Practical Mixed-Cell-Height Legalization Considering Vertical Cell Abutment Constraint

Speaker: Teng-Ping Huang
Advisor: Shao-Yun Fang

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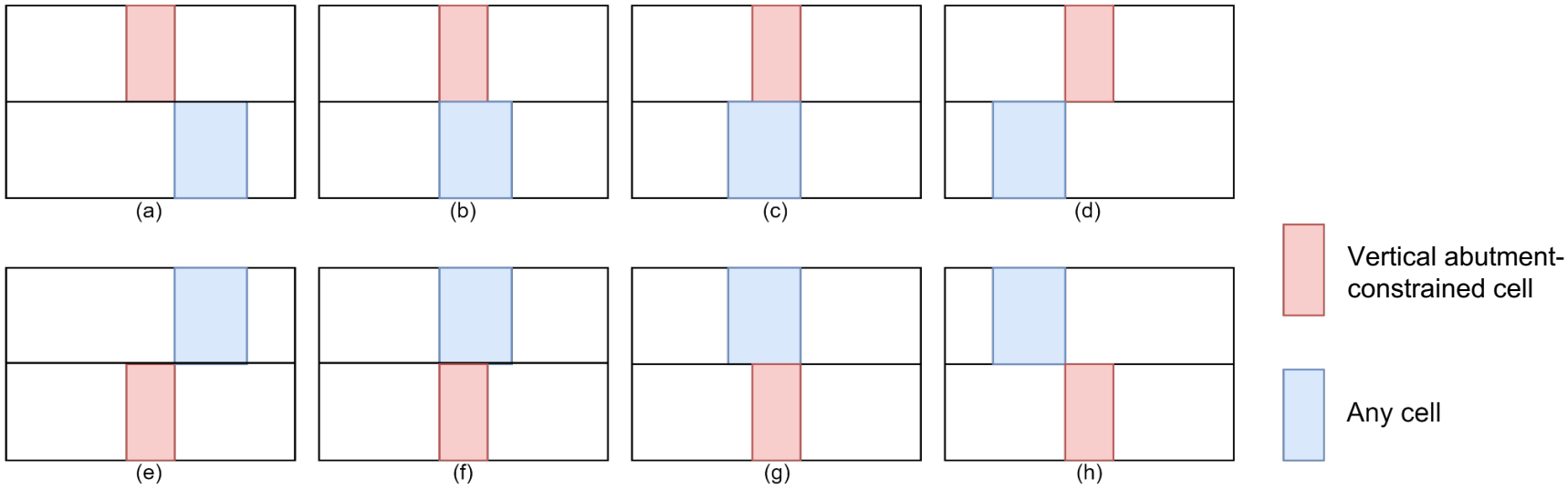
The Electronic Design Automation Laboratory
Department of Electrical Engineering
National Taiwan University of Science and Technology
Taipei 106, Taiwan

Outline

INTRODUCTION

Vertical Abutment Constraint

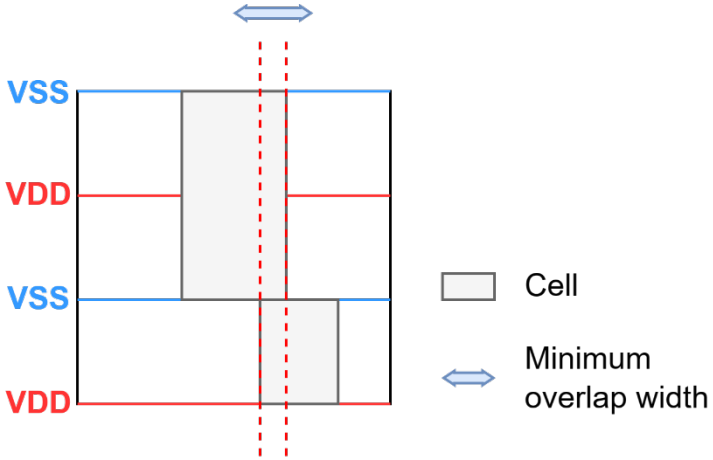
- **Proposed to model the existing and forthcoming inter-row constraints.**
- **Forbid cells to be placed above or below the vertical abutment-constrained cell at certain relative positions.**



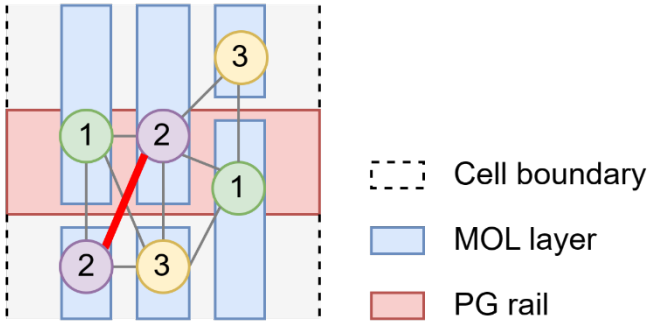
The forbidden relative positions in our experiments

Previous Works

- **Inter-row constraints in placement**
  - Minimum implant area (MIA)



  - Middle-of-line structure (MOL)



Problem Definition

- **Given**
  - The global placement result
  - The hard constraints including:
    - Power/ground rails alignment constraint
    - Edge spacing constraint
    - Vertical abutment constraint
    - Cells must not overlap with each other or with fixed macros.
    - Cells must be placed on the manufacturing site.

- **The objective is to satisfy the above constraints while minimizing:**
  - The average cell displacement
  - The maximum cell displacement

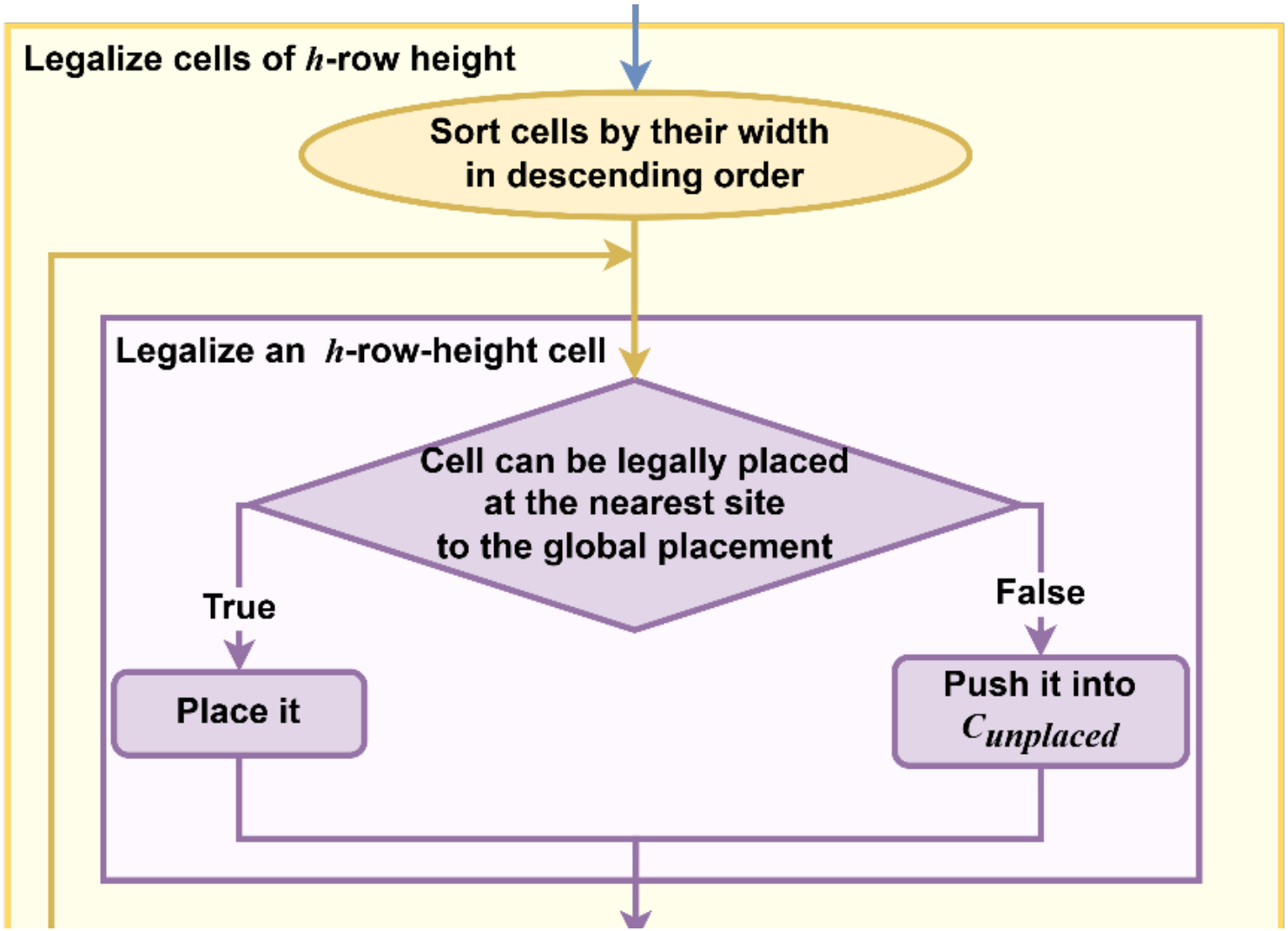
PROPOSED ALGORITHM

Sequential Order

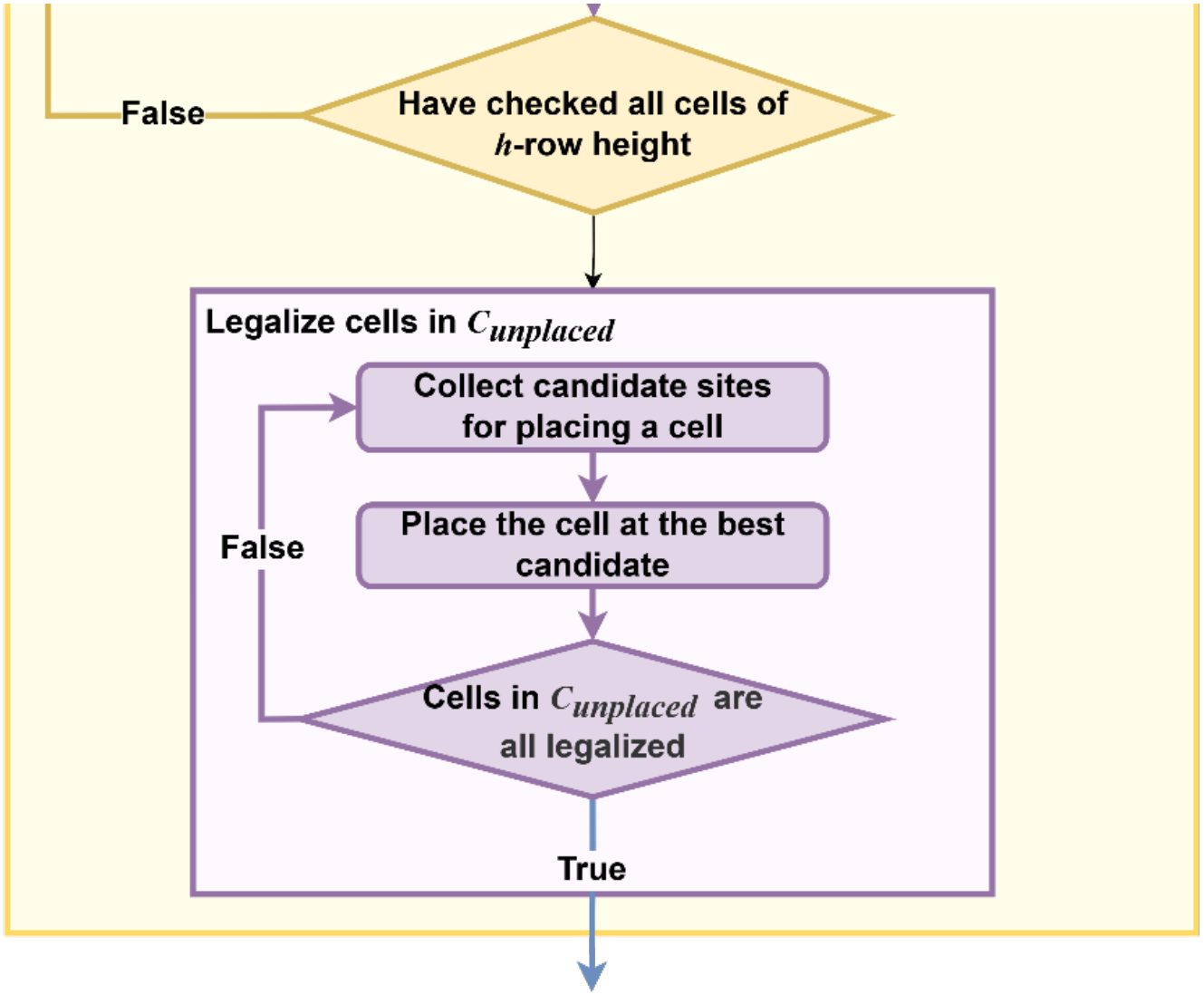
- **Sorting criterion for legalization**
  1. Cell height
  2. Cell width

- **The reason why we adopt this approach**
  - The algorithm are allowed to shift previously legalized cells.
    - Need to minimize the impact on previously legalized placement.
    - A cell with greater height can potentially impact a larger number of rows at a time.

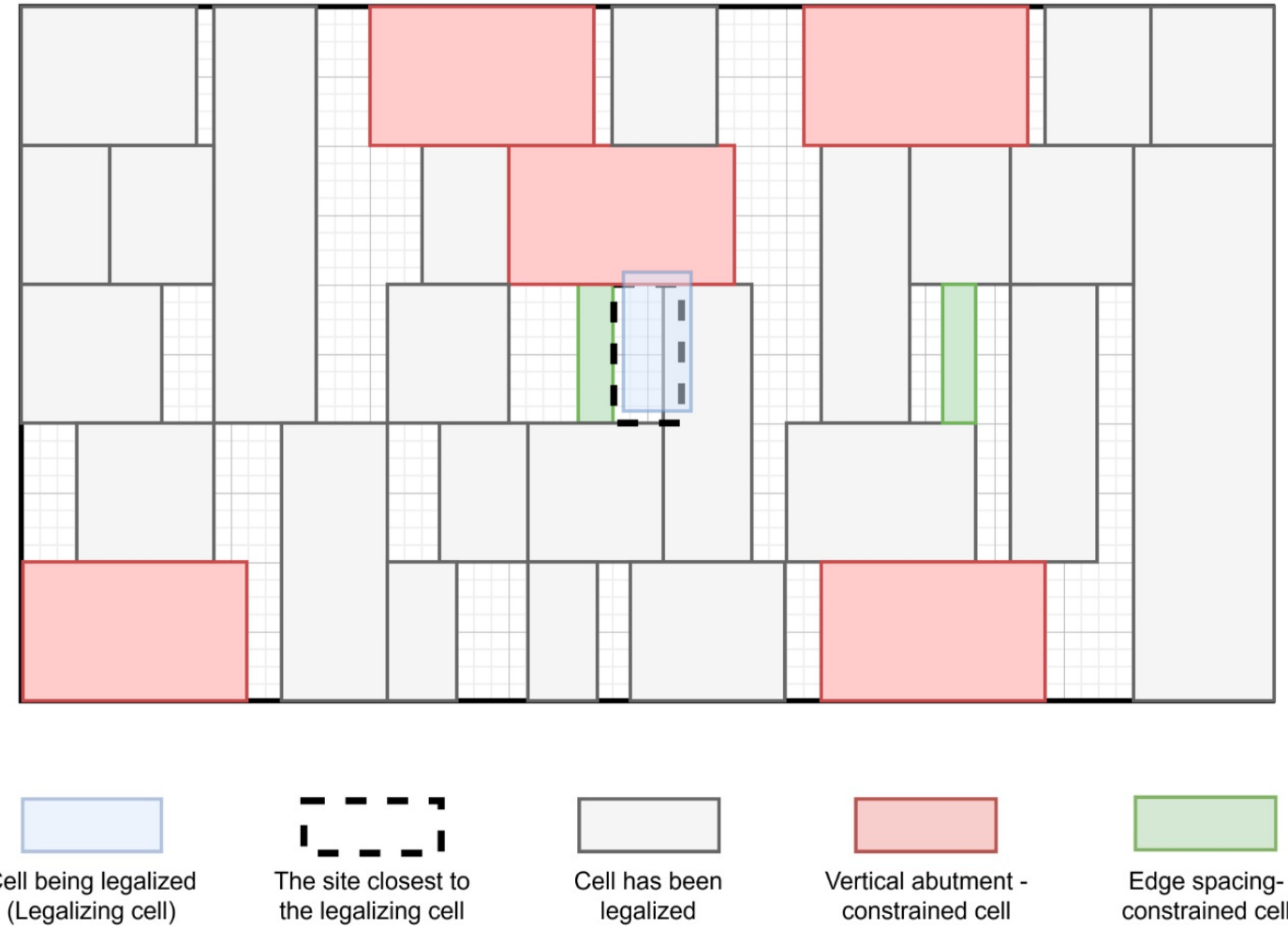
Flow


Legalize cells of h-row height
Sort cells by their width in descending order
Legalize an h-row-height cell
Cell can be legally placed at the nearest site to the global placement
True
False
Place it
Push it into $C_{unplaced}$

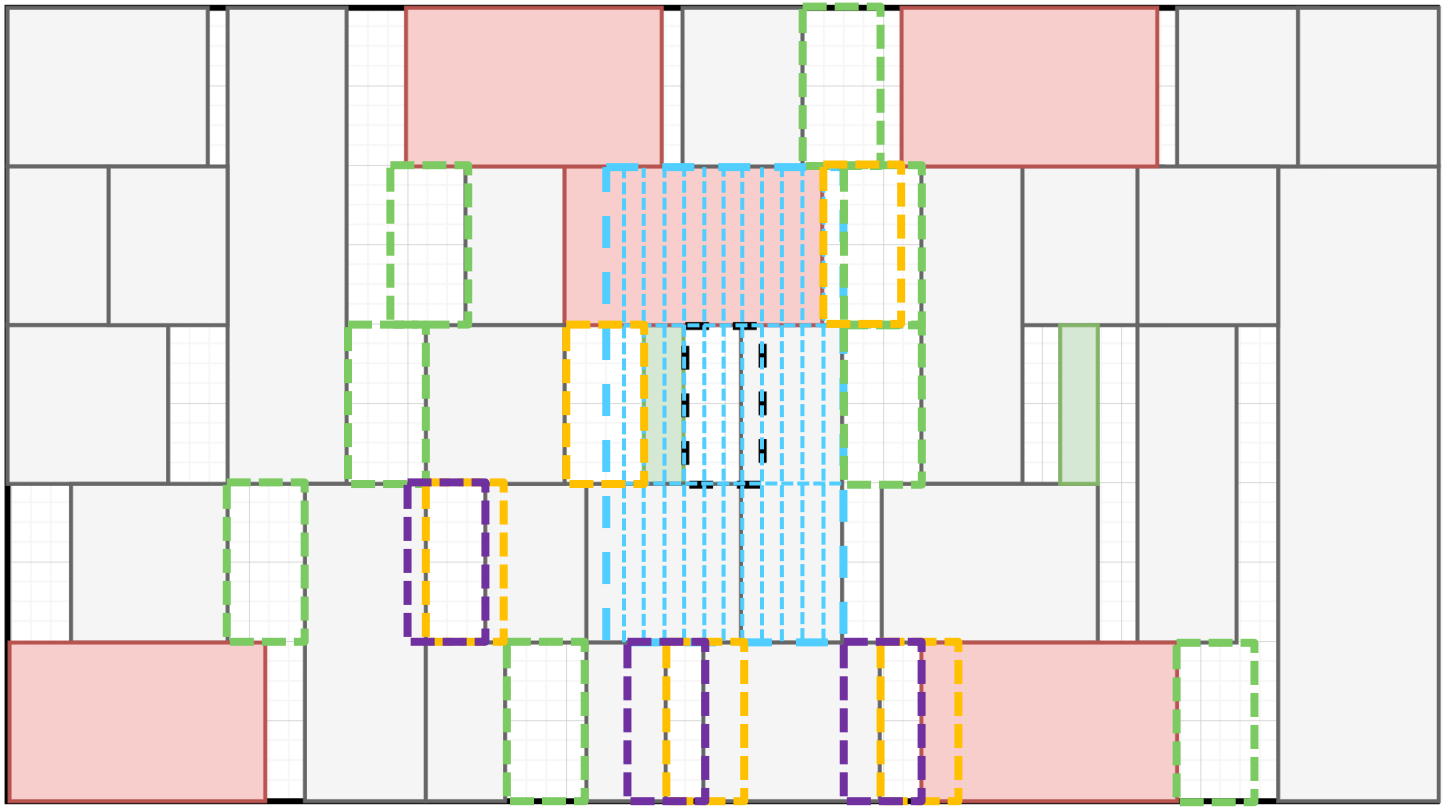
Flow


False
Have checked all cells of h-row height
Legalize cells in $C_{unplaced}$
Collect candidate sites for placing a cell
Place the cell at the best candidate
False
Cells in $C_{unplaced}$ are all legalized
True

Example


Cell being legalized
(Legalizing cell)
The site closest to
the legalizing cell
Cell has been
legalized
Vertical abutment -
constrained cell
Edge spacing-
constrained cell

Candidate Sites for Target Cell



Violation-free candidate

Illegal candidate

Nearby window

The site closest to the legalizing cell

Cell has been legalized

Vertical abutment - constrained cell

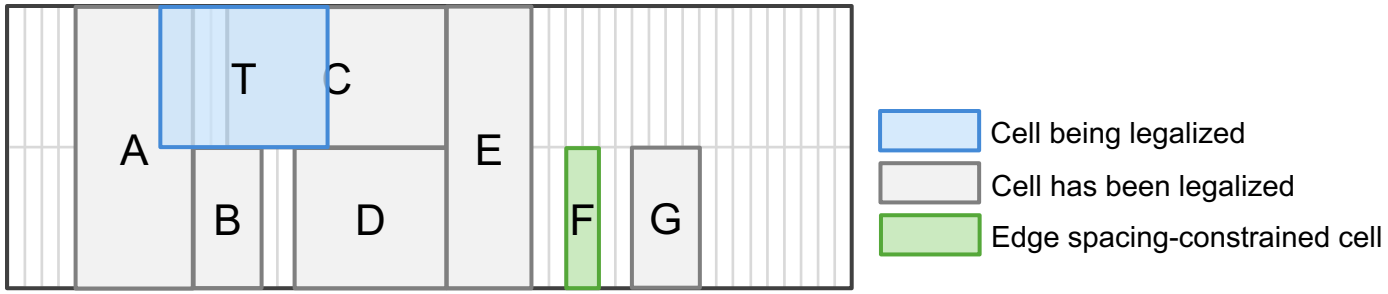
Edge spacing-constrained cell

Candidate Sites Evaluation

- **The subroutine $\boldsymbol{ChooseBestSite}$**
  - Evaluates each candidate site in $\boldsymbol{Candidates}$ as follows:
    1. Try to place the target cell at a candidate site.
    2. If this violates any constraint, the subroutine solves the violations by shifting the cells that have been legalized.
    3. Measure the impact to the placement for the above actions by a cost function.
- **Shift legalized cells to resolve violations.**
  - Placing the target cell at an illegal candidate site may result in three types of violations.
    - Overlap
    - Edge spacing violation
    - Vertical abutment violation

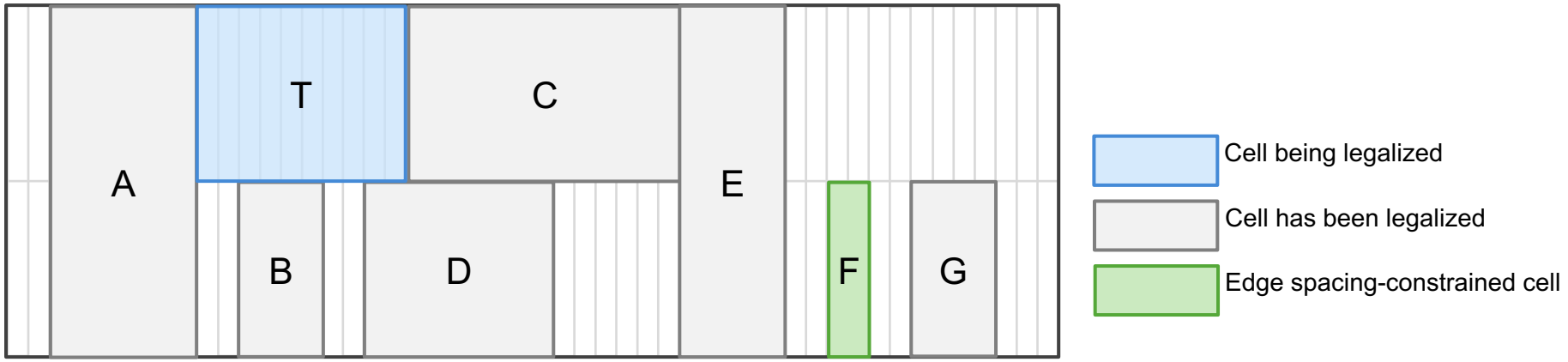
Shift legalized cells

- **Shift to solve overlaps and edge spacing violations**
  - The algorithm first shifts the legalized cells that would cause an overlap when placing the target cell.
    - Determine the shift direction by considering which direction would result in less displacement to the legalized cell.
      - Because the target cell has not yet been inserted into the DAG.



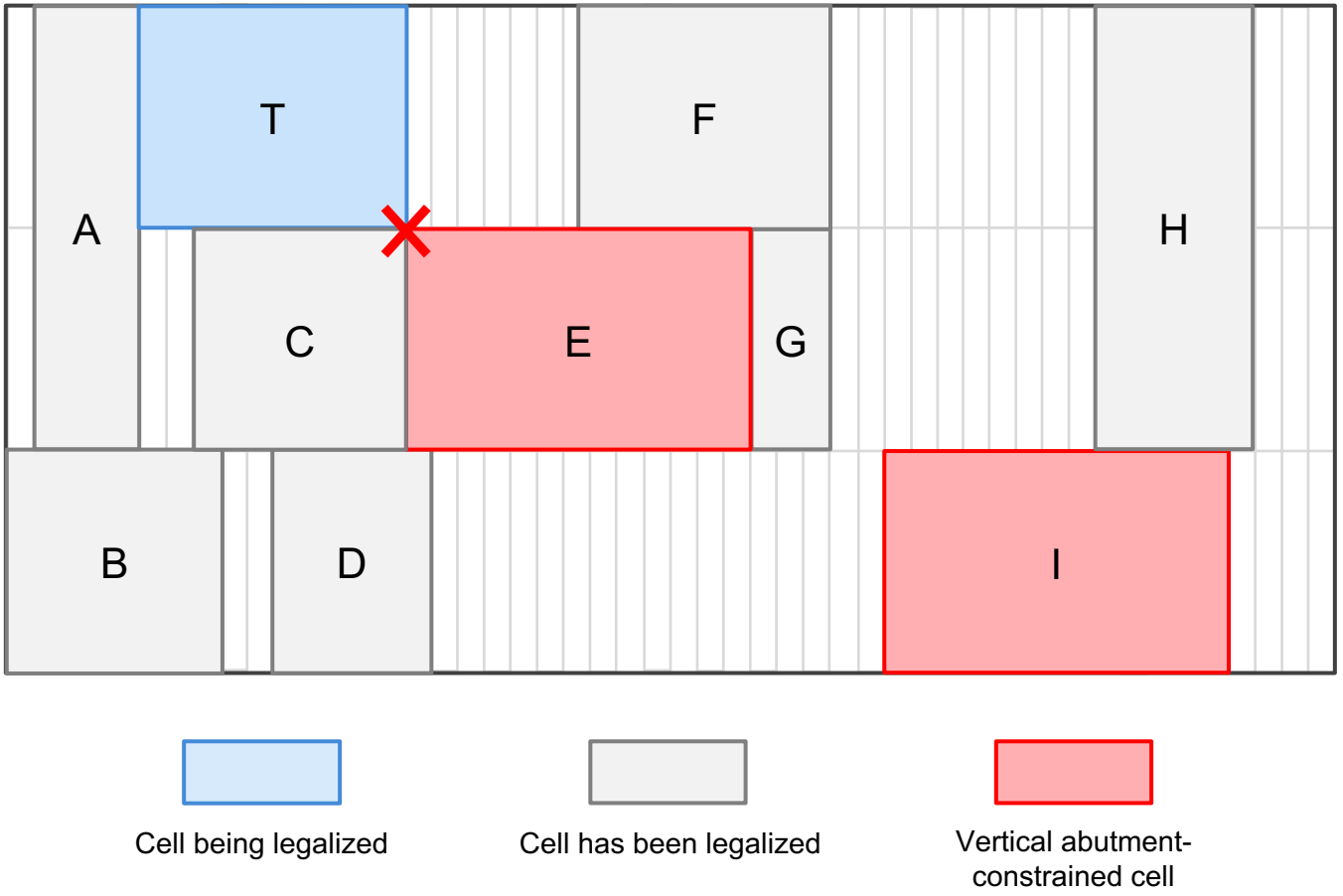
Shift legalized cells

- **Shift to solve overlaps and edge spacing violations**



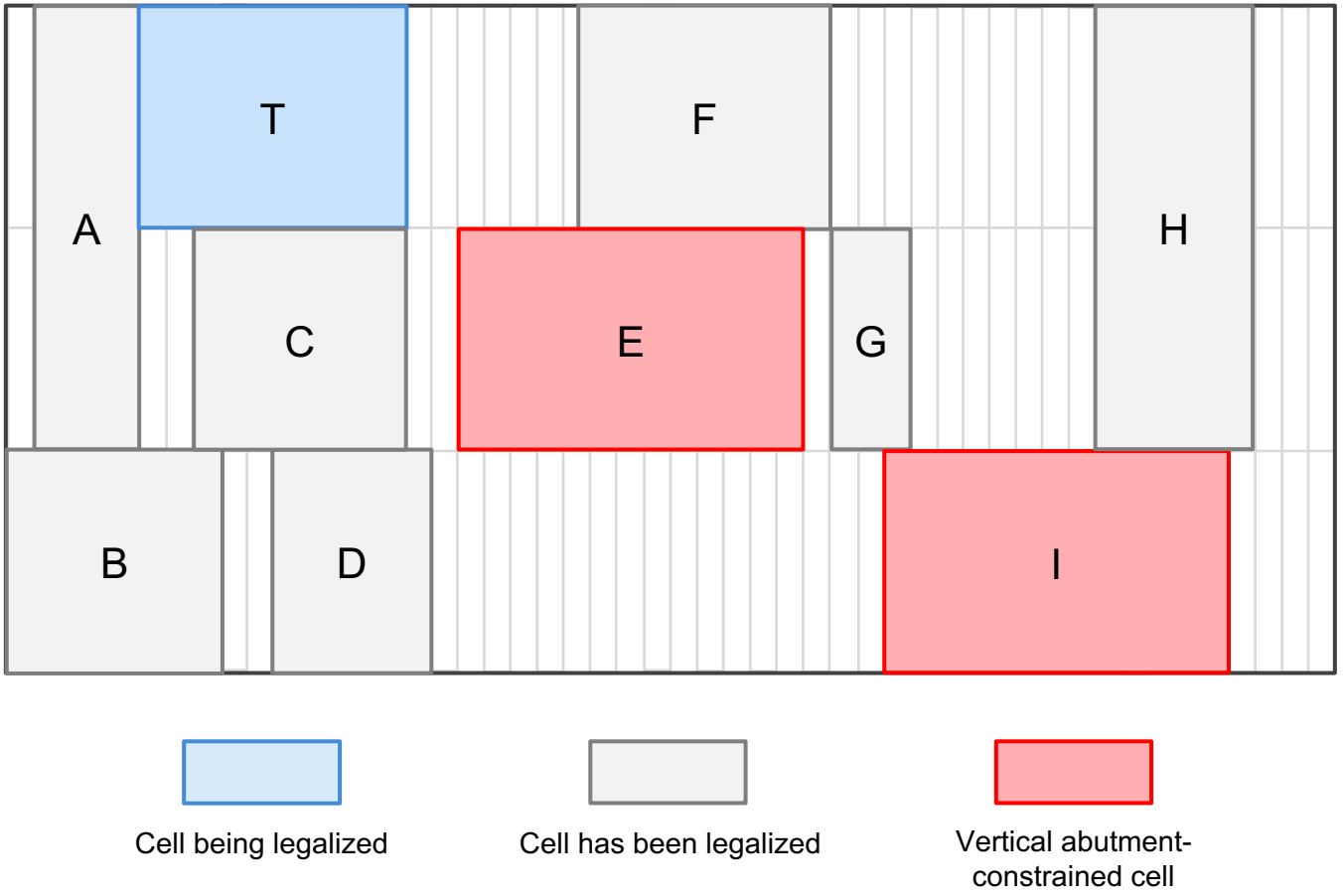
Shift legalized cells

- The shift to solve vertical abutment violation arising from placing the target cell.



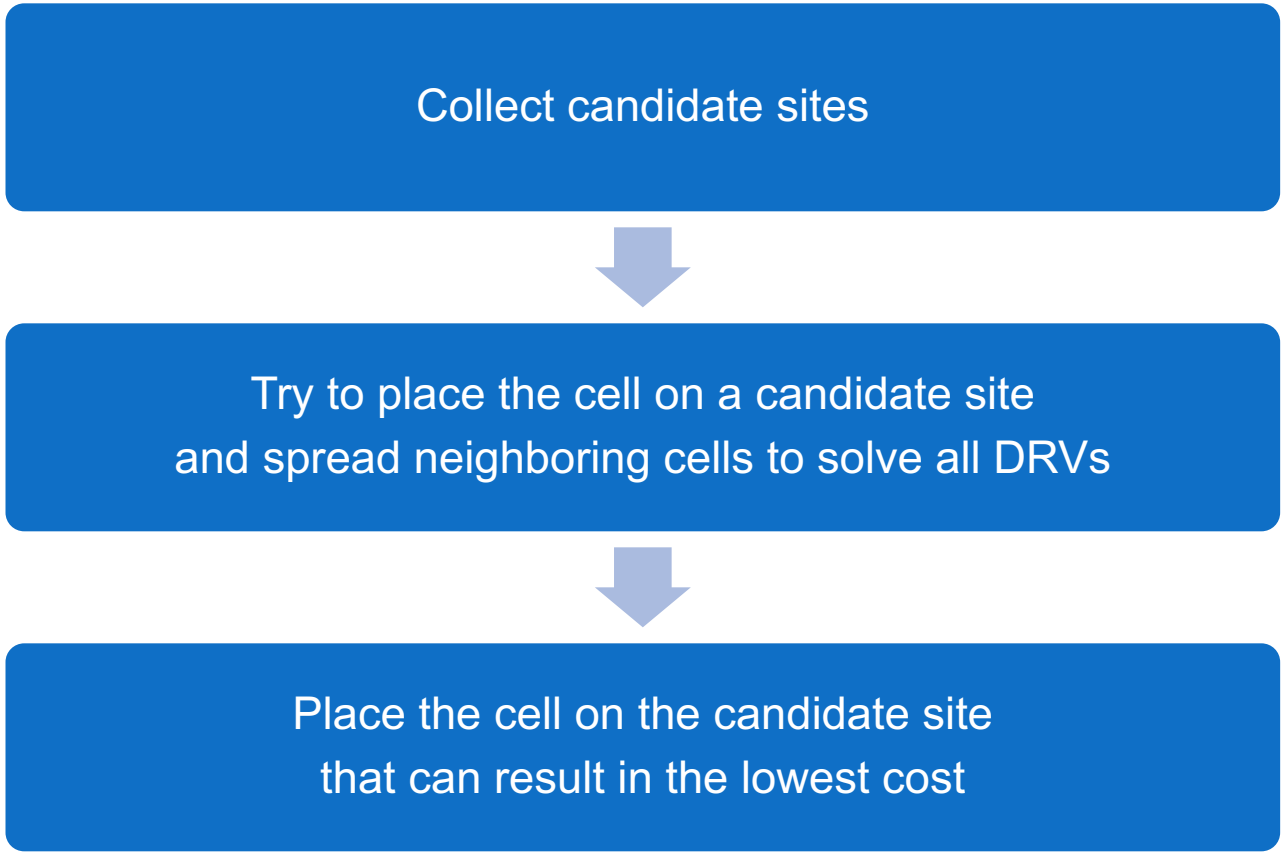
Shift legalized cells

- **The shift to solve vertical abutment violation.**



Legalization Flow

- **For a cell that can not be directly placed at the site that is closest to its global position.**



EXPERIMENTS

Benchmarks

- **IC/CAD-2017 CAD Contest in Multi-Deck Standard Cell Legalization**
  - Representative benchmarks set in the current mixed-cell-height legalization problem

Benchmark	#S. Cell	#D. Cell	#T. Cell	#Q. Cell	Density
des_perf_1	112,644	0	0	0	91%
des_perf_a_md1	103,589	4,699	0	0	55%
des_perf_a_md2	105,030	1,086	1,086	1,086	56%
des_perf_b_md1	106,782	5,862	0	0	55%
des_perf_b_md2	101,908	6,781	2,260	1,695	65%
edit_dist_1_md1	118,005	7,994	2,664	1,998	67%
edit_dist_a_md2	115,066	7,799	2,599	1,949	59%
edit_dist_a_md3	119,616	2,599	2,599	2,599	57%
fft_2_md2	28,930	2,117	705	529	83%
fft_a_md2	27,431	2,018	672	504	32%
fft_a_md3	28,609	672	672	672	31%
pci_bridge32_a_md1	26,680	1,792	597	448	50%
pci_bridge32_a_md2	25,239	2,090	1,194	994	58%
pci_bridge32_b_md1	26,134	1,756	585	439	27%
pci_bridge32_b_md2	28,038	292	292	292	18%
pci_bridge32_b_md3	27,452	292	585	585	22%

Experiments

1. **Examination of the ability to address fundamental constraints**
   - Address the following technology constraint:
     - Power rail alignment constraint
     - Edge spacing constraint

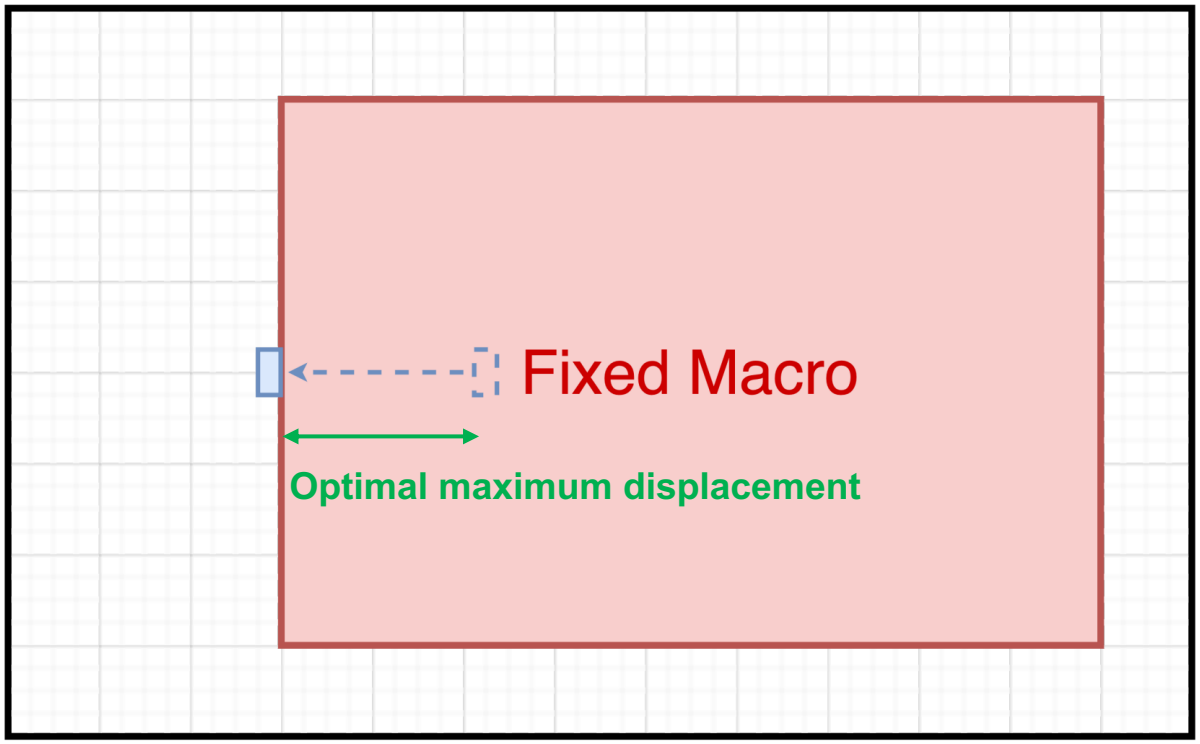
2. **Examination of the ability to address the vertical abutment constraint**
   - Address the following technology constraint:
     - The constraints in experiment 1 and **vertical abutment constraint**
   - The fourth most frequently used cell type in each design is set as the vertical abutment-constrained cell.

Experiment 1

- **Examination of the ability to address fundamental constraints**
  - 1st: The first place of IC/CAD-2017 CAD Contest
  - [3]: Wu et al., "Linear-time Mixed-Cell-Height Legalization for Minimizing Maximum Displacement," ISPD' 22

Benchmarks	Avg. Disp. (sites)			Max. Disp. (sites)			Runtime (s)		
	1st	[3]	Ours	1st	[3]	Ours	1st	[3]	Ours
des_perf_1	7.11	6.81	**6.45**	76.69	**38.49**	67.07	12.3	1.8	3.09
des_perf_a_md1	7.53	5.61	**5.52**	625.78	***607.3**	***607.3**	7.72	1.21	3.65
des_perf_a_md2	7.72	5.5	**5.41**	679.76	480.55	***403.86**	7.76	1.21	3.7
des_perf_b_md1	5.41	4.58	**4.54**	90.47	**30.27**	37.53	6.59	1.48	0.99
des_perf_b_md2	6.16	4.97	**4.93**	199.78	**30.62**	32.87	6.26	1.74	1.42
edit_dist_1_md1	7.07	**5.45**	5.53	79.17	**52.84**	52.99	8.58	2.12	3.75
edit_dist_a_md2	6.19	5.16	**5.14**	**164**	**164**	168	7.59	1.33	2.65
edit_dist_a_md3	9.18	7.56	**6.8**	279.54	**233**	237	85.36	2.18	4.13
fft_2_md2	**7.72**	8.49	7.74	66.06	**45.01**	69.88	1.6	0.42	0.98
fft_a_md2	5.34	**4.58**	4.59	***343.48**	***343.48**	***343.48**	1.41	0.2	3.53
fft_a_md3	5.04	**4.31**	4.32	***109.62**	***109.62**	***109.62**	1.36	0.18	1.82
pci_bridge32_a_md1	6.9	5.3	**5.29**	425.72	**63.76**	69.95	1.43	0.2	0.42
pci_bridge32_a_md2	8.32	6.89	**6.57**	271.89	***121.35**	***121.35**	2.71	0.25	0.84
pci_bridge32_b_md1	7.83	5.54	**5.47**	876.62	**332.72**	338.01	1.71	0.28	1.1
pci_bridge32_b_md2	6.66	5.2	**5.15**	723.45	452.09	***429.04**	1.55	0.17	1
pci_bridge32_b_md3	8.21	5.68	**5.56**	682.12	476.91	***398.58**	1.86	0.19	1.3
Average	7.02	5.73	**5.56**	355.88	223.88	**217.91**	9.74	0.94	2.21
Norm. Avg.	1.26	1.03	1.00	1.63	1.03	1.00	4.41	0.42	1.00

Optimal Maximum Displacement



The cell resulting in the maximum displacement

The cell's global position

Experiment 2

- **Examination of the ability to address the vertical abutment constraint**
  - The fourth most frequently used cell type in each design is set as the vertical abutment-constrained cell.
  - #VAV: the number of the vertical abutment violations
  - w/ and w/o VAC: with and without addressing the vertical abutment constraint.

Benchmark	# VAV	AVG Disp (sites)		Max Disp (sites)		Runtime (s)	
	w/o VAC	w/o VAC	w/ VAC	w/o VAC	w/ VAC	w/o VAC	w/ VAC
des_perf_1	13			67.07	76.4	3.09	11.1
des_perf_a_md1	9			607.3	607.3	3.65	17.79
des_perf_a_md2	9,567	5.41	5.54	403.86	403.86	3.7	18.01
des_perf_b_md1	7,920	4.54	4.6	37.53	35.69	0.99	4.86
des_perf_b_md2	10,190	4.93	5.03	32.87	30.21	1.42	7.6
edit_dist_1_md1	8,015	5.53	5.52	52.99	52.99	3.75	10.43
edit_dist_a_md2	9,653	5.14	5.21	168	168	2.65	9.44
edit_dist_a_md3	12,677	6.8	7.11	237	237	4.13	17.96
fft_2_md2	4,751	7.74	7.86	69.88	95.09	3.53	9.31
fft_a_md2	1,671	4.59	4.62	343.48	343.48	1.95	3.77
fft_a_md3	1,686	4.32	4.35	109.62	109.62	1.82	3.39
pci_bridge32_a_md1	1,392	5.29	5.33	69.95	72.48	0.42	1.59
pci_bridge32_a_md2	2,014	6.57	6.7	121.35	121.35	0.84	3.98
pci_bridge32_b_md1	1,145	5.47	5.5	338.01	338.01	1.1	3.54
pci_bridge32_b_md2	1,186	5.15	5.18	429.04	429.04	1	3.31
pci_bridge32_b_md3	1,289	5.56	5.59	398.58	398.58	1.3	6.48
Average		5.56	5.67	217.91	219.94	2.21	8.29
Norm. Avg.		0.98	1.00	0.99	1.00	0.27	1.00

Nearly the same!

Only 2% overhead!