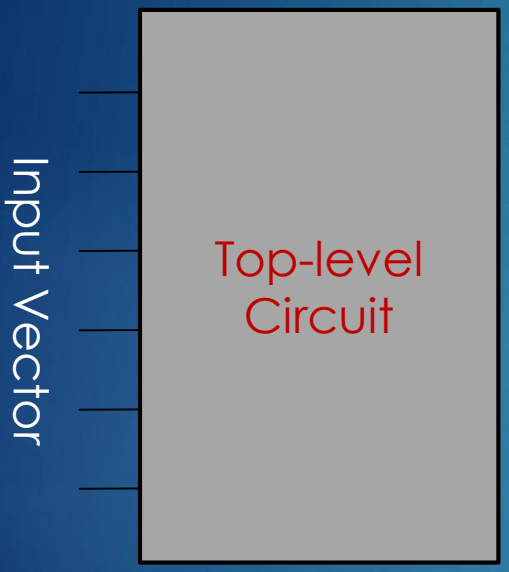






Input	Output	Leakage /nA
00	1	1.37
01	1	28.92
10	1	52.53
11	0	1.259

Implementation




```
Minimize_Leakage(C, n)
    input[] = random(n);
    leak = evaluate(input);
    T = T0;
    while(T<Tfinal){
        index = random(n);
        input[index].flip();
        new_leak = evaluate(input);
        if(new_leak < leak){
            leak = new_leak;
            // save input vector
        }
        else{
            prob = e^-(new_leak-leak)/T;
            if(random() < prob){
                leak = new_leak;
            }
            else{
                // restore
                input[index].flip();
                continue;
            }
        }
        T = (1 - a) * T;
    }
```

Extra heuristics

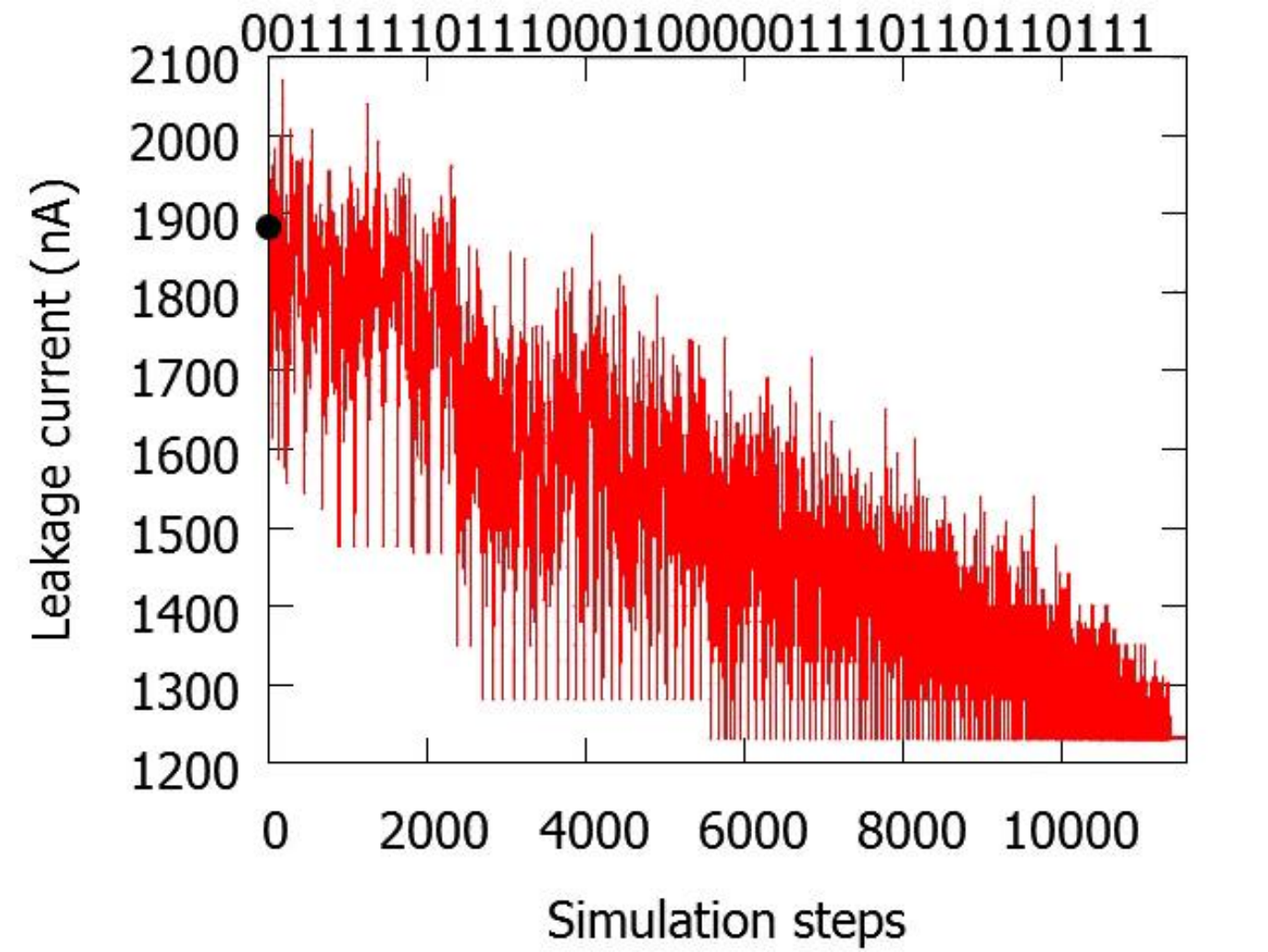
- Since only one bit is flipped, possibility of getting stuck
  - Example: T=0.5
  - 0000000011000000 10
  - 0000000010000000 15
  - 0000000001000000 15
  - 0000000000000000 8
- Solution: Do relaxation after several iterations
  - Enumerate and try all possible two-bit flips

Results and Discussion

- Everything implemented in Java
  - 2535 lines of code
- NOT, AND, OR, NAND, NOR, XOR, FA, etc. tens of gates extracted from GSCLIB090 technology library.
- Tested on a number of benchmark circuits

Simulated Annealing

16-bit Adder



Benchmark

Circuit	Inputs	Gate count	Min. Leakage(nA)	Time(s) (By bruteforcing)	Avg. annealing Leakage(nA)	Time(s) (By annealing)	Ratio
Adder-4	9	4	307.9	0.1	307.9	0.1	1.00
C17	5	6	35.4	0.1	35.4	0.1	1.00
C432	36	160	3360.6	-	3389.1	1.0	1.008
C880	60	383	9716.7	-	9815.9	6.0	1.010
C1355	41	546	11081.9	-	11081.9	5.0	1.00
C3540	50	1669	52588.5	-	52588.5	25.0	1.00
C6288	32	2416	75939.3	-	75939.3	22.0	1.00
C7552	207	3512	1.05×10^5	-	1.07×10^5	439.0	1.019

ISCAS85 Benchmark circuits

Conclusion

- An improved version of random search for input vector control is developed based on widely-used simulated annealing algorithm
- The effectiveness and validity of the algorithm is verified.
- Possible further improvements
  - Use more efficient programming language such as C++

References

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Thanks!