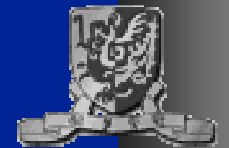# On Strong Locality Properties of Alternative Wires in Digital Circuits

Yu-Liang Wu, Wang Wong,

Kai-Cheung Cheng and Chak-Chung Cheung

The Chinese University of Hong Kong, Hong Kong

Hongbing Fan, University of Victoria, Canada

The 11th Workshop on Synthesis And System Integration of Mixed Information technologies

Outline

- **Definition & Revision**

- **Improvement on GBAW**

- **Analysis of Locality Properties of Digital Circuit**
    - **Distribution**
    - **Topological**
    - **Pattern**

- **Speed Comparison**

- **Conclusion**

Definition - N-Local Patterns

- **Target Wire**
  - Wire(s) to be removed

- **Alternative Wire**
  - Wire(s) added to the circuit

- **N-Local**
  - Distance between Target Wire and Alternative Wire is N levels of circuit depth
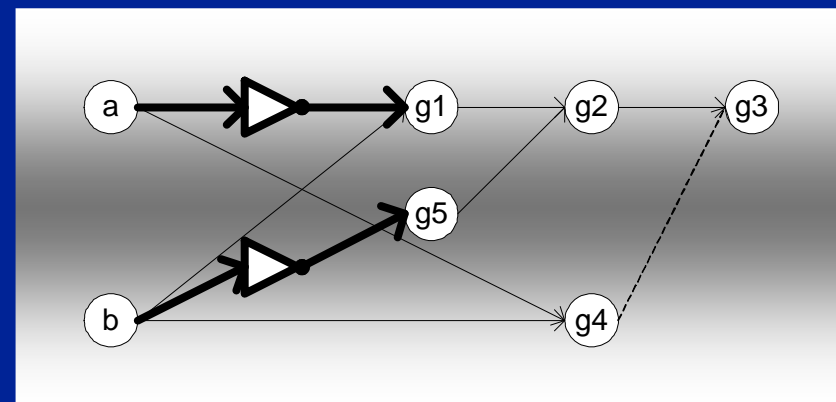
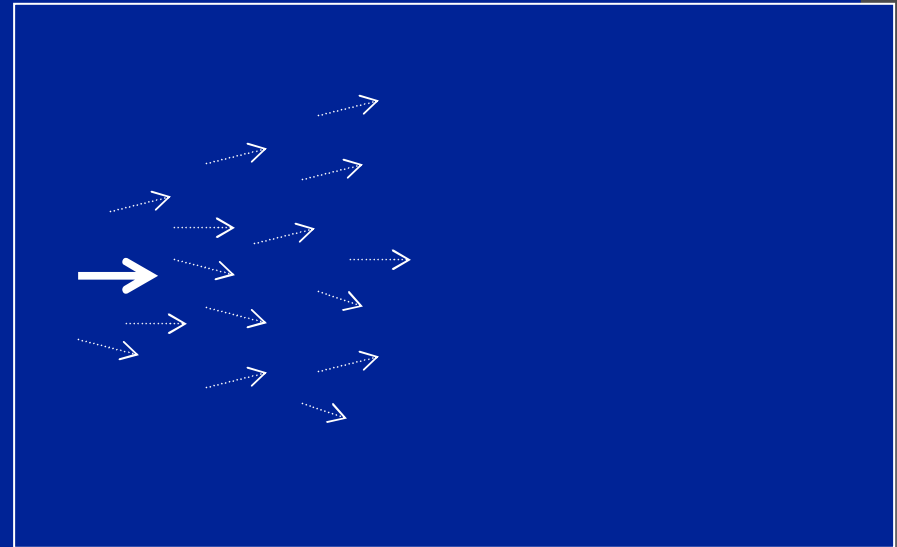# N-local Pattern

- ## N-local Pattern Example :

Target Wire

op1

op2

a
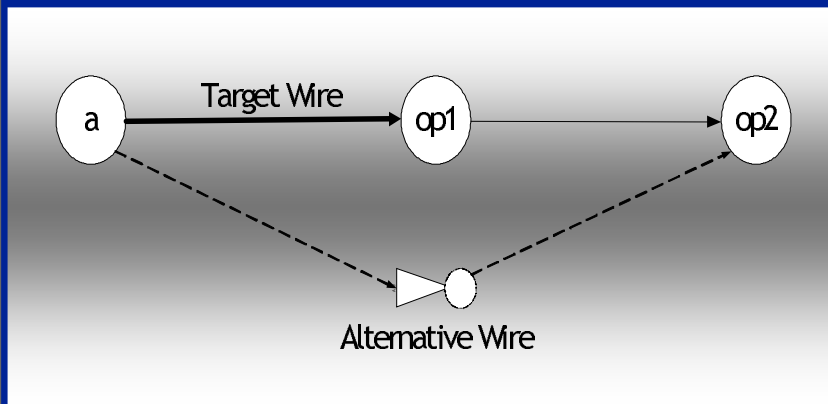
Alternative Wire

1-Local Pattern

Target Wire

Alternative Wire

2-Local Pattern

a g1 g2 g3

g5

b g4
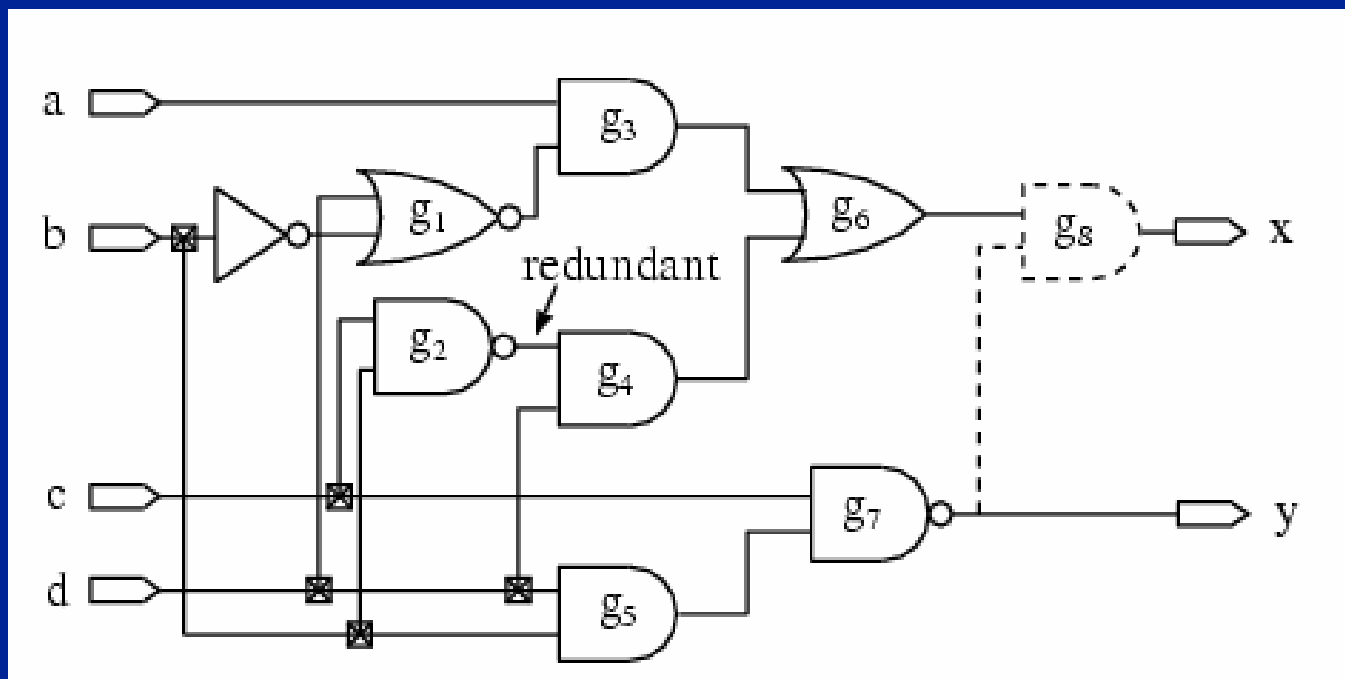
Definition - Locality vs. Distributivity

- **Distribution of AW**
  - ⊙ **Is Alternative Wires evenly distribution?**
  - ⊙ **Graph Representation**
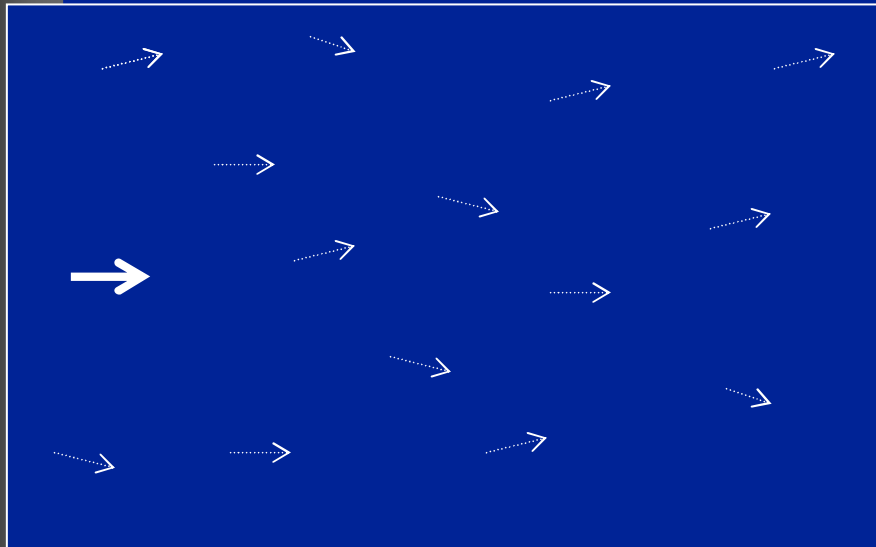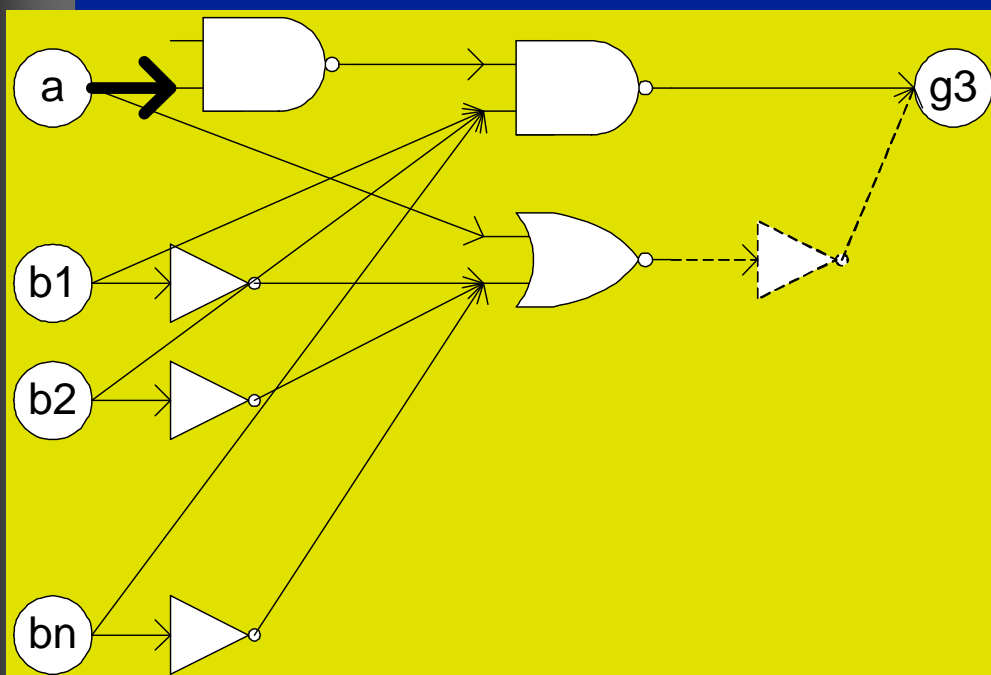
Revision of RAMBO

- **Redundancy Addition-and-removal for Multilevel Boolean Optimization**

- **Methodology: ATPG Based**

- **Time consuming**

Revision of GBAW

- **Graph Based Alternative Wiring**

- **Methodology: Pattern matching**

2-Local Pattern (Cluster 3 Set 6a)

2-Local Pattern (Cluster 1)

On Strong Locality Properties of Alternative Wires in Digital Circuits
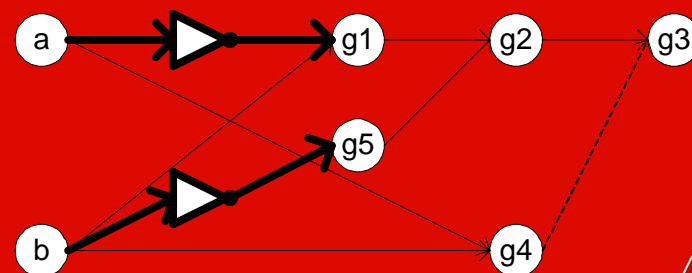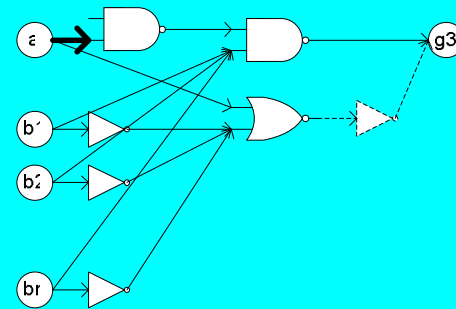
GBAW improvements

- **Implement the improvements**
  - ⊙ **Partial Pattern Matching**
  - ⊙ **Reverse Matching**

- **Locality Analysis**
  - ⊙ **Analysis on GBAW data**
  - ⊙ **Testing on RAMBO vs. GBAW**

Partial Pattern Matching

Not matched by old GBAW

Wire remembered by *Partial Pattern Matching*

2-Local Pattern (Cluster 3 Set 6a)
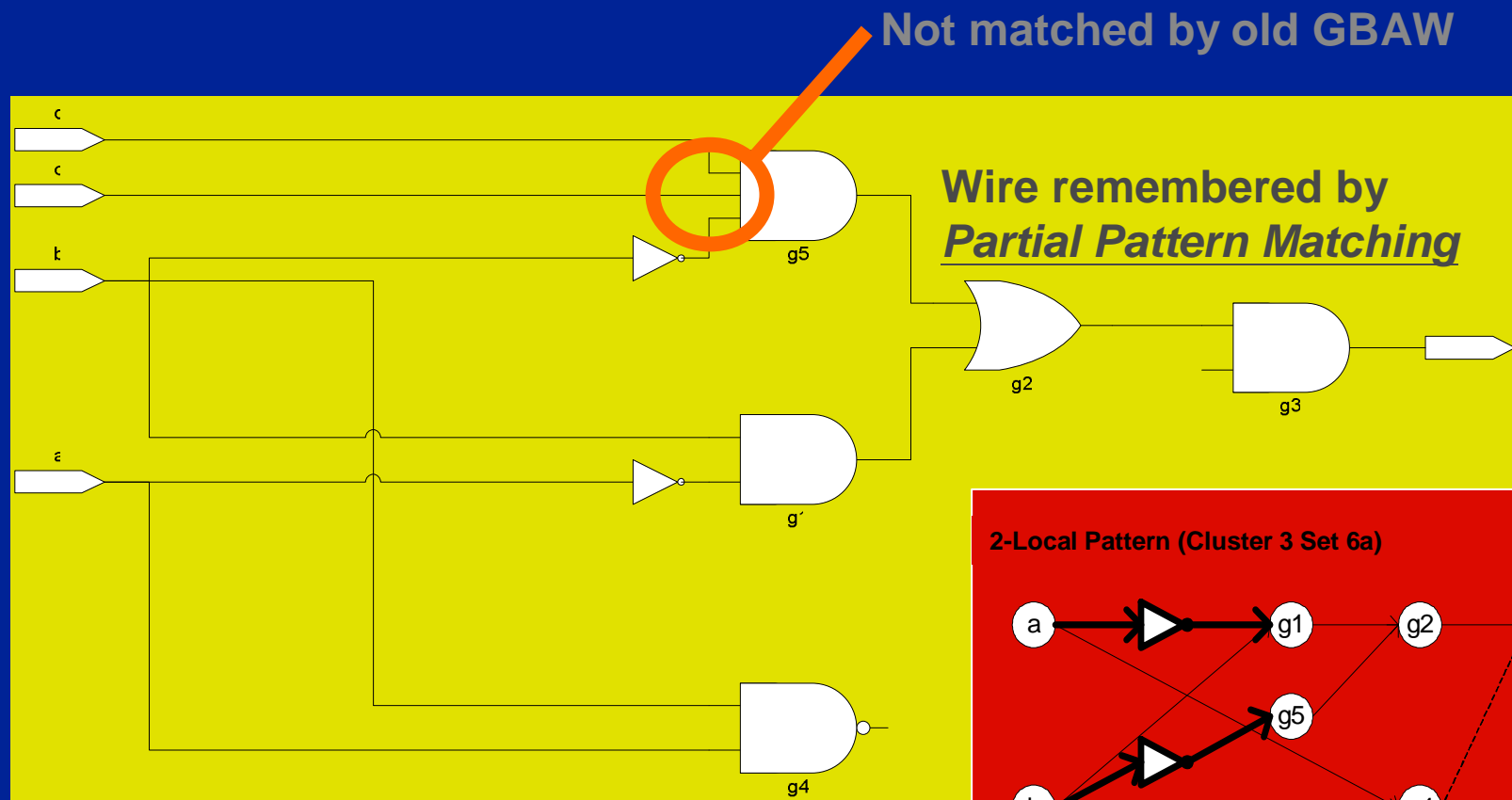
Reverse Searching

- **Implement Reverse Searching**

- **Increase GBAW's search power**
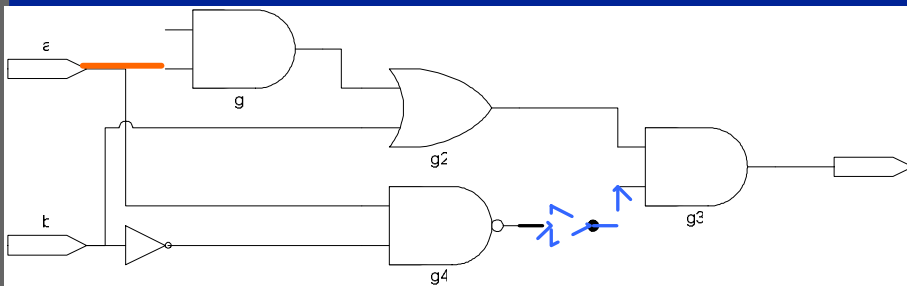
Forward Order

Search from fanin to fanout

Search from fanout to fanin
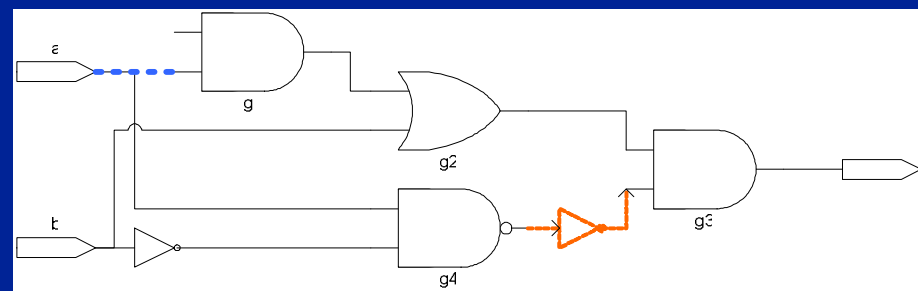
Backward Order (Old GBAW cannot find this pattern)

Statistics of finished GBAW

- **Simulation Environment**
  - **Machine: Sun Ultra 5/270, 128MB Ram**
  - **Public MCNC Benchmark Circuit - 100 Trials**

Circuit	Old GBAW		New GBAW	
	Cluster-3 AW found	CPU Time (s)	Cluster-3 AW found	CPU Time (s)
C432	0	0.35	0	0.42
C499	0	0.44	0	0.44
C880				0.76
C1355				1.13
C2670	14	0.54	15	0.54
C3540	8	1.47	12	1.82
C6288	0	2.6	0	2.76
Sum of Other Circuits	159	26.23	248	25.3
Total	181	36.79	275	34.97

AW Increased 53%

Locality – CAD Tools Features

- **Implication Based (e.g. RAMBO)**
  - very slow
  - Rely on ATPG testing on the redundancy

- **Recursive Learning (e.g. RAMFIRE)**
  - Limit the learning space
  - 10 times faster than RAMBO

- **Graph Based (e.g. GBAW)**
  - Rely on pattern matching

Locality - Introduction

- **Usage of Localities**
  - **Information about AW properties**

- **Three types of Locality Properties**
  - **Distribution Locality**
  - **Topological Locality**
  - **Pattern Locality**

Distribution Locality

- **Study on All AW located**

- **Difference from Topological Locality**
  - **Locate multiple AW for each target wire**
  - **More choice for future usage, e.g. perturb & simplify**

Alternative Wire W_{a5}
(4-Local)

Alternative Wire W_{a4}
(3-Local)

Alternative Wire W_{a1}
(1-Local)

Alternative Wire W_{a3}
(2-Local)

Target Wire W_t

Alternative Wire W_{a2}
(1-Local)

Distribution Locality	
1-Local AW	x 2
2-Local AW	x 1
3-Local AW	x 1
4-Local AW	x 1
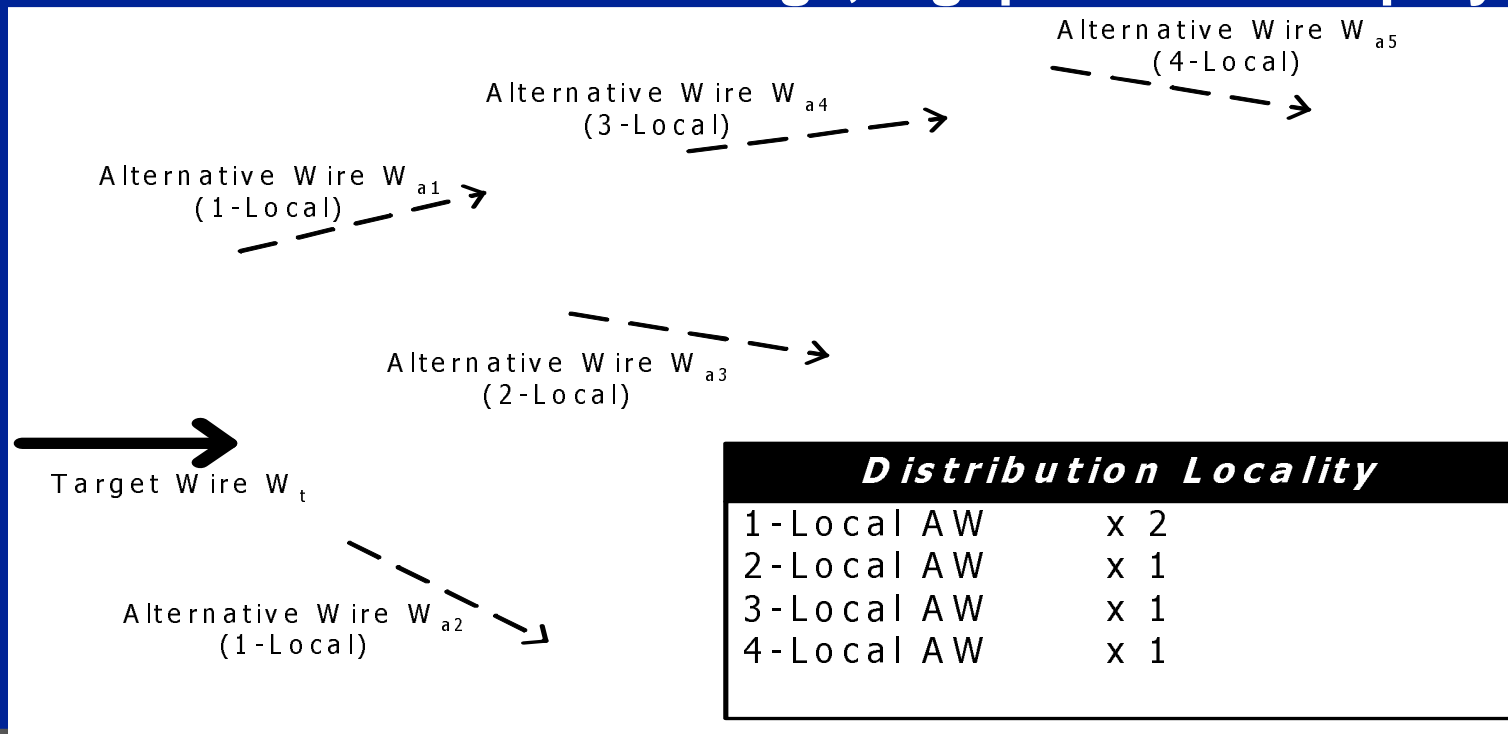
Distribution Locality
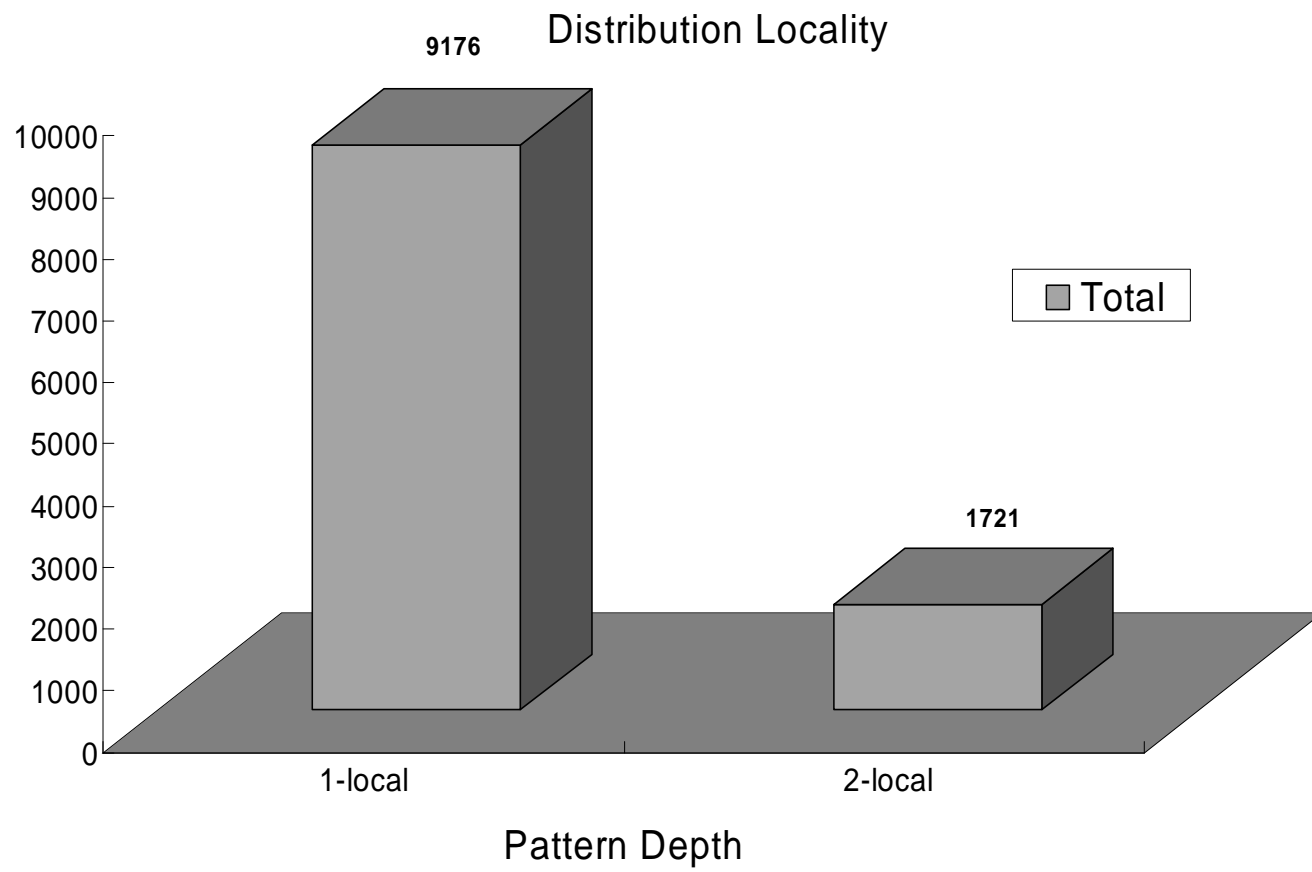
Statistics

- **Published papers claim that 30% of circuit wires got AW**

Circuit	Wires Tested	AW Found
C432	399	248
C499	886	30
C880	806	252
C1355	1087	
C2670	1583	471
C3540	2289	1137
C6288	5227	1344
Sum of Other	18011	7137
Total	30288	10865

10865 / 30288= 35 %

Topological Locality

- **Locate only the closest AW**

- **1st wire definition**

- **Why choose the 1st wire?**
  - ⊙ **only one AW can be chosen for actual usage**

Alternative Wire W$_{a5}$
(Local)

Alternative Wire W
(3-Local)

X

X

Alternative Wire W$_{a1}$
(1-Local)

Only W a1 (or W a2) is counted as Topological Locality consider the closest alternative wire only

X

When W t is replaced by W$_{a1}$, other alternative wires all becomes invalid.

Alternative Wire W$_{a}$
(2-Local)

Target Wire W$_{t}$

Topological Locality	
1-Local AW	x 1

X

Alternative Wire$_{a2}$
(1-Local)
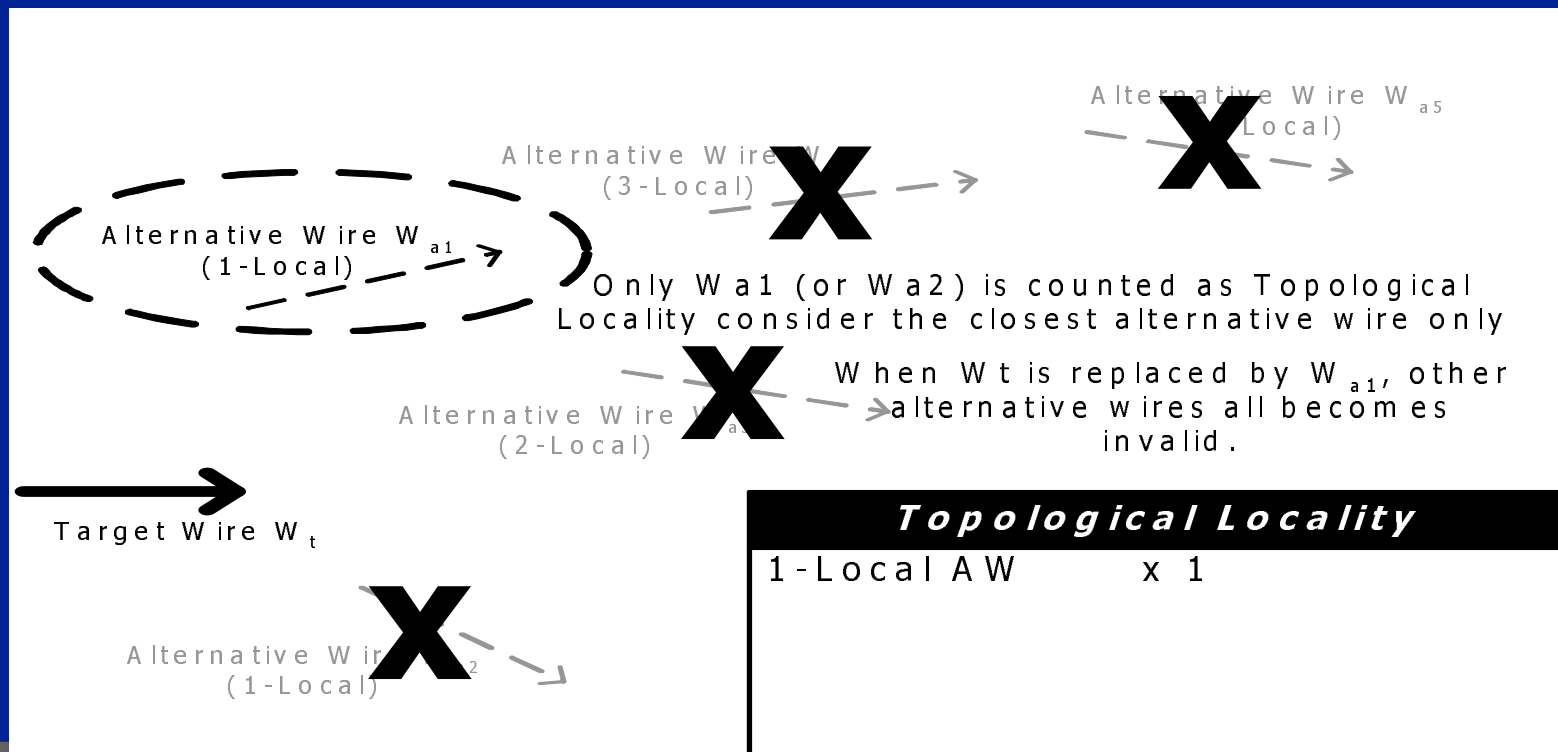
Statistics

About 30% wires got AW

Circuit	Wires Tested	AW Found
C432	399	188
C499	886	30
C880	806	216
C1355	1087	
C2670	1583	352
C3540	2289	802
C6288	5227	1344
Sum of Other Circuits	18011	5432
Total	30288	8610

8610 / 30288 = 28 %

Analysis on AW Circuit Depth
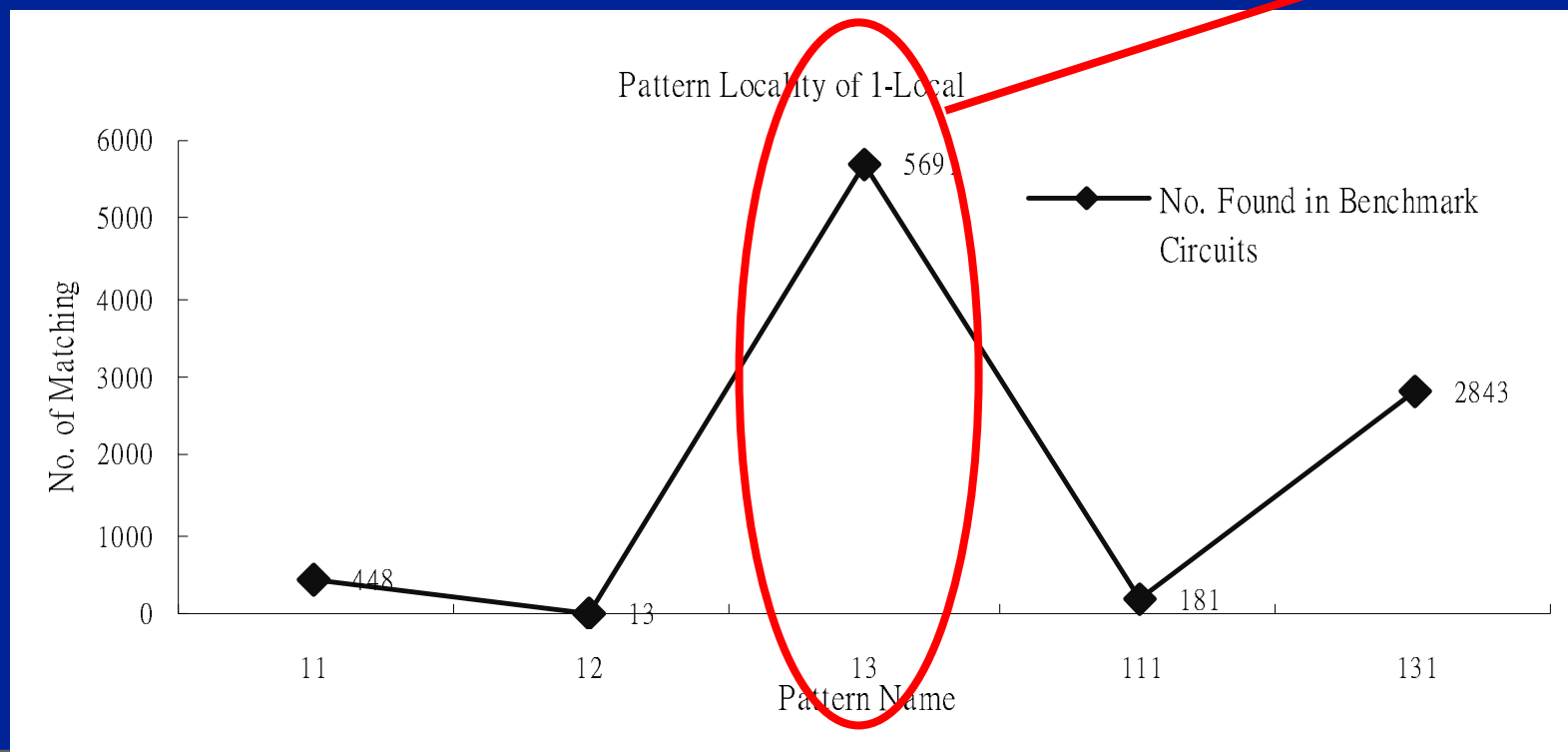

Topoplogical Locality of 1st AW
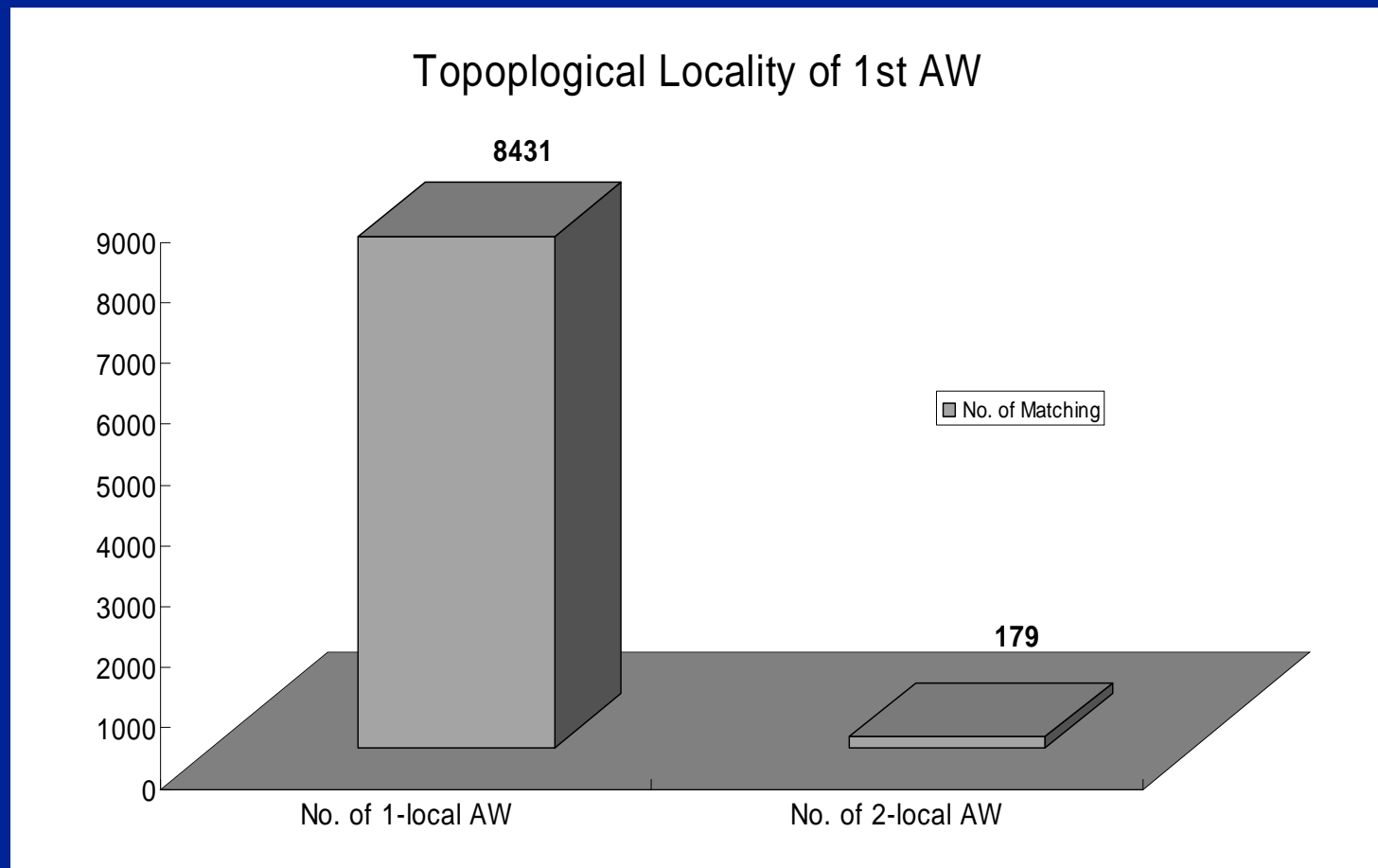
Pattern Locality

- **Study focused on the pattern occurrence**
  - ⦿ **Full Overview on occurrence of patterns**
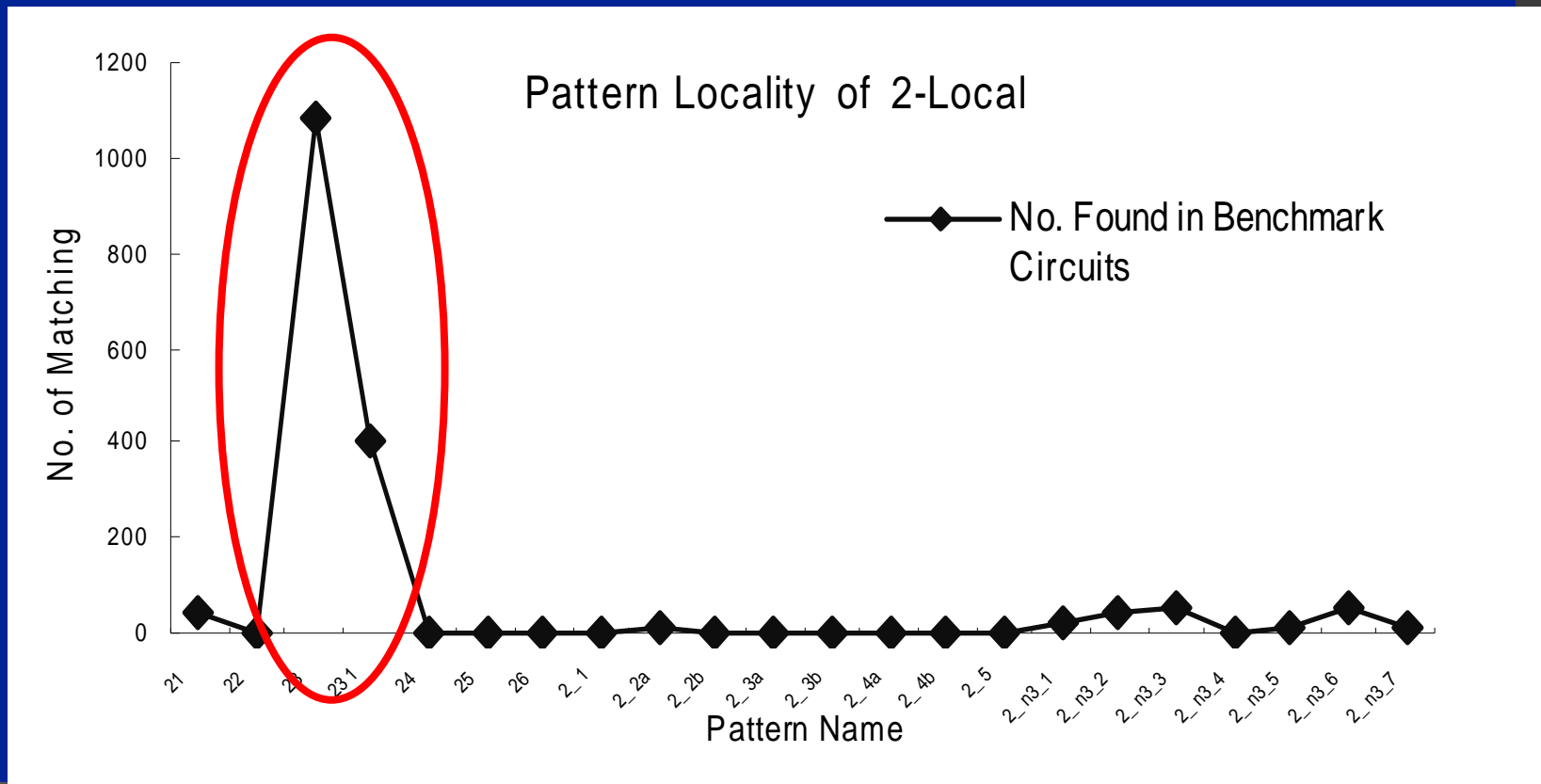 - ⦿ **Most AW are found within 2-local patterns**

- **1-Local Pattern**
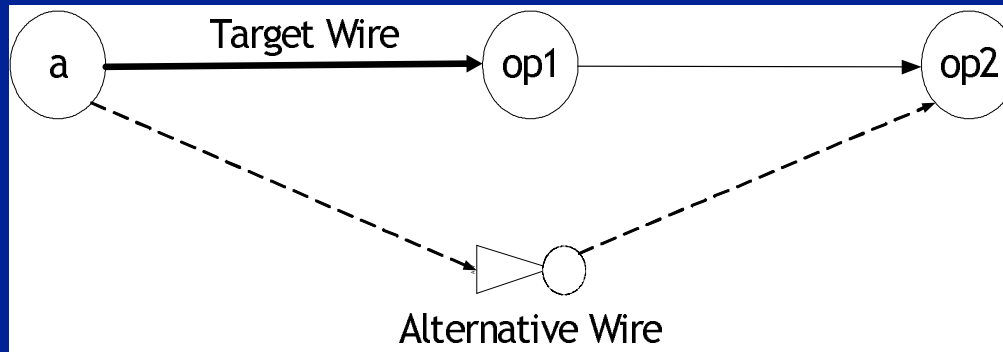
Matching relies on a few patterns only

Pattern Locality of 1-Local

No. Found in Benchmark Circuits

No. of Matching / Pattern Name

448, 13, 5691, 181, 2843

11, 12, 13, 111, 131

Uneven Distribution

- **2-Local Pattern**

Pattern Locality of 2-Local

No. of Matching (y-axis): 0, 200, 400, 600, 800, 1000, 1200

Pattern Name (x-axis): 21, 22, 23, 23.1, 24, 25, 26, 2_1, 2_2a, 2_2b, 2_3a, 2_3b, 2_4a, 2_4b, 2_5, 2_n3_1, 2_n3_2, 2_n3_3, 2_n3_4, 2_n3_5, 2_n3_6, 2_n3_7
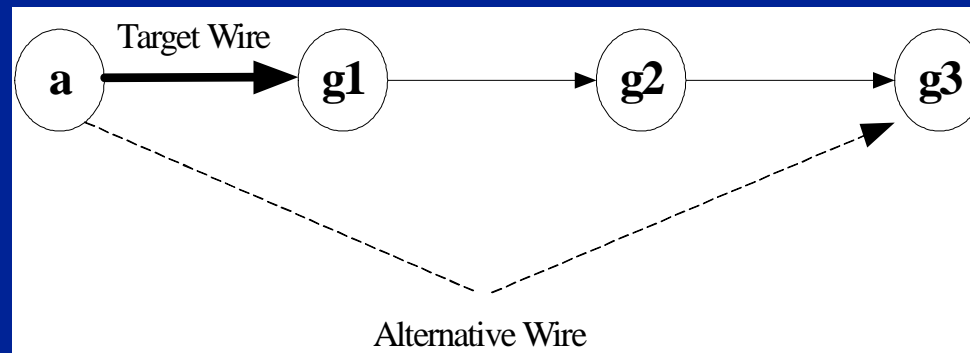
◆ No. Found in Benchmark Circuits

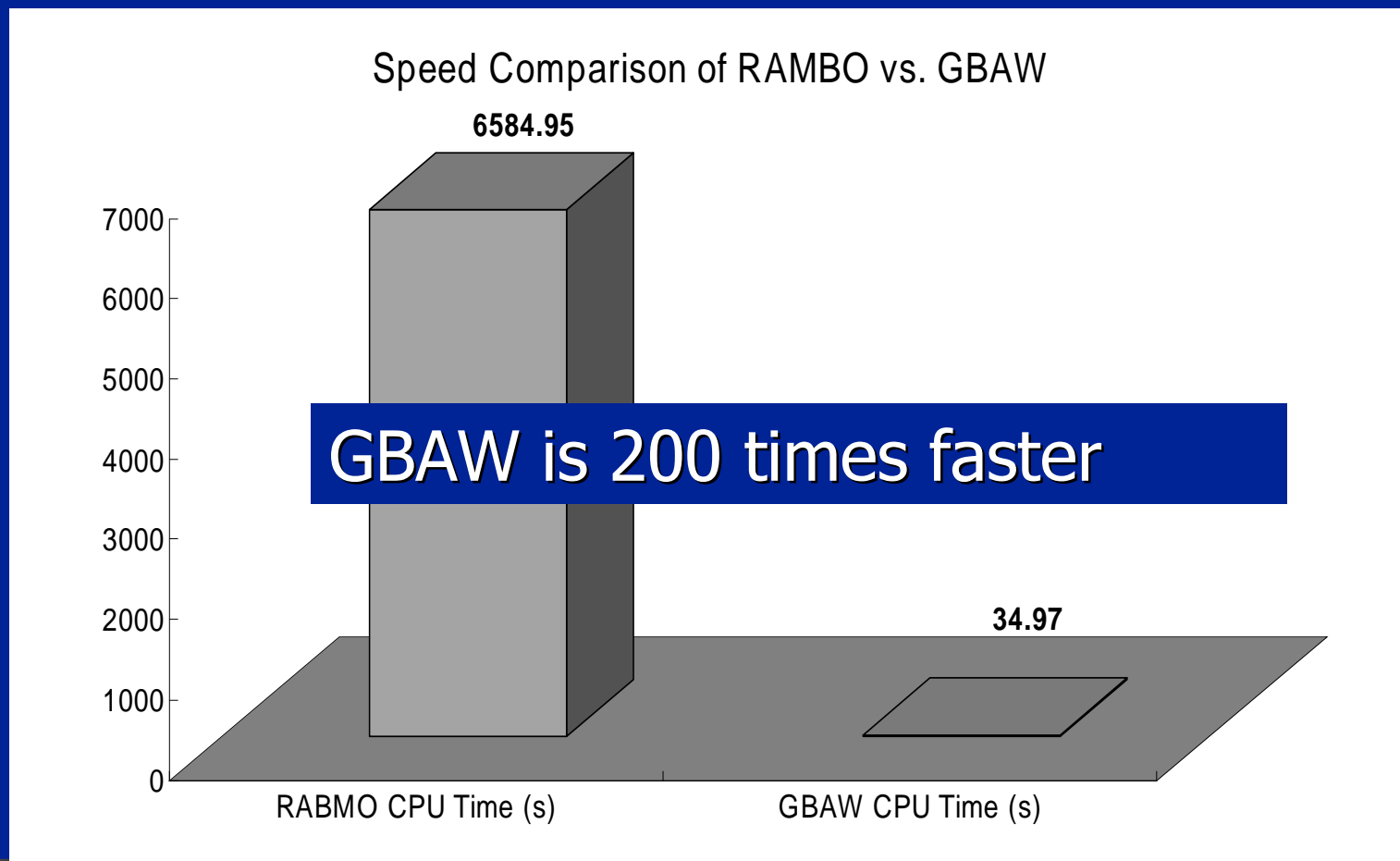# Champion Patterns – Simple

Pattern 13 for 1-local

Pattern 23 for 2-local

Locality Conclusion

- **Locality – RAMBO result**
  - **Similar Pattern Locality**
  - **95% AW within 2-local depth**
  - **75% 1-local pattern**

- **Implication on AW properties**
  - **About 30% of circuit wire got AW**
  - **Concentrate within 2-local**
  - **Rely heavily on simple patterns**

Speed comparison

- **Same Testing environment**
  - ◉ **Ultra 5/270, 128MB RAM**
  - ◉ **Standard MCNC benchmark circuits**

Speed Comparison of RAMBO vs. GBAW

6584.95

7000

6000

5000

4000

GBAW is 200 times faster

3000

2000

34.97

1000

0

RABMO CPU Time (s)   GBAW CPU Time (s)

Conclusions

- **AW properties**
  - **Tend to be close to the target wire**
    - **all AW & the 1st AW**
  - **Most are from simple patterns**

- **GBAW advantages**
  - **Implement simple pattern matching**
  - **As a result, consume very little CPU time**
  - **Can be integrated into various CAD tools**