NuCAD

Pessimism Reduction in Static Timing Analysis using Timing and Logic Filtering

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Industry Support

intel Leap ahead

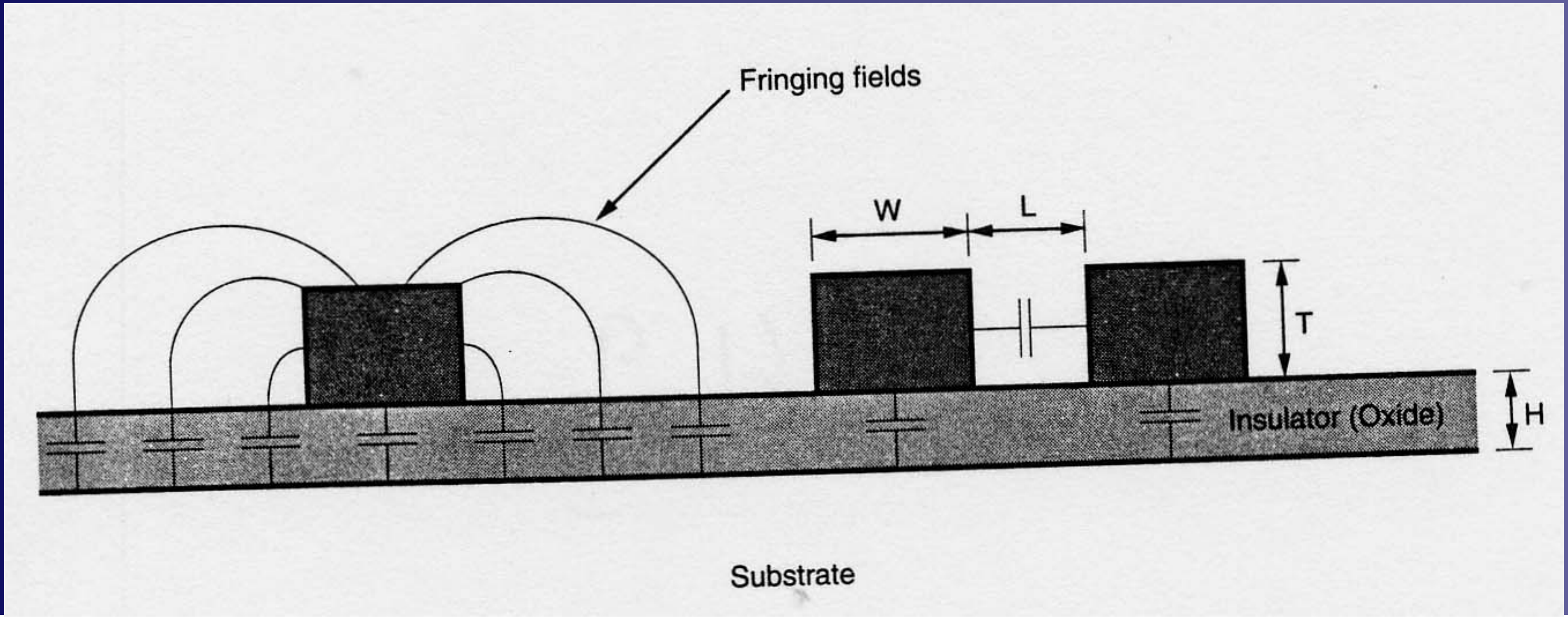
Outline

- Coupling aware timing analysis
- Charge sharing based accurate coupling model
- Logic Filtering overview
- Filtering algorithm
- Experimental results
- Conclusions

Origin of coupling : Increase in aspect ratio

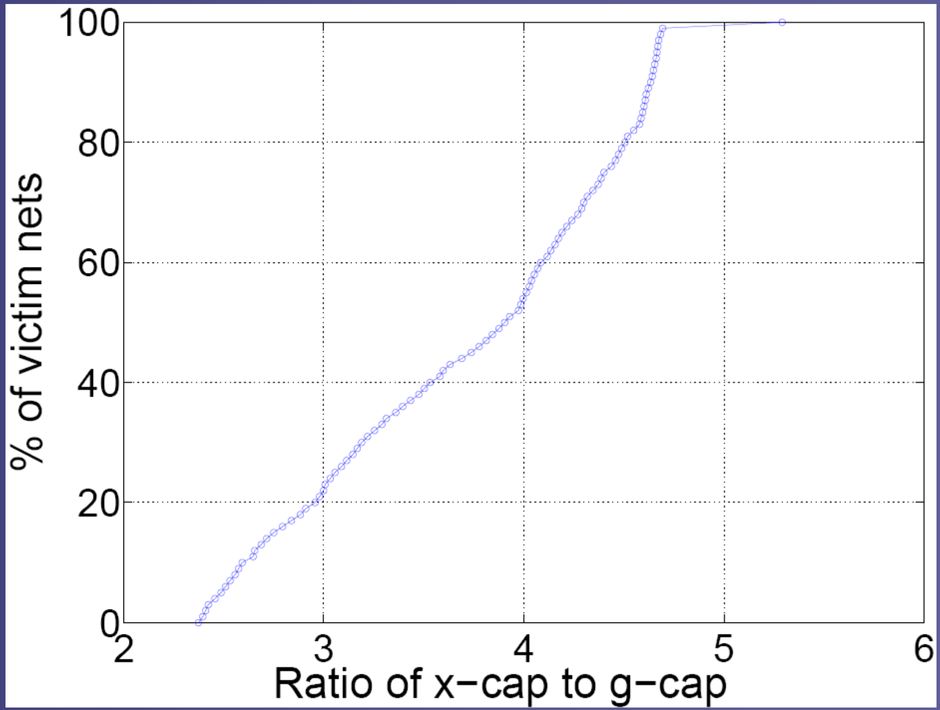
- **Pitch = W + L**
- **Aspect ratio: AR = T/W**
  - **Old processes had AR << 1 T << W**
  - **Modern processes have AR ≈ 2 T ≈ 2W**
    - **Pack in many skinny wires**

Significant Lateral Cross Sectional Area



Coupling dominates

- **Coupling cap dominates interconnect parasitics**
- **Graph shows ratio of coupling cap vs. ground cap of nets**
  - **Parasitics extracted from 65 nm logic block**
  - **Industrial Microprocessor design from Intel**



Coupling aware Timing Analysis

- Timing Analysis with x-cap iterative
- Iterative analysis with continous models: Chen et.al ICCAD 2000
- Iterative analysis with discrete models: Sapatnekar et.al ICCAD 2000, Chen et.al ICCAD 2000, Arunachalam et.al DAC 2000, Das et. al ICCD 2006
- Iterative coupling aware analysis without logic constraints is pessimistic

Pessimism reduction using Logic Filtering

- Generating Logic Conditions on a set of nets
  - False path identification (numerous papers)
  - Finding false aggressors using logic implications (Glebov et. al.)
  - Finding false aggressors using propositional satisfiability(Sakallah et. al.)
  - Generating SAT formulas based on timing window convergence
    - False Coupling Exploration in Timing Analysis (Tseng et. al.)
    - Temporofunctional crosstalk noise analysis (Chai et. al.)
- Previous research gives potential optimistic results
  - No iteration on logic assumptions
  - Ignoring logic and timing interaction
  - Overly-simplistic coupling model

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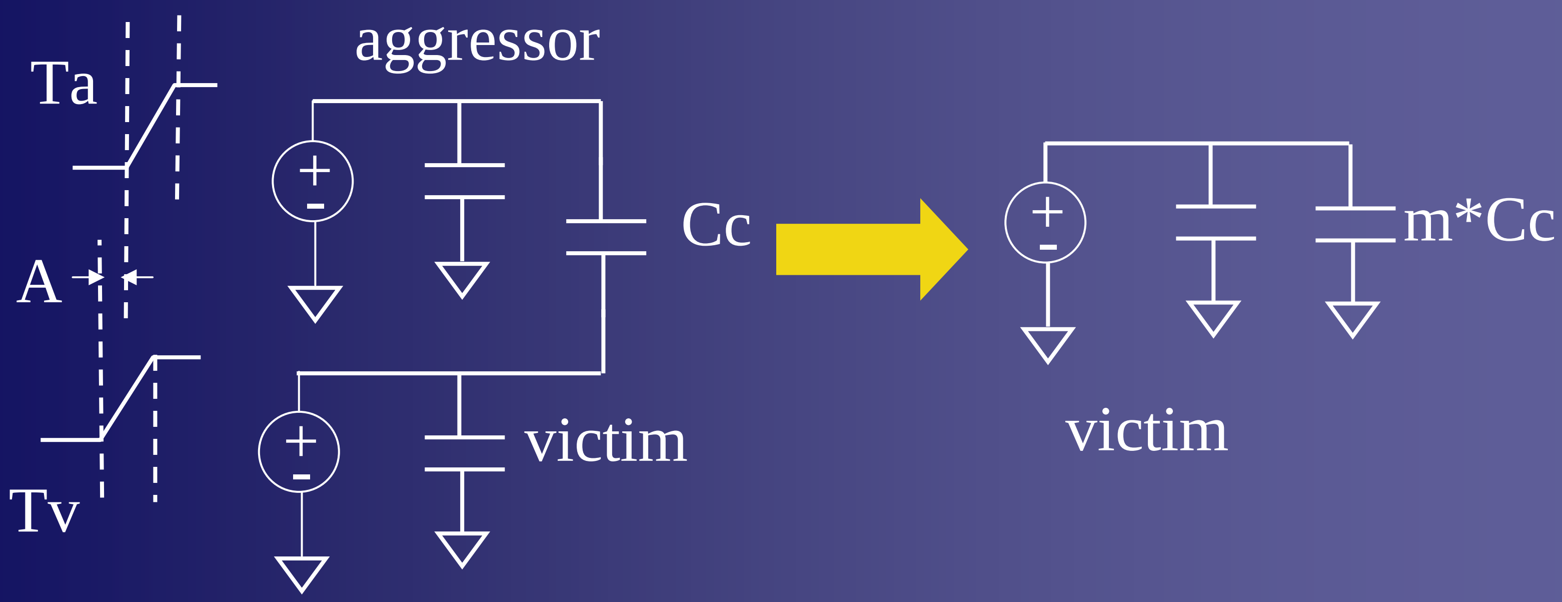
Coupling Model

- Arrival time and slope based coupling model (charge sharing)
  - m = f(victim arrival time and slope, aggressor arrival time and slope)
- Circuit model for Noise cluster



- Arrival Time : 0% , Slope : 0-100%, difference in arrival times = A

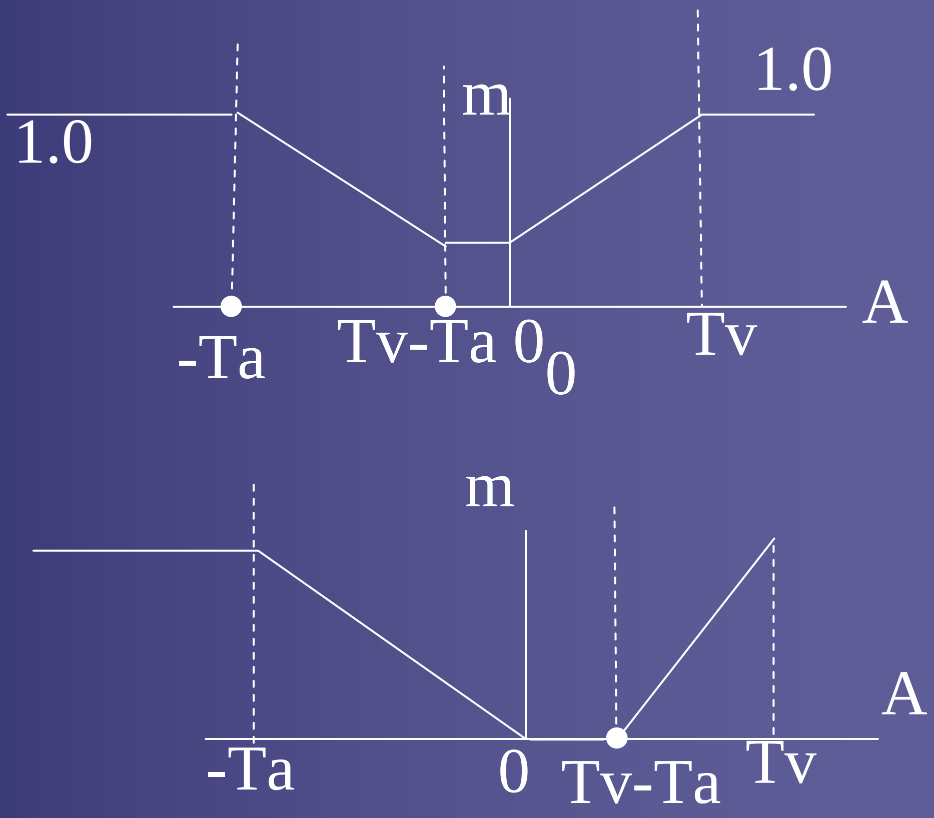
m vs A Plot (Similar Switching)

Case 1 : Ta>Tv

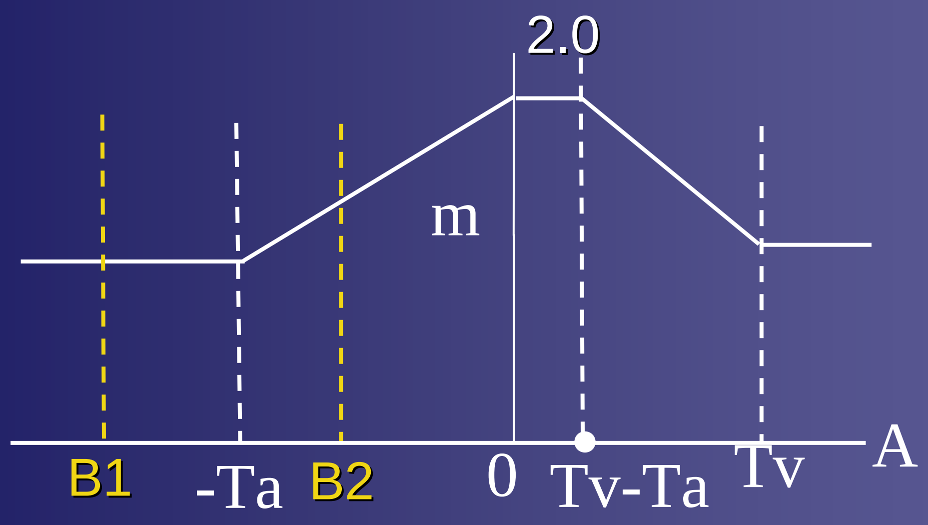
m_{min} = 1-Tv/Ta

Case 2: Ta < Tv

m_{min} = 0



Model Extension to Static Timing



- **Bounds B1,B2 obtained by AT difference**
- **Ta : Min TT associated with Aggressor**
- **Tv : Max TT associated with Victim**
- **Worst m within B1 and B2**

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Logic Filtering

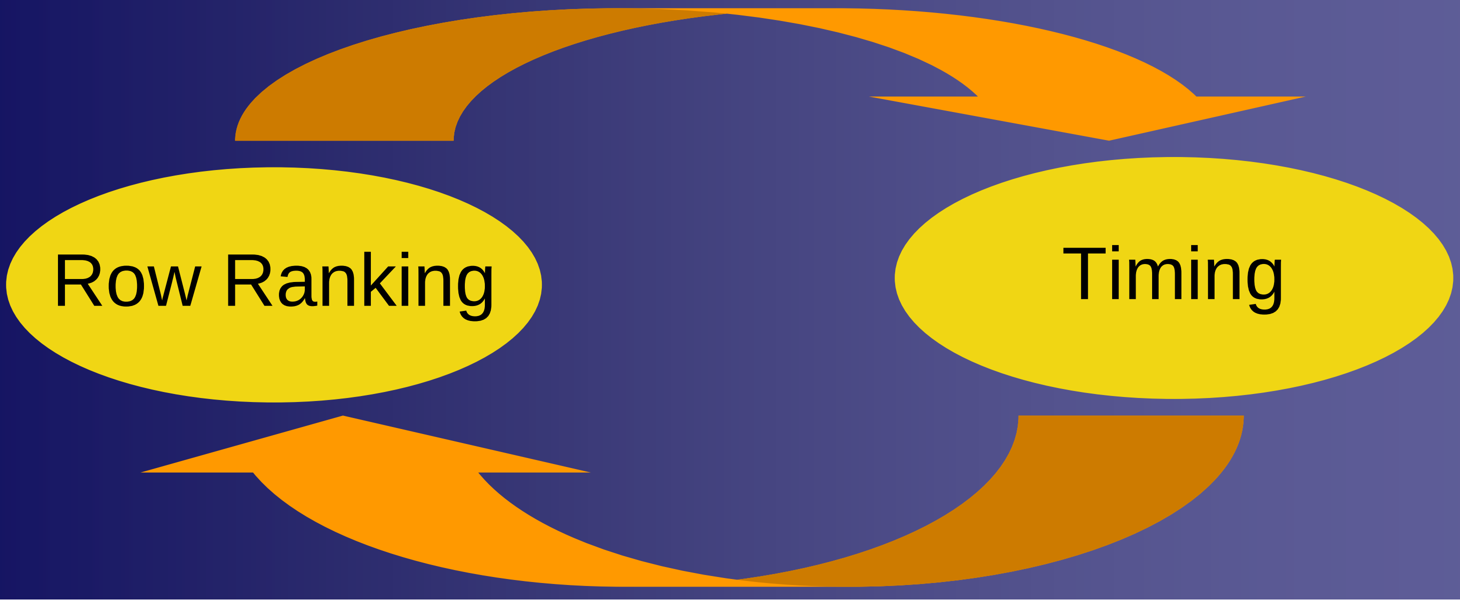
- **Worst case might not happen (Due to Logic)**

V	A1	A2	
R	R	R	X
R	S	R	✓
R	F	F	X
R	S	F	✓
.	.	.	
.	.	.	

- **Idea is to find "worst" logically feasible row**
  - **Worst = Worst stage delay**

Logic Filtering: Chicken Egg Problem

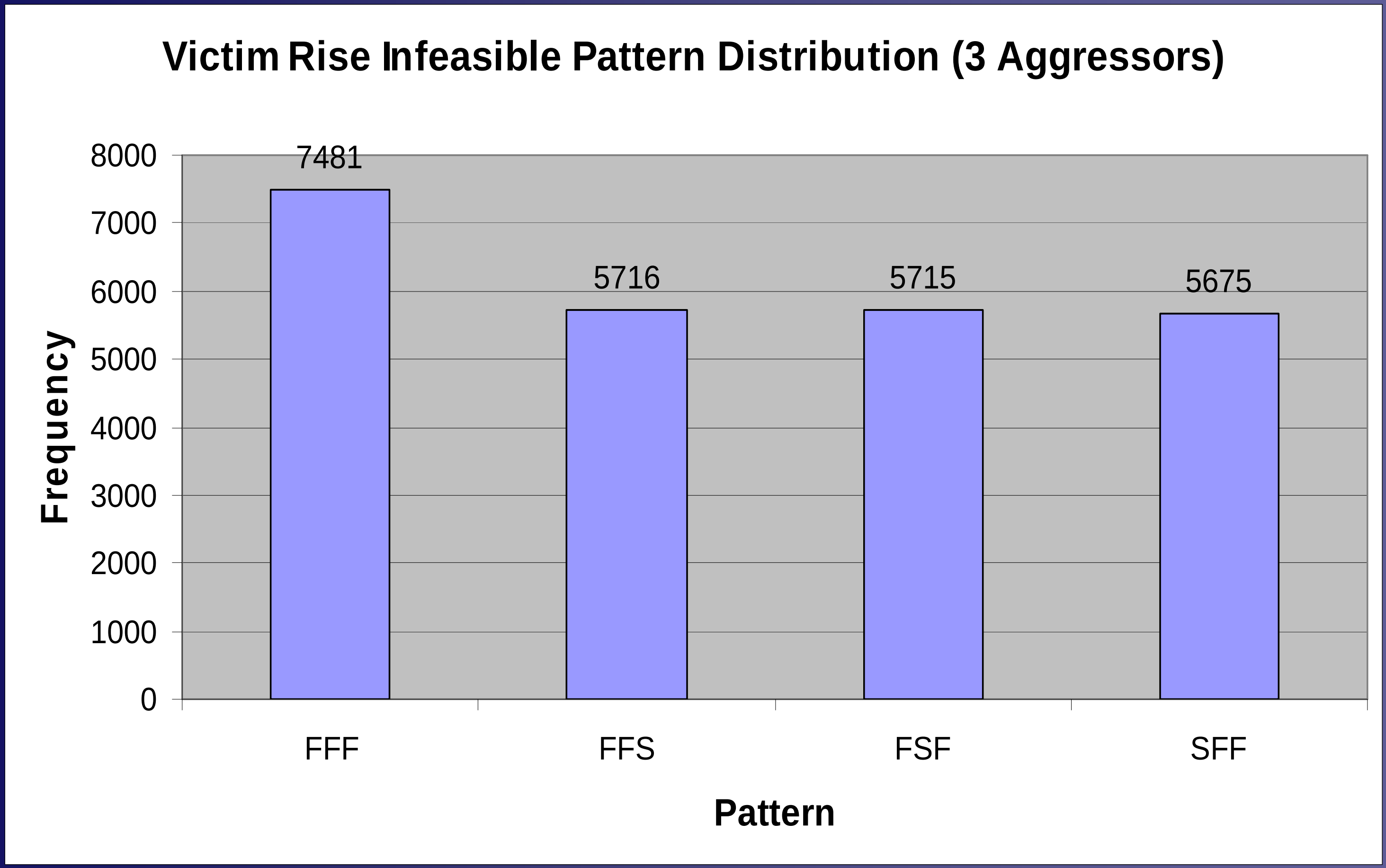
- **Worst row generation (ranking) from Logic Tables**
  - **Row rank R = f(m, P) where P = Parasitics**
  - **m = g(A, Tv, Ta)**
  - **A = h1(m, P), Tv = h2(m, P), Ta = h3(m, P)**



Logic Table Generation

- We used
  - Random circuit simulation with vectors
  - Logic implication based pruning
  - ATPG based techniques
  - SAT based techniques
- Guaranteed conservative ignoring glitches
  - 0-delay model
- Complexity: expensive if SAT clause > 6 literals
  - 20K Victim nets, 5 aggressors each : $20K \times 2 \times 3^3$ = 1,080,000 = ½ day
  - If Aggressors = Median of #aggs (25) : $20K \times 2 \times 3^{25}$ = EEK!
- We used clause size 4: 1 victim, 3 aggressors

Logic Condition Generation



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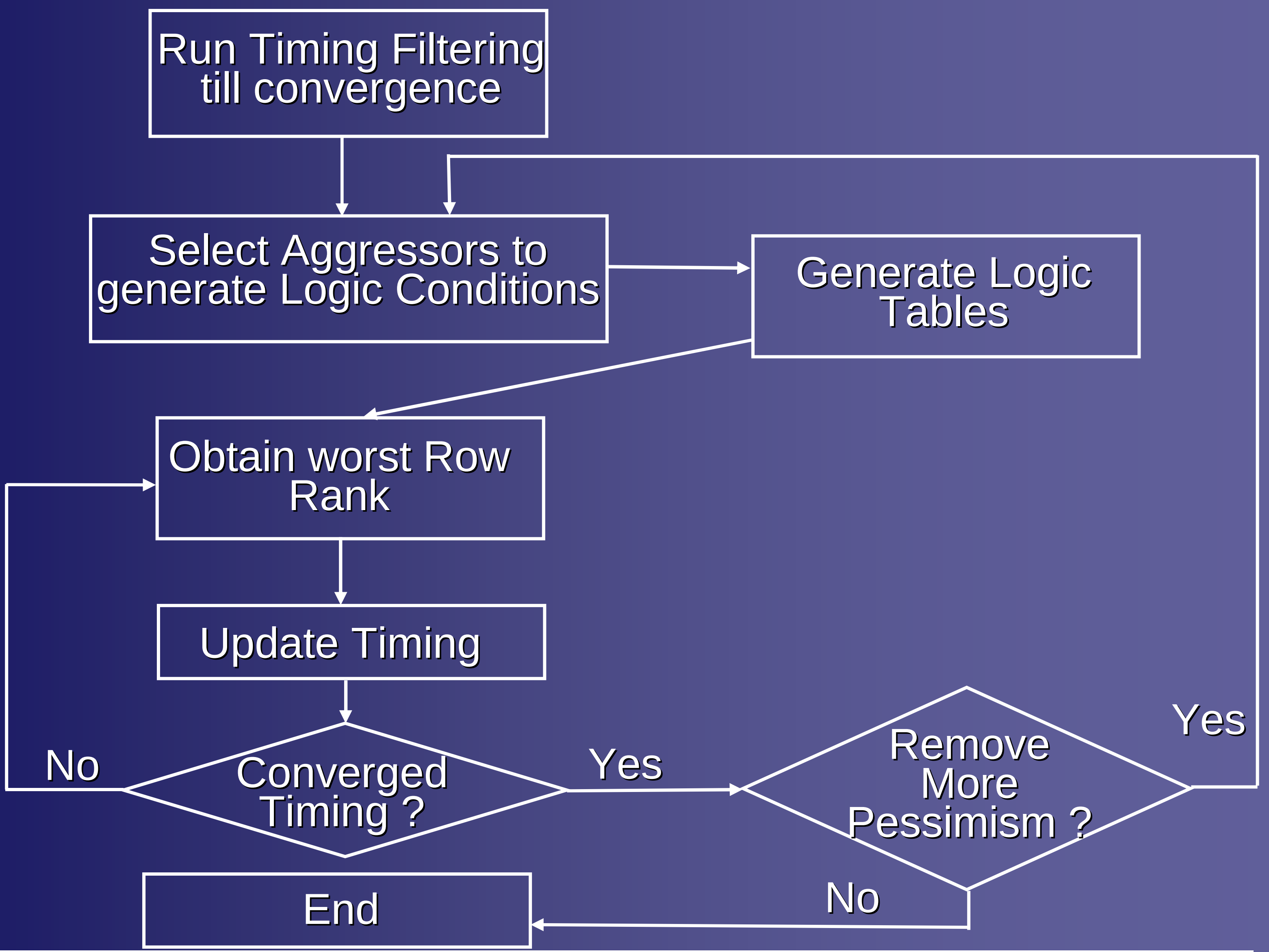
Proposed Flow



Aggressor Selection

- **Compute sensitivities of each aggressor**
  - **Victim V, 3 Aggressors A1, A2, A3**
  - **Converged Timing m's : $m1_{nom}$, $m2_{nom}$, $m3_{nom}$**
  - **Receiver elmore delay = f(m1,m2,m3)**

- $f(m1,m2,m3) = f(m1_{nom}, m2_{nom}, m3_{nom})$
  $+ (\partial f/\partial m1)x(m1 - m1_{nom}) + \ldots$

  - $\partial f/\partial m1 = \{f(m1,m2_{nom},m3_{nom}) - f(m1_{nom},m2_{nom},m3_{nom})\} / (m1 - m1_{nom})$
  - $S_{m1} = (\partial f/\partial m1) / f(m1_{nom},m2_{nom},m3_{nom})$
  - Change m1 to 1.0 for $\partial f/\partial m1$ computation

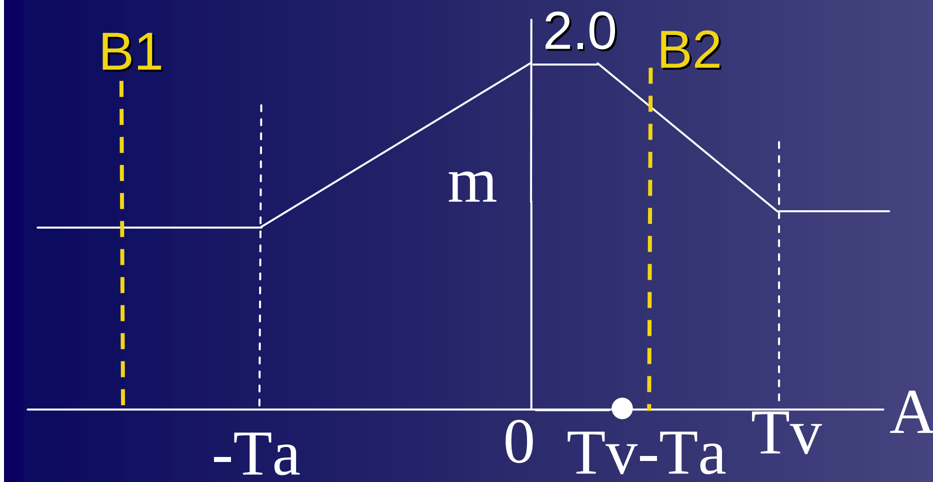
Logic Filtering Algorithm

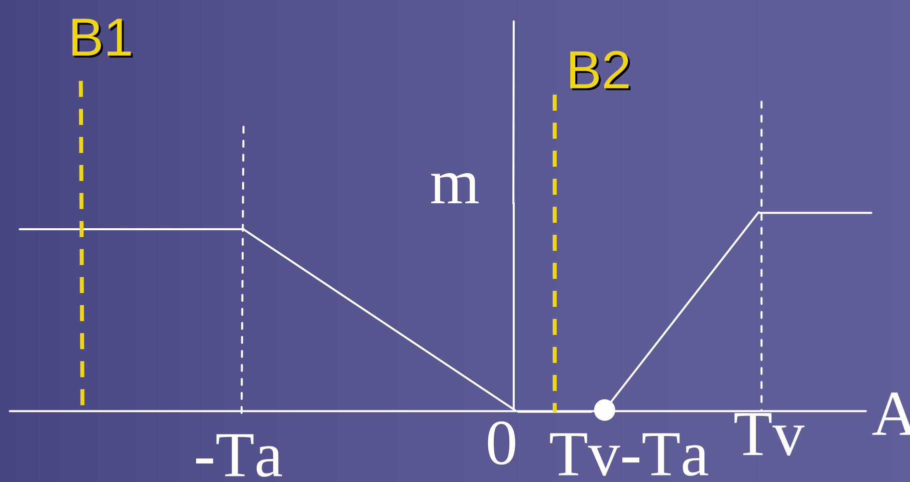
- Initialization : $lmcf_0, mcf_0 \leftarrow (0,2)$, $Windows_0 \leftarrow f(mcf_0)$
- while($|Windows_i - Windows_{i-1}| > \varepsilon$)
  - if(LOGIC_FILTERING)
    - Compute $lmcf_i$ for selected aggressors
    - $R \leftarrow$ Identify worse ranked row using $lmcf_i$
    - $mcf_i \leftarrow g(Windows_{i-1}, R)$
  - else if (TIMING_FILTERING)
    - $mcf_i \leftarrow h(Windows_{i-1})$
  - $Windows_i \leftarrow f(mcf_i)$

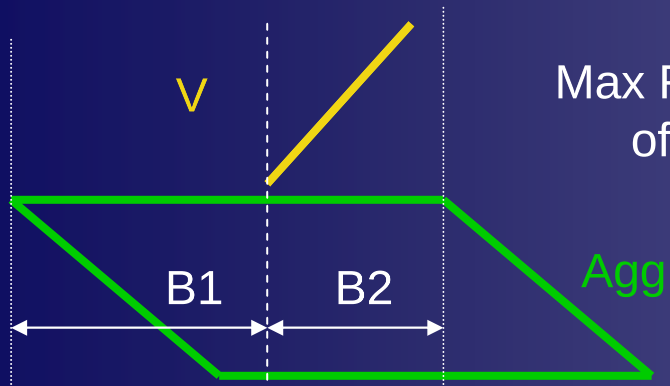
Logic MCF

Fix Point Computation

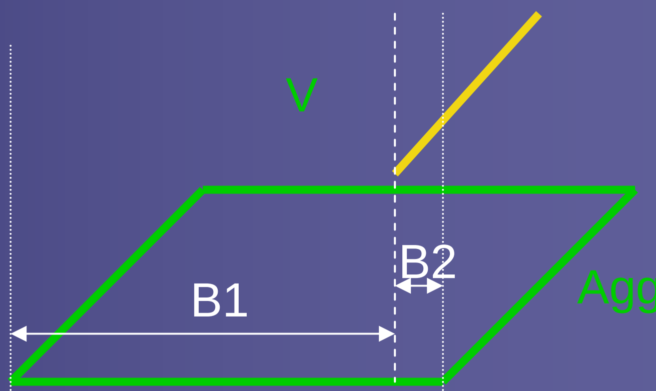
Logic MCF Computation (Example)







Max Rise Event
of Victim



Logic MCF Fall
(Fall Twin of Aggressor)
Max MCF = 2.0

Logic MCF
Stable = 1.0

Logic MCF Rise
(Rise Twin of Aggressor)
Max MCF = 1.0

Logic Filtering Algorithm: Worst Row Calculation

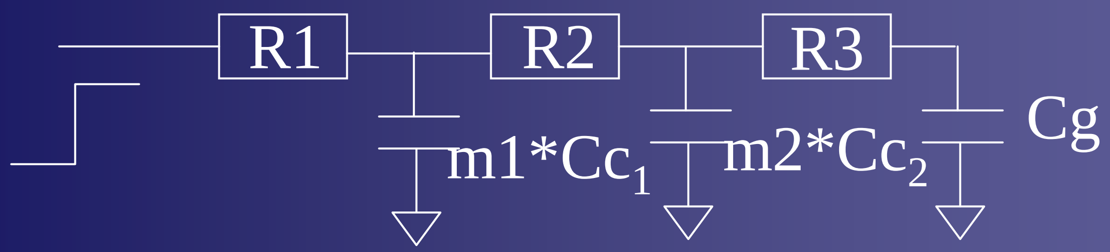
- Given Victim Cluster <V,A1,A2,A3>
- x-caps: CC_{A1}, CC_{A2}, CC_{A3}
- LMCFs: $LMCF_{A1}$, $LMCF_{A2}$, $LMCF_{A3}$
- Logic Feasibility Table for cluster

V	A1	A2	A3
R	F	S	S
R	S	R	S
F	S	S	R
F	S	R	S

$$Rank = LMCF_{A1}[F] x CC_{A1} + LMCF_{A2}[S] x CC_{A2} + LMCF_{A3}[S] x CC_{A3}$$

Accurate Ranking

- **We should not ignore resistances and ground cap !**
- **Circuit model of victim cluster**



$$E_d = m1Cc_1*R1 + m2Cc_2*(R1+R2) + C_g(R1+R2+R3)$$

- **Ranking by Elmore delay computation**
  - **Choose the row with worst Elmore delay**

Conservative Row Ranking

- Consider MAX RISE event of victim
- CC_{A1}= 3, CC_{A2} = 2.5, CC_{A3}=2
- $LMCF_{A1}$={ F = 2.0, R = 1.0, S = 1} , $LMCF_{A2}$={ F = 1.8, R = 1.0 , S = 1}

V	A1	A2	A3
R	F	S	S
R	S	R	S
F	S	S	R
F	S	R	S

Iteration i

Rank(i) = 2.0x3+1.0x2.5+1.0x2 = 10.5

Rank(i) = 1.8x3+1.0x2.5+1.0x2 = 9.9

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Conservative Row Ranking

- Consider MAX RISE event of victim
- CC_{A1}= 3, CC_{A2} = 2.5, CC_{A3}=2
- $LMCF_{A1}$={F = 1.6, R = 1, S = 1} , $LMCF_{A2}$={F = 1.7, R = 1, S = 1}

V	A1	A2	A3
R	F	S	S
R	S	R	S
F	S	S	R
F	S	R	S

Iteration i+1

Rank(i+1) = 1.6x3+1.0x2.5+1.0x2
= 9.3

Rank(i+1) = 1.7x3+1.0x2.5+1.0x2
= 9.6

Conservative Row Ranking

- Consider MAX RISE event of victim
- CC_{A1}= 3, CC_{A2} = 2.5, CC_{A3}=2
- $LMCF_{A1}$={ F = 1.6, R = 1, S = 1} , $LMCF_{A2}$={ F = 1.7, R = 1, S = 1}

V	A1	A2	A3
R	F	S	S
R	S	R	S
F	S	S	R
F	S	R	S

Iteration i+1

Rank(i+1) = 1.6x3+1.0x2.5+1.0x2 = 9.3

Rank(i+1) = 1.7x3+1.0x2.5+1.0x2 = 9.6

Must Consider same direction
Even in MAX !

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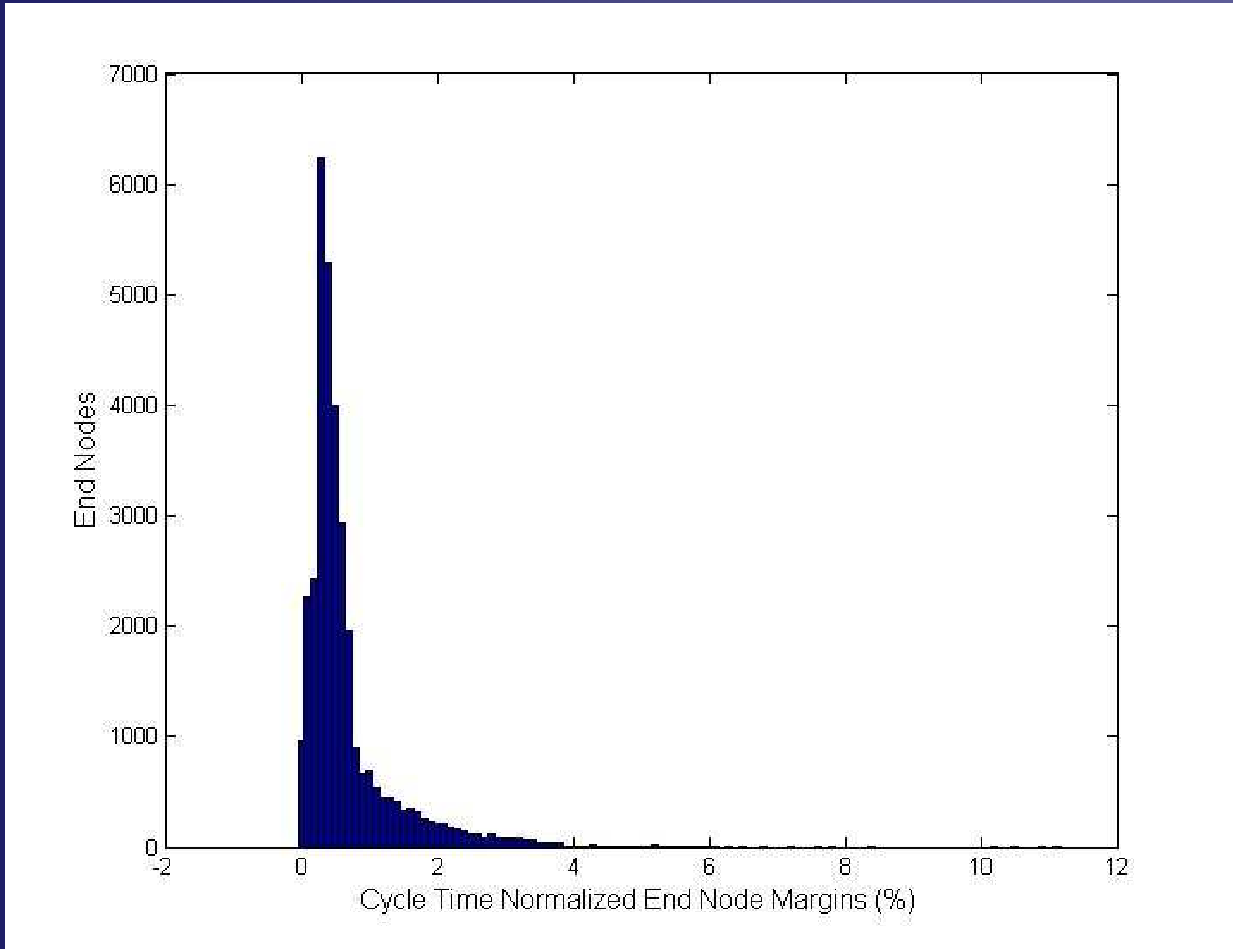
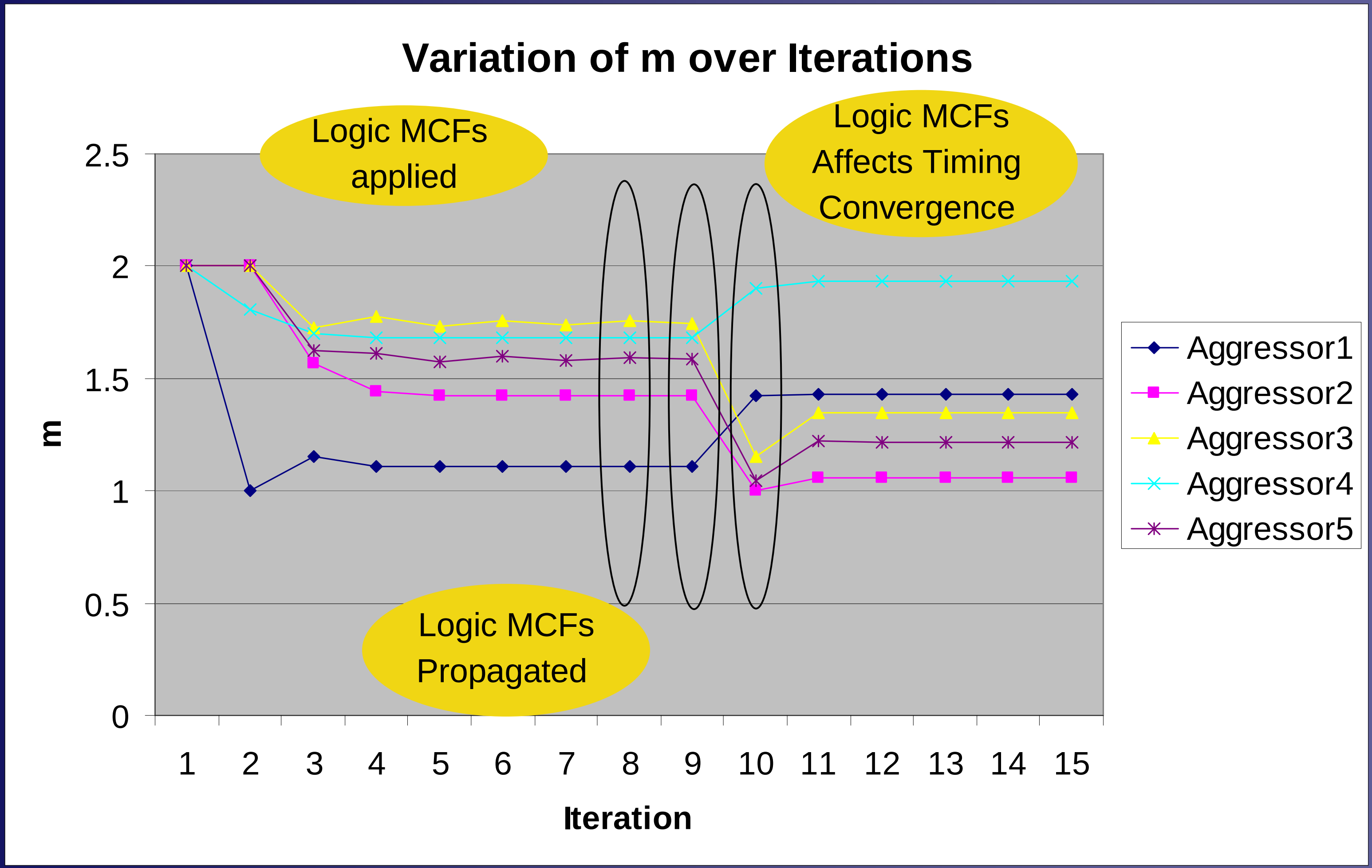
Results

- **Pessimism Reduction**
  - **Logic Conditions applied after 8 iterations.**
  - **Maximum : 11.18% Median : 0.44%**



Results

- **Variation of m under logic + timing iterations**



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Conclusions

- Proposed novel algorithm to do coupling aware static timing analysis with logic constraints
- Dynamics of complex coupling model under timing and logic filtering is presented
- Iterations are needed to generate conservative timing data
- 11.18% maximum pessimism reduction observed on a functional block from 65 nm industrial microprocessor
- Future work includes extending such a model to statistical timing analysis and optimization

Thank You