ICCAD-2016 CAD Contest in Non-exact Projective NPNP Boolean Matching and Benchmark Suite

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Outline

- Problem Description
- Benchmark Suites
- Contest Results

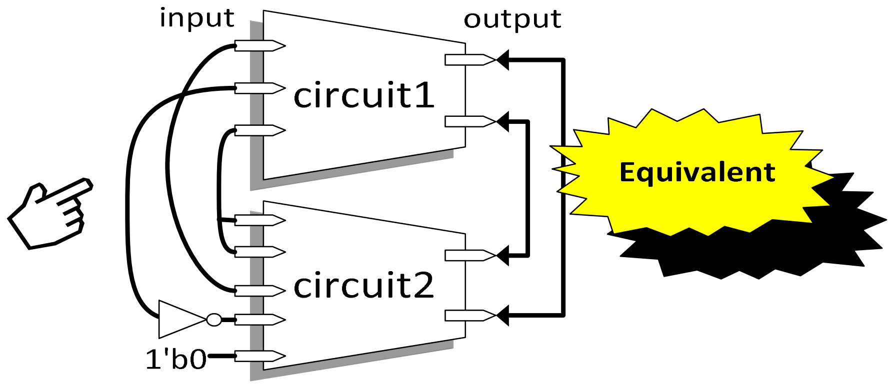
Introduction

- Boolean Matching Problem
  - Given two designs, this problem is to decide the matching and modification of their primary inputs (PIs) and outputs (POs) such that two designs can be equivalent.
  - For example, given two Boolean functions:
    $g = (a \wedge b) \vee c$
    $h = (d \vee \neg e) \wedge (d \vee f)$
    A matching solution can be $\{ (a,\neg e), (b,f), (c,d), (g,h) \}$.

- The engine of solving Boolean matching can be applied in many EDA applications.
  - Library binding
  - Logic synthesis
  - Engineering change order
  - Logic verification
  - Hardware Trojan detection

Non-exact Projective NPNP Boolean Matching

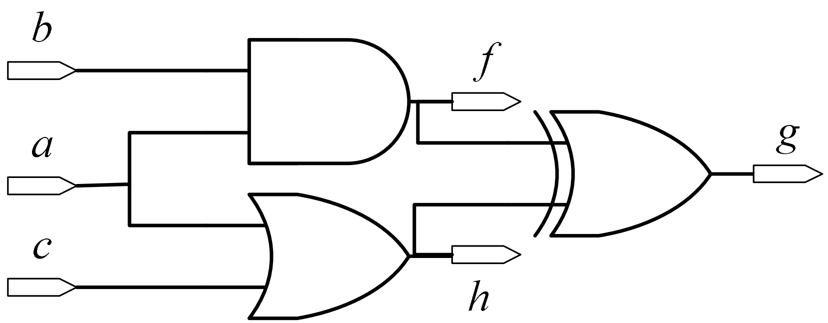
- NPNP Boolean matching is to achieve two circuits' functional equivalence by negating(N) and permuting(P) the primary inputs and primary outputs.
- In this contest, we re-formulate problem to Non-exact Projective NPNP Boolean matching to fit industry applications.
  - Projective: allow to merge PIs, group POs, and tie PI to constant in one circuit to match the other.
  - Non-exact: get maximum number of equivalent POs instead of matching all POs.



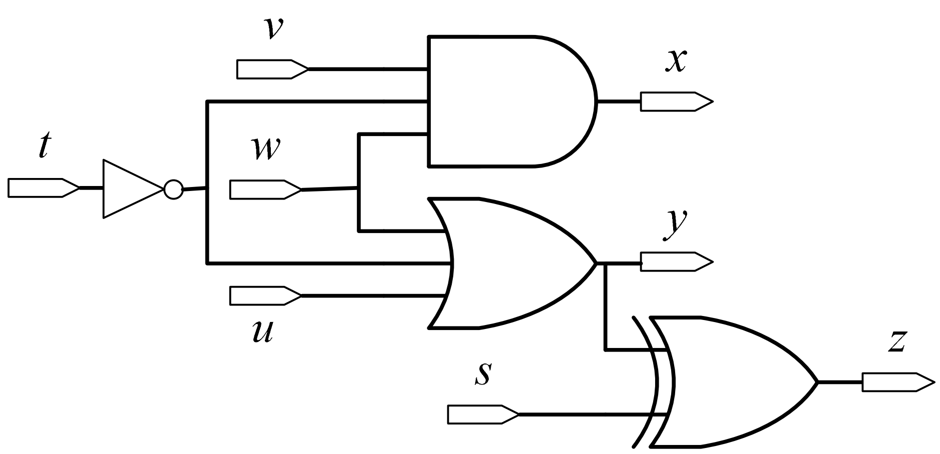
Example: Boolean Matching for Two Circuits

- Only allow to merge PIs, group POs, tie constant to PI in circuit2

Circuit1



Circuit2

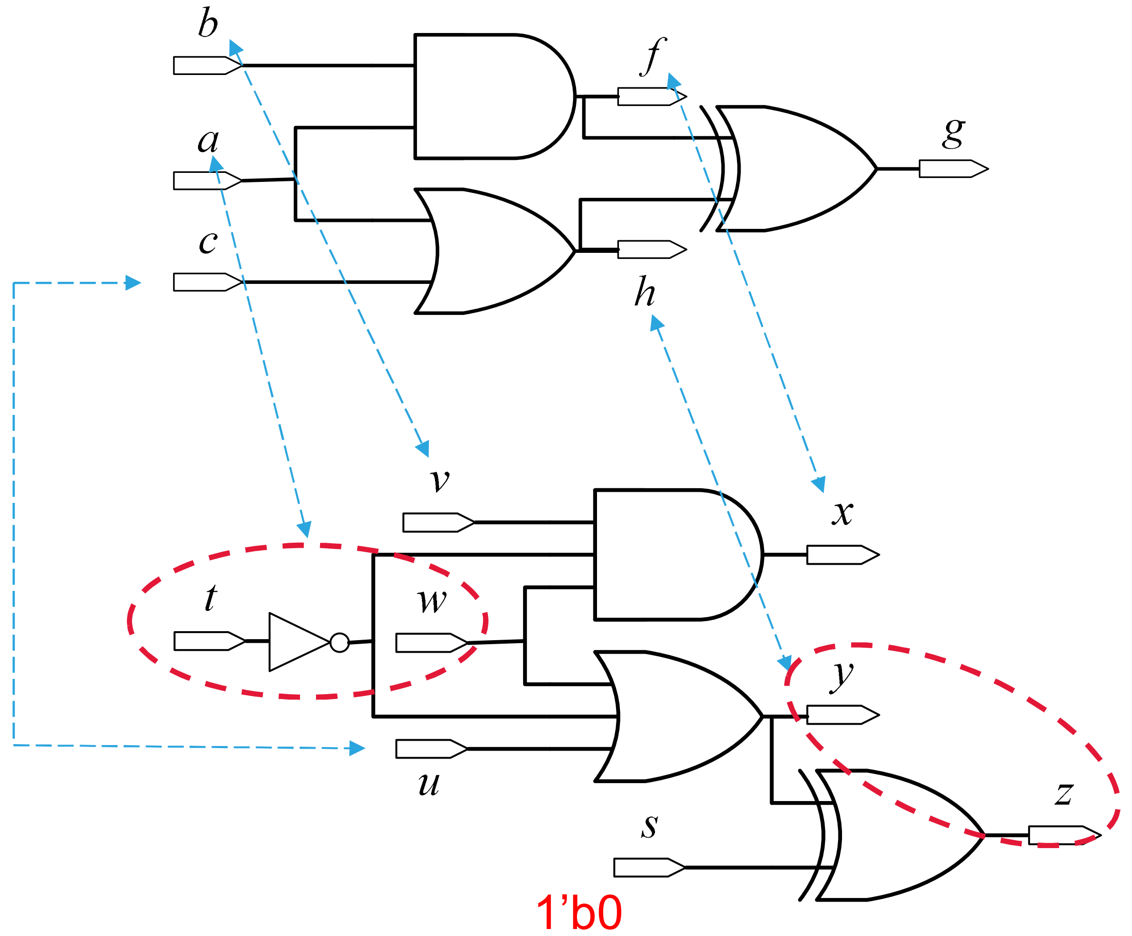


Example: One Matching Solution

- Two equivalent PO groups: (f , x) and (h , y , z)

Circuit1

Circuit2



Methodology of Boolean Matching

- Signature-based Methods
  - Utilize structure, simulation, and partial functional information

  Pros
  - Prune the solution space efficiently
  - Have more scalability for large designs

  Cons
  - Usually have less accuracy
  - Cannot guarantee the correctness of solution
- Formal-based Methods
  - Utilize BDD, SAT to solve the problem model

  Pros
  - Smartly explore the solution space
  - Can guarantee the correct solution

  Cons
  - Cannot handle large or complex design

Contest Problem Description

- Input: two designs “circuit1” and “circuit2”
- Output: PI/PO group for Non-exact Projective NPNP Boolean Matching
- Goal: The output groups should achieve the maximum number of PO equivalences between two designs.

- Rules:
  - Only PIs and POs in “circuit2” can be allowed to be negated, tied to constant, and merged.
  - Time limitation is 1800 seconds. Program needs to output a result before timeout.

Score Evaluation

- The score is designed to evaluate how many PO equivalences contestants can achieve, and there is bonus on finding grouped POs in the circuit2.
- Contestants get 10+N score for achieving an equivalent PO group which includes N POs.
  - For example, given 1 PO f in “circuit1” and 2 PO g,h in “circuit2”.
    For a PO group (f,g,h), if f == g == h, contestants get 13 score.
    But if $f \neq g$ or $f \neq$ h or $g \neq$ h, contestants get 0 score.
- One case can potentially have many PO groups. The total score is the sum of scores in all cases.
- The highest score is the winner.
  If two teams have the same score, shorter runtime is better.

Challenges on This Problem

- Compared to normal Boolean Matching
  - Instead of decision problem, it becomes an optimization problem because not all POs need to be equivalent
  - It has large possible solution space. PIs can be merged or tied to constants, and partial POs are really not equivalent.

- Its algorithm may need to use the hybrid of optimization and formal methods.

- The “circuit1” design may be very dissimilar to “circuit2” due to some merged or constant inputs in their functions, so structure-based method may lose some accuracy.

Benchmarks Suite

- Total 27 cases
- The category of these cases
  - Boolean Operations: Combination of primitive gates, MUX, SHIFT.
  - Datapath operations: Combination of adders, substractors, multipliers.
  - Mixed operations: Mix Boolean and datapath operations.
  - Extracted Functions from Special Designs: Extract functions from some designs for special purpose, such as CPU, decoder, CRC, etc.
  - Hidden Cases: cases not public to contestants before final submission and only used in final evaluation.

Category	Cases
Boolean Operations	case0, case10, case12
Datapath Operations	case1, case2, case4, case5, case13
Mixed Operations	case6
Extracted Functions from Special Designs	case3, case7, case8, case9, case11, case14, case15, case16, case17
Hidden Cases	case18~case26

Benchmarks Feature

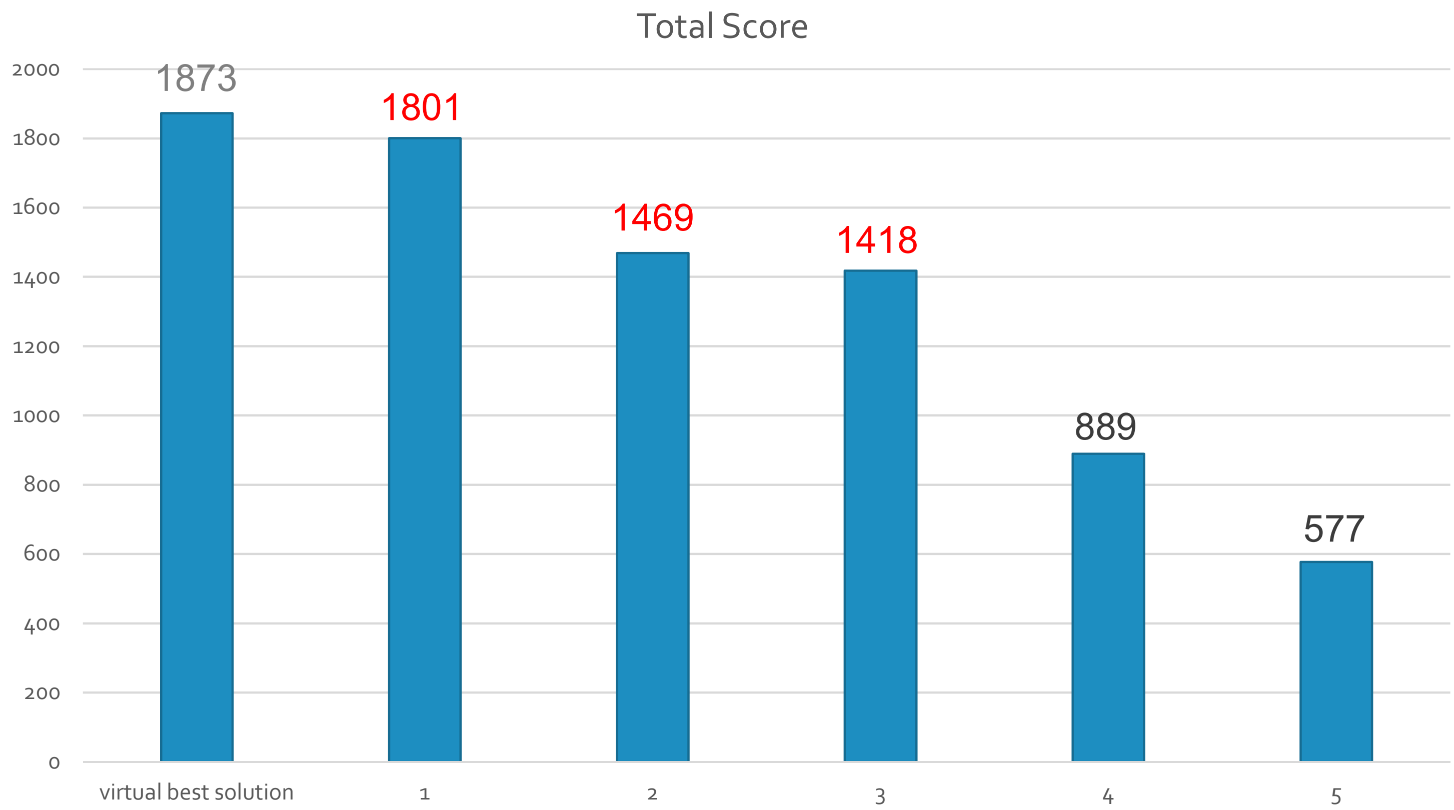
- Cases are designed or extracted to be at most 16 outputs.
- Cases have various structures and functions. The number of gates are different between two circuits.

Case	The Number of Gates	
	circuit1	circuit2
case0	3	4
case1	422	470
case2	338	355
case3	4654	1846
case4	427	470
case5	8659	9273
case6	5782	3066
case7	11029	24563
case8	8220	7969
case9	10770	23838
case10	14	16
case11	3614	2829
case12	2069	2566

Case	The Number of Gates	
	circuit1	circuit2
case13	77428	117514
case14	217	351
case15	269	269
case16	31	38
case17	234	235
case18	8659	9273
case19	3529	3889
case20	3865	5822
case21	10822	23800
case22	2069	2566
case23	5802	16226
case24	62095	172330
case25	448	1003
case26	6347	5305

Final Results of Rank 1 to 5

- First three teams show good performance.
- Top-rank score is close to the score of virtual best solution from all teams.



Score Detail of Each Case

- Red mark is good performance achieved by some teams because only 1~2 of them can achieve the highest score.
- Unsolved cases consist of concatenated multipliers, huge XOR-tree, and constants' propagation.

Team	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Total
1st place	25	192	192	180	192	0	0	0	0	0	24	0	60	120	84	120	96	120	0	0	24	0	60	0	0	192	120	1801
2nd place	25	192	192	136	192	0	0	0	0	0	24	0	60	0	84	120	96	120	0	24	48	0	48	0	0	108	0	1469
3rd place	25	192	192	180	192	0	0	0	0	0	24	0	60	0	84	120	96	120	0	0	0	0	60	0	0	73	0	1418
4th place	25	84	192	132	24	0	0	0	0	0	24	0	0	0	12	108	60	120	0	0	0	0	0	0	0	108	0	889
5th place	25	36	36	84	24	0	0	0	0	0	24	0	0	0	0	60	96	0	0	0	72	0	0	0	0	0	120	577
Virtual Best Solution	25	192	192	180	192	0	0	0	0	0	24	0	60	120	84	120	96	120	0	24	72	0	60	0	0	192	120	1873

Conclusion

- Contestants did good jobs to develop the new kind of Boolean matching engine.
- Non-exact Projective NPNP Boolean matching is a challenging problem. In this benchmark, 37% cases are still unsolved.
- This contest drives extended research topics and related applications.

Winners

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THIRD PLACE

cada093: ALCom

Yi-Tin Sun, Kuan-Hua Tu, Yao-Wen Mao,
Cheng-Min Chiang,
Prof. Jie-Hong Roland Jiang

National Taiwan University

SECOND PLACE

cada045: ricisgod

Yi-Hong Lu, Ko-Ching Liang, Cheng-Han Yang,
Kuan-Yu Lin,
Prof. Chung-Yang (Ric) Huang

National Taiwan University

FIRST PLACE

cada090: CUHK_NP3

Chak-Wa Pui, Peishan Tu, Haocheng Li,
Gengjie Chen,
Prof. Evangeline F.Y. Young

The Chinese University of Hong Kong