A Unified Multi-Corner Multi-Mode Static Timing Analysis Engine

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Outline

- Introduction & Problem formulation
- MCMM STA
- The Unified MCMM STA Engine
- Experimental Result
- Conclusion

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Introduction

- Two approaches to conquer process variation in static timing analysis (STA)
- Statistical STA
    - Models process variations as random variables
    - And models delay/transition time as PDFs
- Corner-based STA
    - Focuses on worst/best cases only
    - Conservative but efficient

Statistical STA

- Defects of SSTA
  - The variables may be asymmetric or uncertain and can not be modeled as Gaussian distribution
  - Inabilities dealing with variable correlations
  - The accuracy depends on the modeling provided by technology files which is not controllable by common users

Corner-based STA

- Advantage
  - The timing model can be easily modified from the usual timing library
  - Linear time approach covering all corners exists
  - The same algorithm flow can be used to consider multiple “power modes”
- Disadvantage
  - The accumulated pessimistic boundary may cause the design hard to converge

Proposed Techniques

- Modify the branch-and-bound method [Heloue, DATE07] to maintain upperbound quality
- Adopt linear time upper-bound technique [Onaissi, ICCAD06] to reduce the search space
- Devise an integrated parallel mechanic to achieve balance between performance and quality

Problem formulation

- Perform STA under multiple process parameters and only care about the corner values.
- Objective of this work:
  - To find the exact worst case delay/delay corner more efficiently and robustly than previous works.

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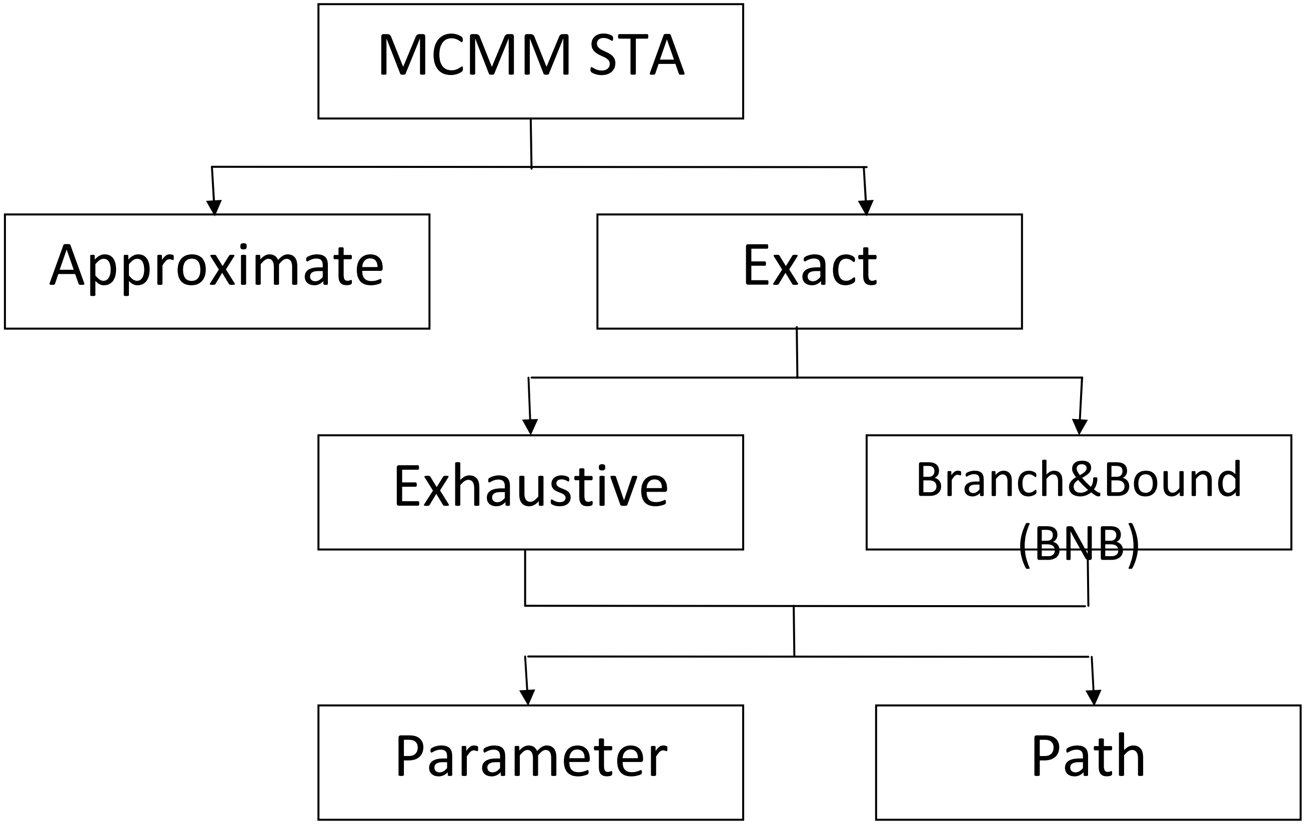
- Introduction & Problem formulation
- MCMM STA
  - Exact algorithms
  - Approximate algorithms
- The Unified MCMM STA Engine
- Experimental Result & Conclusion

Categorization of MCMM STA



Complexity of Exact MCMM

- Given P parameters and N cells
- **Path-based** timing analysis
  - Add operation along a path is exact.
    - $(2-X_1+3X_2)+(6+2X_1-2X_2)=8+X_1+X_2$
  - For a single path, we can calculate all the timing corners together, which is linear to P.
  - However, the number of paths can grow exponentially with N, so the complexity is $O(P2^N)$.

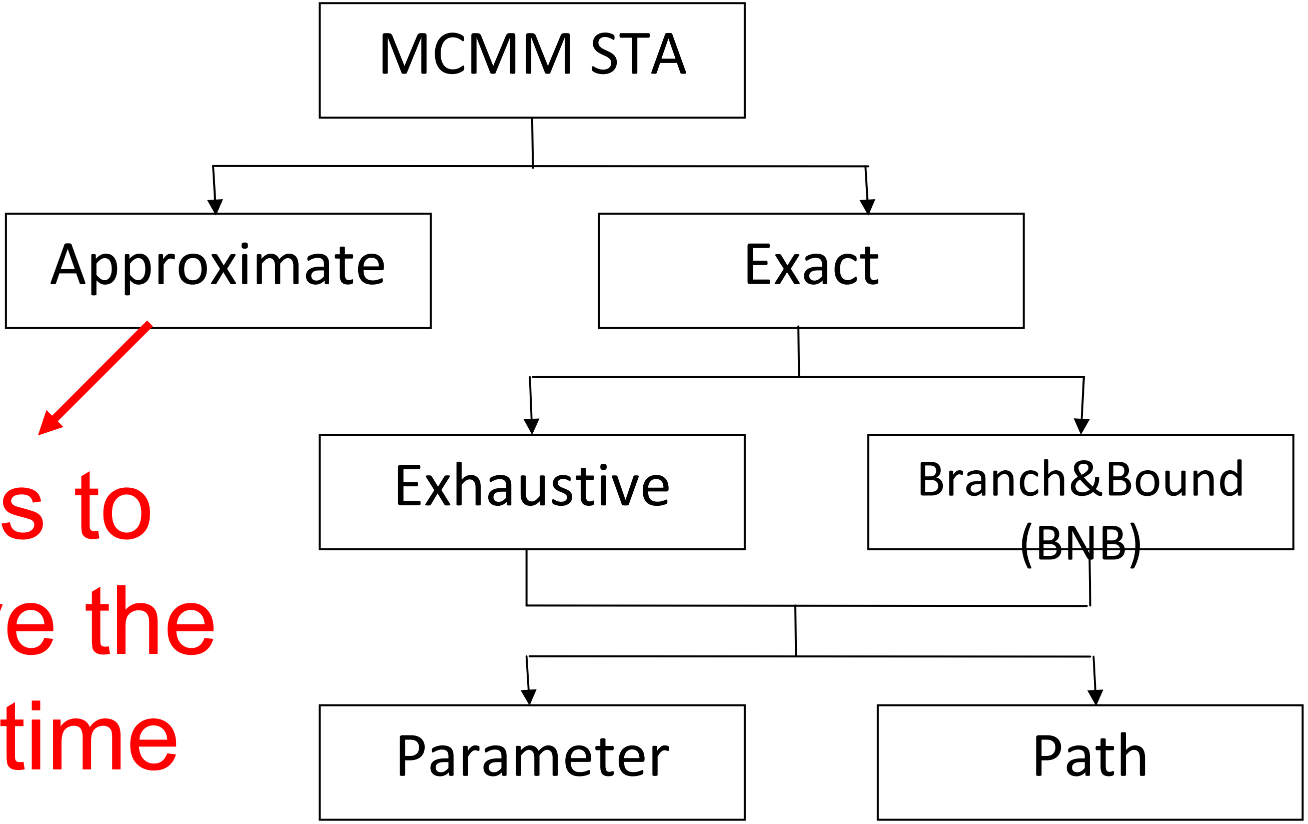
Not favorable for circuits with large number of Paths!!

Complexity of Exact MCMM

- **Parameter-based** timing analysis (block-based)
  - Max operation in a cell is not exact but an upper bound
    - $\max(2-X_1+3X_2, 6+2X_1-2X_2)=6+2X_1+3X_2$
  - The complexity of the timing analysis for each corner is linear to N.
  - But we must run such a procedure for each of the 2^P corners, so the complexity is $O(N2^P)$.

Not favorable for large number of corners!!!

Categorization of MCMM STA



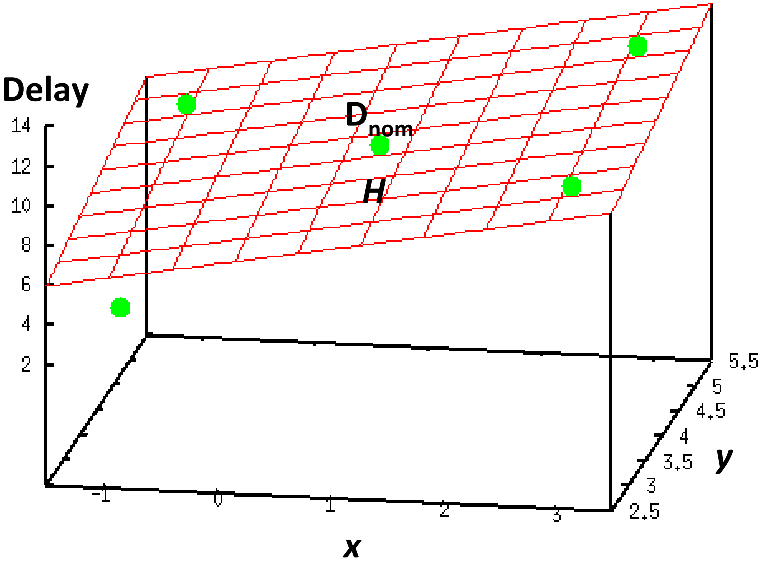
Tries to solve the run time issue

Complexity of Approximate MCMM

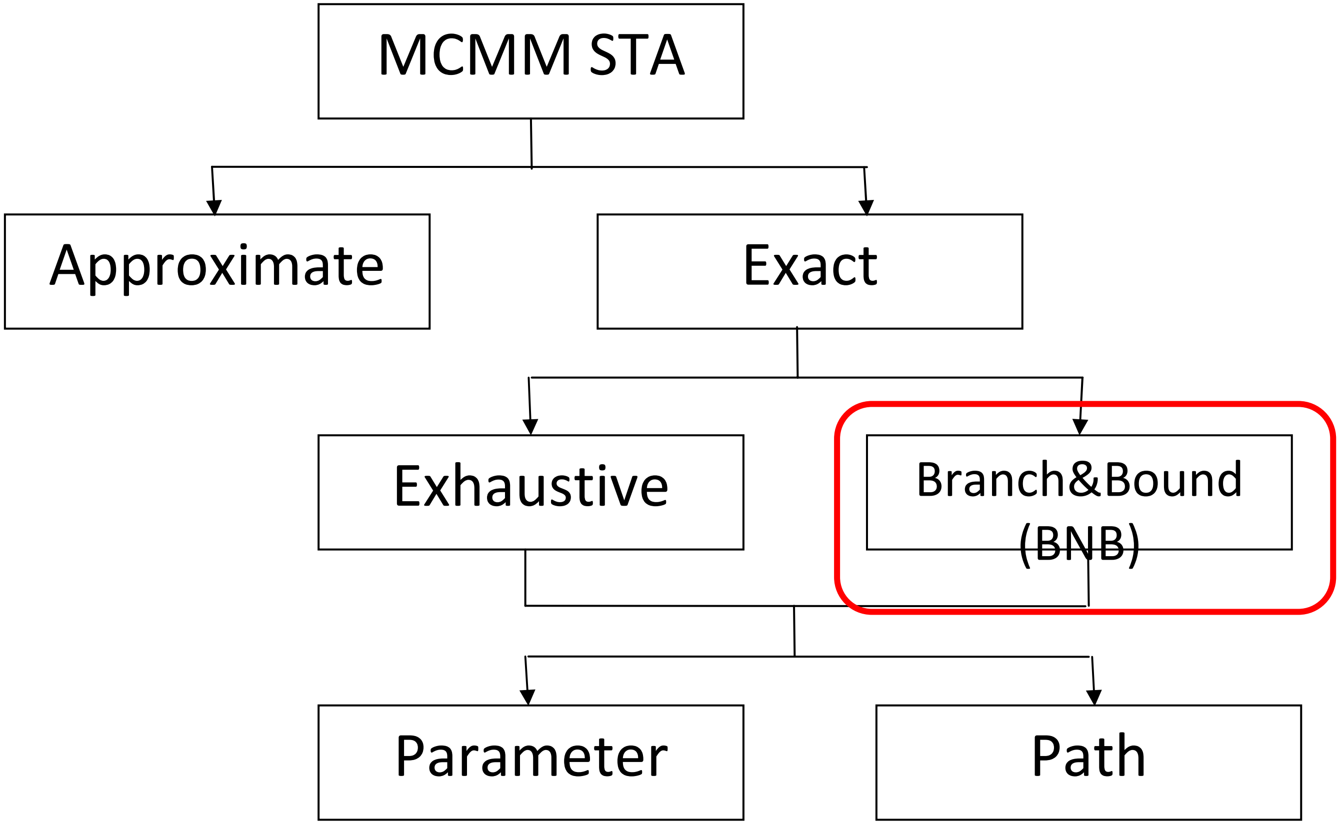
- Single-run block-based timing analysis
  - Performs max operation for N gates, each max operation costs O(P).
  - Total complexity O(NP), efficient but just an estimated upper bound.
  - "A Linear-Time approach for Static Timing Analysis Covering All Process Corners" in [Onaissi, ICCAD06]
- Different "max" operations:
  - Loose: choose the maximum coefficients.
    - maxLoose(2-2X, 0+X)=2+X
  - Tight: not overestimate the overall peak value
    - maxTight(2-2X,0+X)=2-X

Linear Model of Process Variation

- Cell delays are modeled as linear functions of the process variations or operation modes.
  - $D = D_0 + a_1 X_1 + a_2 X_2 + \ldots + a_{p-1} X_{p-1} + a_p X_p$



Categorization of MCMM STA



MCMM STA

Approximate

Exact

Exhaustive

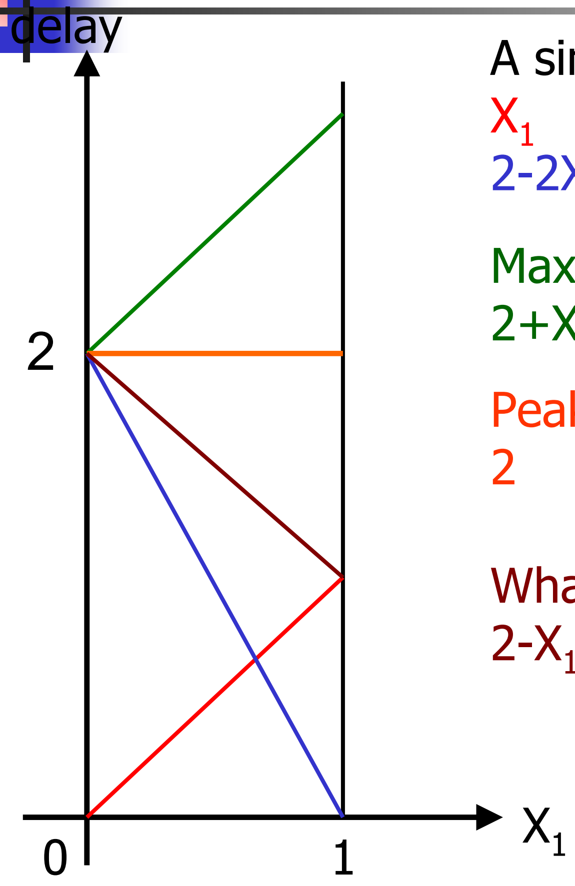
Branch&Bound (BNB)

Parameter

Path

What if I want more accurate results?

The Tight and Loose Max Operation



A simple 1-D case:

X_1

$2-2X_1$

Max operation O(P):

$2+X_1$

Peak Value:

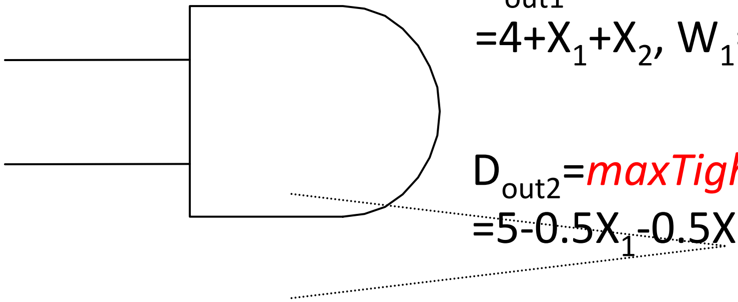
2

What we want O(?):

$2-X_1$

- Finding the peak value of all corners and choose the highest (P+1) points to form the upper bound. But the complexity is $O(2^P)$.
  - Linking <(0),2> and <(1),1> in this case
- O(P) method to get tighter upper bound exists under the linear delay model.

Improvement on Pruning Power



D_{in1}=3+X_1+X_2

D_{in2}=4-X_1-X_2

D_{out1}=*maxLoose*(D_{in1},D_{in2})
=4+X_1+X_2, W_1=6

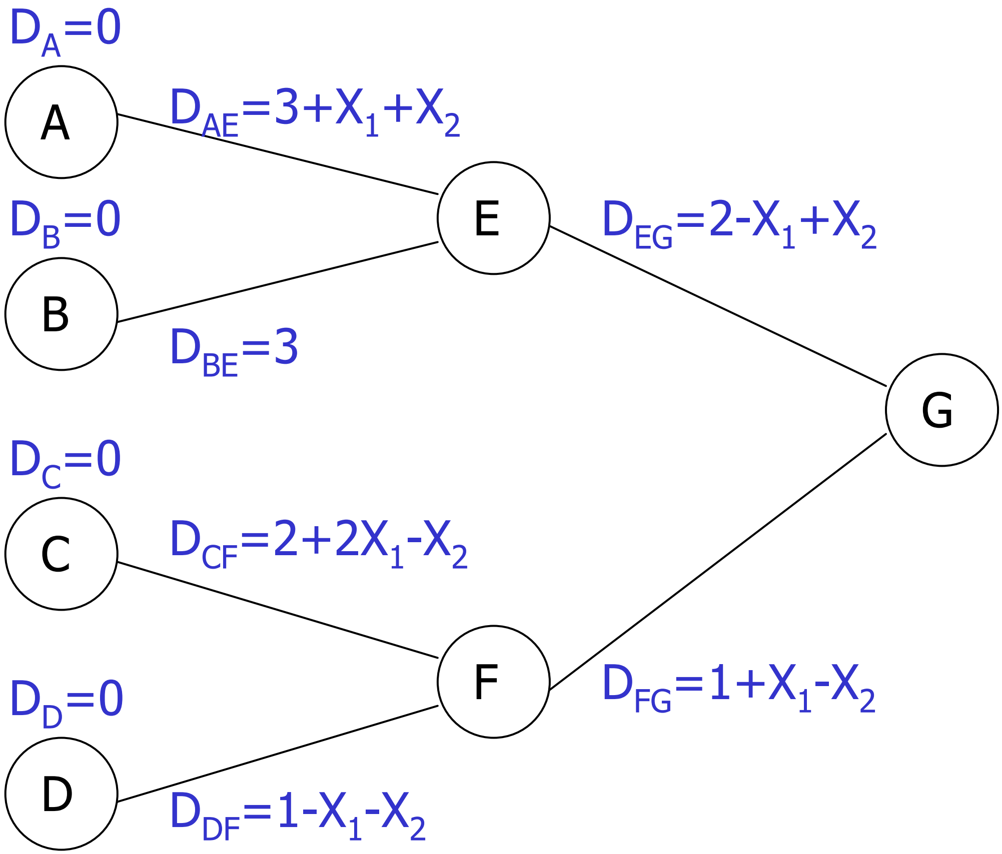
D_{out2}=*maxTight*(D_{in1},D_{in2})
=5-0.5X_1-0.5X_2, W_2=5

- If current worst delay is 5.5, then this group would be pruned with *maxTight* and would not be pruned with *maxLoose*.
- The difference could be used to improve pruning power!!

Branch-and-Bound MCMM STA

- Dynamic pruning methods (branch-and-bound)
  - Path-based BNB
  - Parameter-based BNB

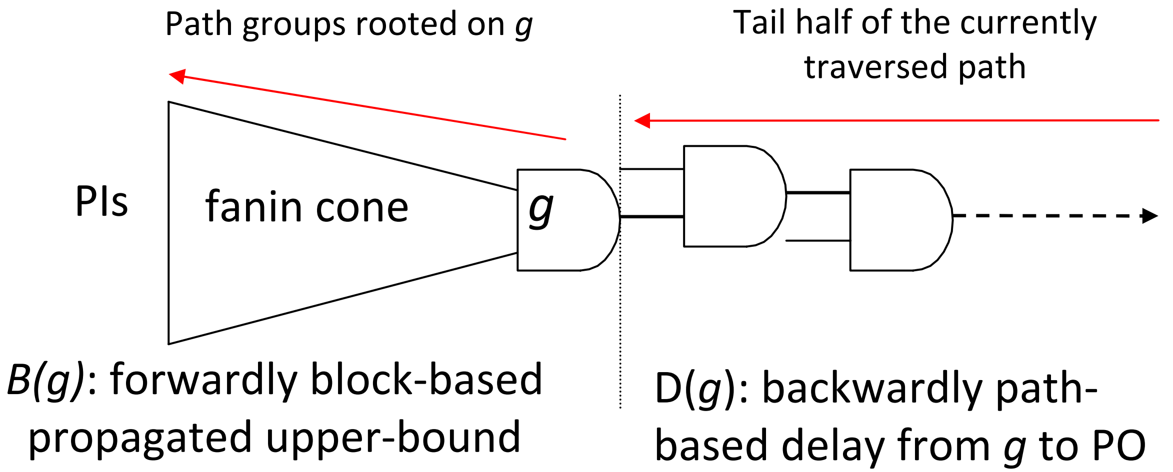
Path-based MCMM STA



Path	Delay	Worst	Corner
AEG	$5+2X_2$	7	(X,1)
BEG	$5-X_1+X_2$	6	(0,1)
CFG	$3+3X_1-2X_2$	6	(1,0)
DFG	$2-2X_2$	2	(X,0)

Worst delay is 7 at the corner (X,1)

Path-based BNB



Path groups rooted on *g*

Tail half of the currently traversed path

B(g): forwardly block-based propagated upper-bound

D(*g*): backwardly path-based delay from *g* to PO

1. $D_{current}$ = current maximum delay found
2. $(B(g)+D(g)) \leq D_{current}$, pruned.
3. if ($B(g)+D(g) > D_{current}$), continue to explore the fanin cone of g.

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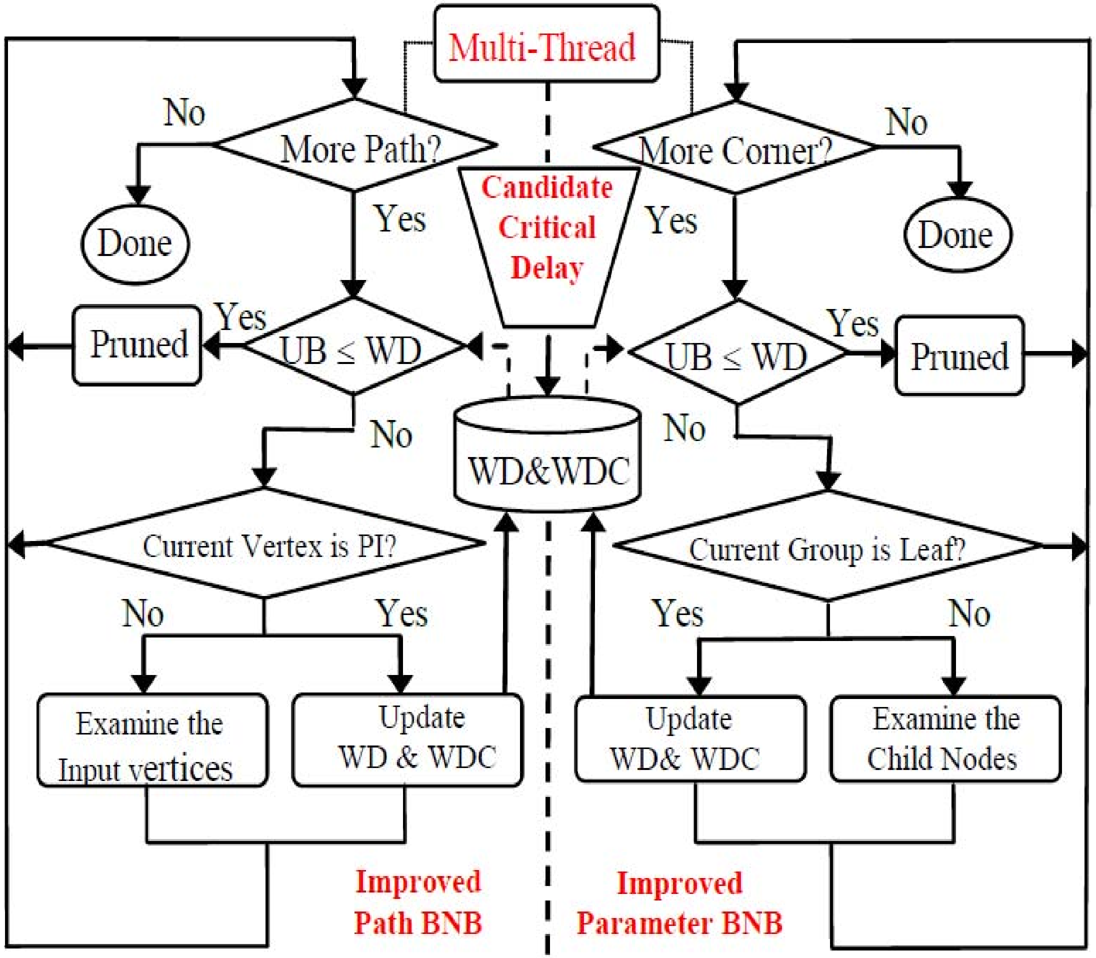
Overview of the Unified Engine

- Improved BNB methods
- Multi-thread controller
- Candidate critical delay as initial bound.
- Share the worst delay/worst delay corner



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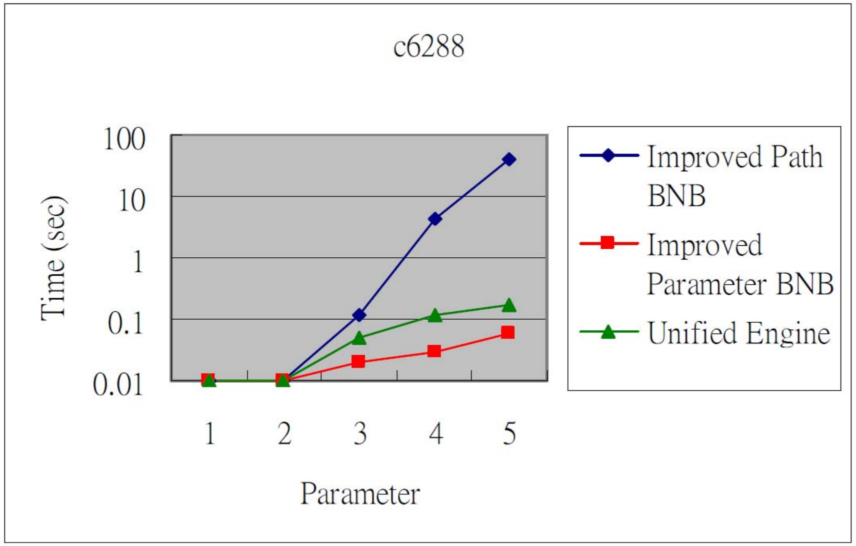
Improved Path BNB

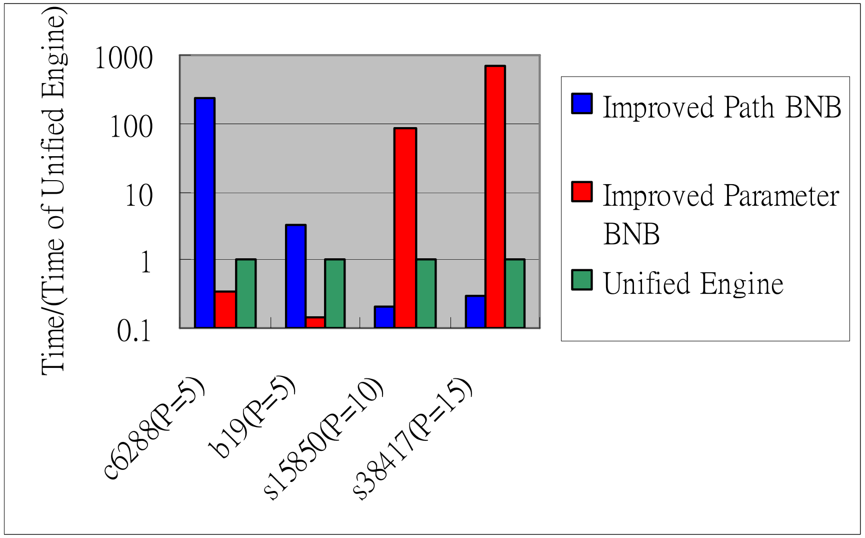
P=5	Circuit Information		Linear Time Approximate [6]		Exact computation (Path-based BNB)[9]		Our Exact computation (Path-based BNB)	
Circuit	**Gate**	**Path**	**Delay (ns)**	**Run Time (s)**	**Delay (ns)**	**Run Time (s)**	**Delay (ns)**	**Run Time (s)**
c6288	2.4k	10^{20}	42.2	0	N/A	-	39.9	40.4
s15850	9.7k	10^{8}	27.0	0.01	25.9	0.27	25.9	0.02
s38417	22k	10^{6}	15.1	0.02	14.6	0.02	14.6	0.02
s38584	19k	10^{6}	18.8	0.03	18.1	0.04	18.1	0.03
b18	111k	10^{24}	54.2	0.16	N/A	-	51.5	8.09
b19	224k	10^{25}	55.5	0.33	N/A	-	52.0	188

Improved Parameter BNB

c6288 gate counts: 2.4k		Exact computation (Parameter-based BNB)[9]		Our Exact computation (Parameter-based BNB)		
Parameter	**Corners**	**Delay (ns)**	**Run Time (s)**	**Delay (ns)**	**Run Time (s)**	**Run Time Improvement**
5	**32**	39.9	0.06	39.9	0.06	0%
6	**64**	40.2	0.13	40.2	0.13	0%
7	**128**	40.9	0.26	40.9	0.2	23%
8	**256**	40.8	0.5	40.8	0.38	24%
9	**512**	42.0	1.05	42.0	0.64	39%
10	**1024**	43.3	1.63	43.3	0.92	44%
15	**32768**	43.6	50.6	43.6	20.6	59%
20	**1048576**	44.6	1659	44.6	668	60%

The Unified MCMM STA Engine





Conclusion

- We proposed a unified MCMM STA engine with:
  - A seamless integration of path and parameter BNB
  - An improved search space pruning technique
  - Candidate critical delay as initial bound
  - Extension to hold time check
- This robust engine will be a solid foundation for the MCMM TA research and a basis for MCMM timing optimization .

Reference

- [6] S. Onaissi and F. Najm, “A Linear-Time Approach for Static Timing Analysis Covering All Process Corners,” In Proceedings of IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 27, 2008, page. 1291-1304.
- [7] K. Heloue and F. Najm, “Parameterized timing analysis with general delay models and arbitrary variation sources,” In Proceedings of Design Automation Conference, 2008, page. 403-408.
- [9] L. Silva, Miguel Silveira L z, and J. Phillips, “Efficient Computation of the Worst-Delay Corner,”In Proceedings of Design, automation and test in Europe, 2007, page. 1-6

Thank You & Have A Nice Day!

Q&A