ICCAD-2017 CAD Contest for Multi-Deck Standard Cell Legalization: Problem Description, Benchmarks, and Results

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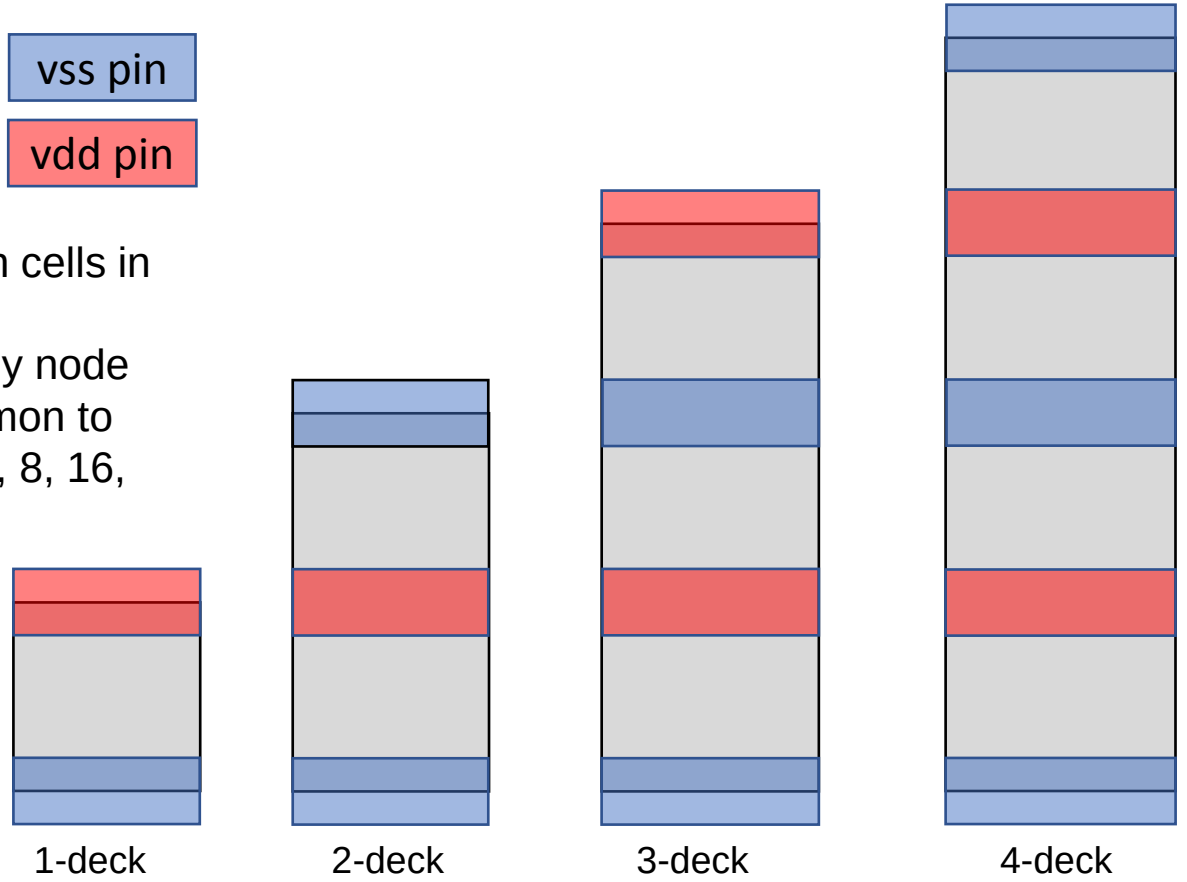
Outline

- **Problem Description & Challenges**
- **Multi-Deck Cell Legalization Problem Constraints**
- **Evaluation Metrics**
- **Benchmark Design Suites**
- **Contest Results**
- **Team Videos**
- **The Winners**

Problem Description & Challenges

A Sample of Multi-Deck Cells

- We used 1-4 deck high cells in the contest.
- In advanced technology node real designs, it is common to common to see 2, 3, 4, 8, 16, 32-deck highcells.



Motivation: Why use multi-deck cells?

Multi-deck cells (e.g. multi-bit registers (MBR's)) are becoming more prevalent in advanced technology nodes (1-10% of cells) since they can improve PPA:

- Lower Power: Fewer number of clock sinks seen by the clock-tree synthesis tool means less overall capacitance driven by the clock net.
- Improve Performance: Shared logic (in clock gating or set-reset logic) and internally timing optimized MBR's from a library team.
- Lower clock skew in sequential gates: clock paths in MBR's are internally balanced.
- Smaller Area Utilization: Total number of clock buffers needed can be reduced.

https://www.embedded.com/design/mcus-processors-and-socs/4433619/2/Using-multi-bit-flip-flop-custom-cells-to-achieve-better-SoC-design-efficiency

Traditional Single-Deck Legalization Requirements

1. Remove cell overlaps.
2. Minimally perturb incoming placed netlist to preserve (or improve) WL, routing, and timing quality metrics.
3. Satisfy complex design rules.
4. Fast and robust to handle large number of cells in state-of-the-art designs.

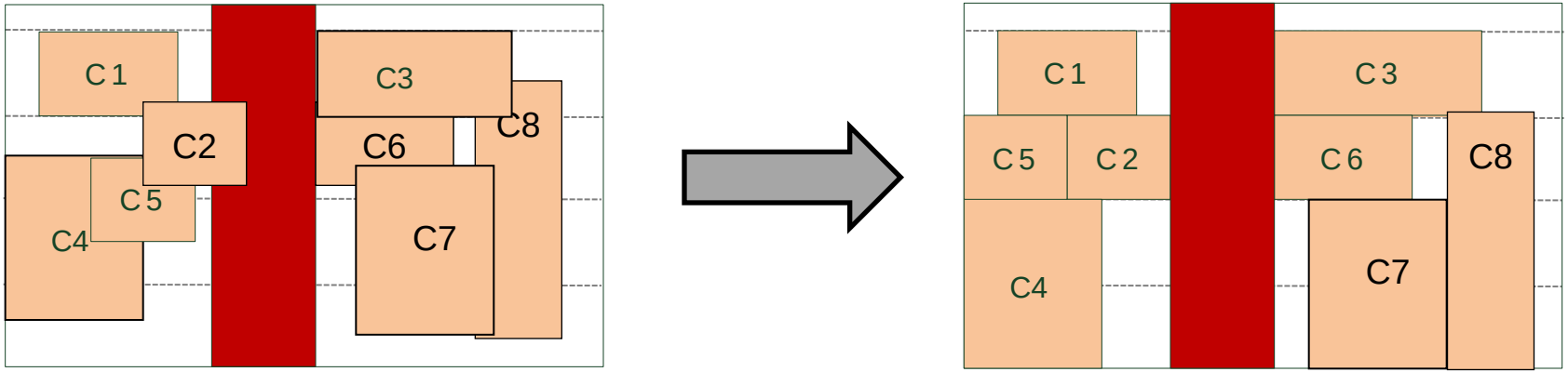
Multi-Deck Standard Cell Legalization Requirements

1. Remove cell overlaps.
2. Minimally perturb incoming placed netlist to preserve (or improve) WL, routing, and timing quality metrics.
3. Satisfy complex design rules.
4. Fast and robust to handle large number of cells in state-of-the-art designs.

Plus,

5. Mixed-size cell legalization problem.

Multi-Deck Standard Cell Legalization Problem

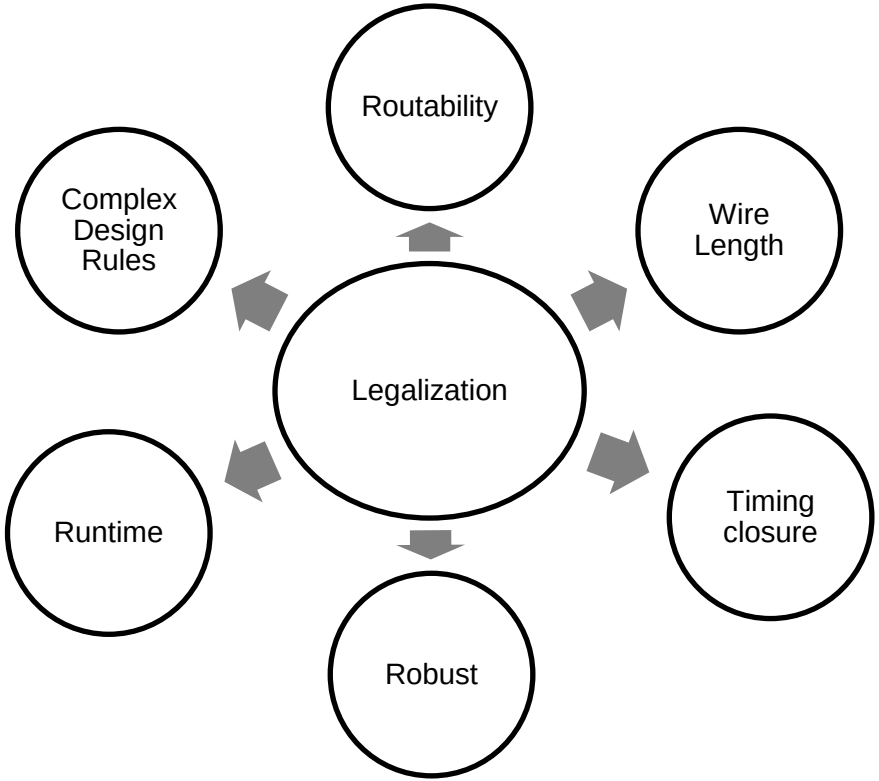


Blocked area

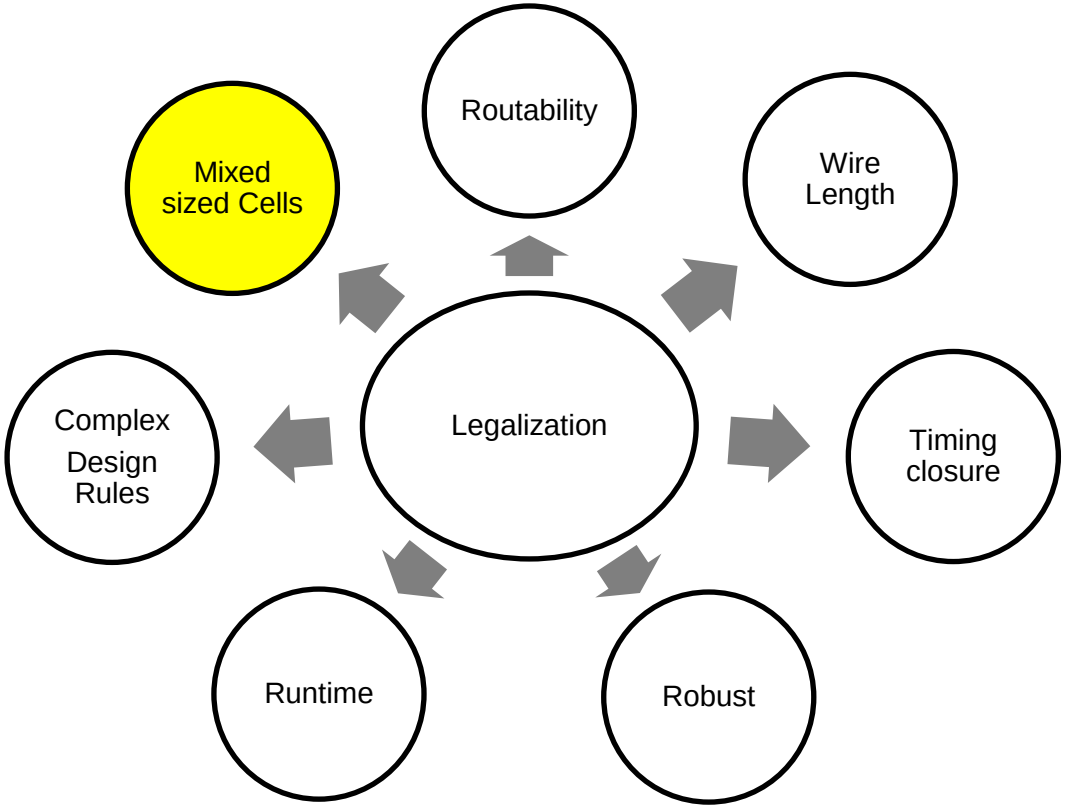
Movable cells

- A **mixed-size** legalization problem.
- More challenging to model than the standard single-deck cell legalization problem.
- Akin to an NP-hard multi-commodity network flow/Assignment problem.

Standard Cell Legalization Challenges



Multi-Deck Standard Cell Legalization Challenges

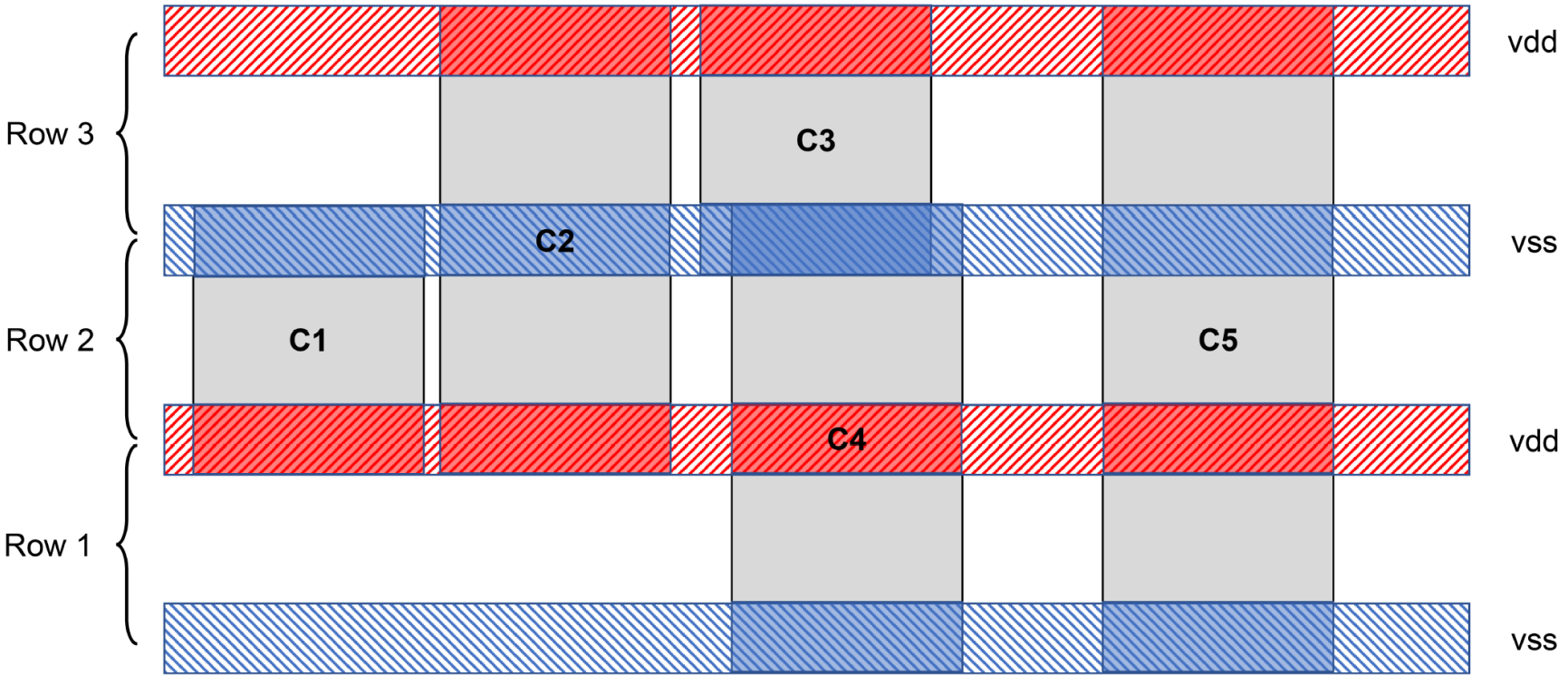


Contest Legalization Problem Constraints

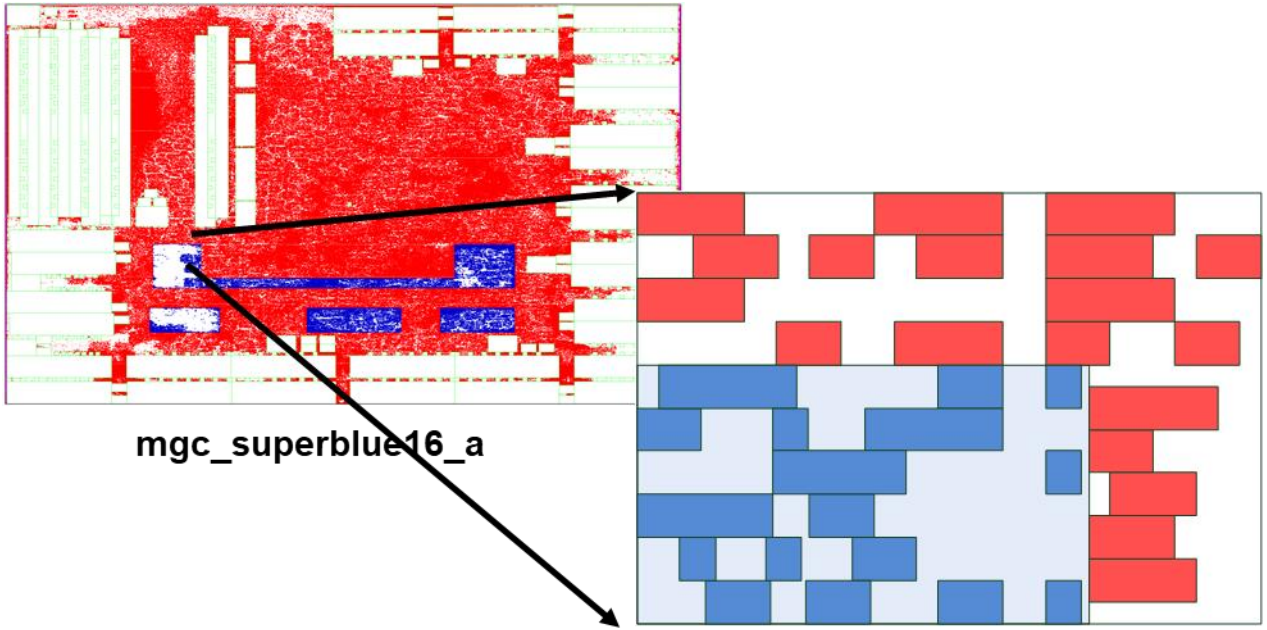
Hard Constraints for the contest

1. P/G alignment
2. Row and site alignment.
3. Fence regions.
4. 30 minute timeout.
5. Maximum 8 threads per run.

P/G Alignment



Fence Region Constraints



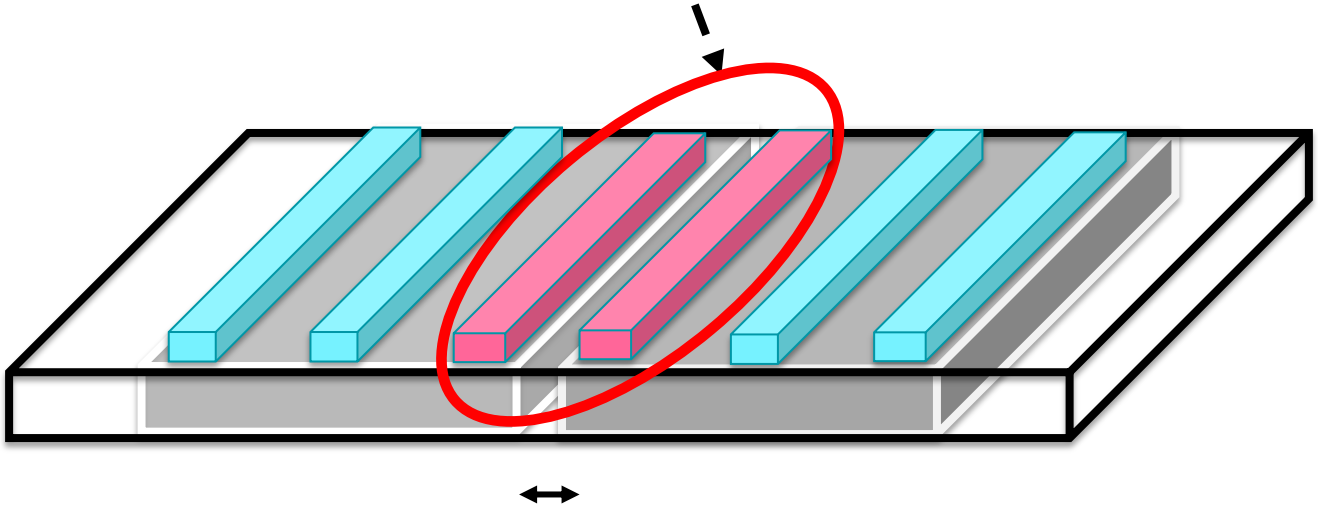
Soft Constraints for the Contest

1. Target Area Utilization
2. Maximum cell movement objective
3. Detailed routing constraints

    - Cell spacing, pin access and shorts.

Challenges – Edge Spacing Constraints

Prone to pin access and short problems



Two cells are too close to each other

Evaluation Metrics

Evaluation Metrics

The score of a solution is computed based on 5 metrics:

1. Maximum cell movement - penalized by the maximum movement specific for the design.
2. Average cell movement
3. HPWL - penalized by the maximum utilization defined for the design.
4. Runtime
5. Detailed routing rule violations

Total Design Score

$$S_{total} = S_{am} * S_{mm} * \left(1 + S_{hpwl} + S_v\right) * (1 + S_t)$$

Where

S_{mm} : Maximum movement score

S_{am} : Average movement score

S_{hpwl} : HPWL score

S_t : Runtime score

S_v : Soft detailed routing rules constraint score

Maximum Cell Movement Score

$$\boldsymbol{S_{mm} = 1 + \left(\frac{M_{max}}{100}\right) * f_{mm}}$$

Where

f_{mm} : $\max\left(\frac{\sum_{c_i \in C_v} M_i}{M_x}, 1\right)$ If M_x is not defined in the design, M_x will be set to N_{rows}

M_{max} : Maximum Cell Movement

M_x : Maximum cell movement constraint defined for the design

M_i : Displacement of cell c_i

C_v : set of cells whose displacements are greater than M_x

Average Movement Score

$$S_{am} = \frac{\sum_{k=1}^{4} M_{avg,k}}{4}$$

Where

$M_{avg,k}$: Average Cell Movement of all cells with a height equal to k rows

HPWL Score

$$S_{hpwl} = max\left(\frac{hpwl_{lg} - hpwl_{gp}}{hpwl_{gp}}, 0\right) max\left((1 + \beta * f_{of}), 0.20\right)$$

Where

f_{of} : Overflow factor determined by same method in the ISPD 2015 contest

$hpwl_{gp}$: HPWL of globally placed design

$hpwl_{lg}$: HPWL of legally placed design

β : 1

Runtime Score

$$S_t = max\left(-0.2, min\left(0.2, 0.05 * log_2\left(\frac{t_{team}}{t_{median}}\right)\right)\right)$$

Where

t_{team} : design runtime for given team

t_{median}: Median design runtime of all teams

Soft Detailed Routing Score

$$S_v = min(0.2, \frac{N_v}{N_{cells}})$$

Where

N_{cells} : Number of cells in the design

N_v : Number of soft constraint violations in the solution

Benchmark Design Suites

Benchmark Format

- **cells.lef** includes the physical characteristics of the technology library for the standard cell library, macros, and IO cells, etc.
- **tech.lef** provides the physical characteristics of the routing layers, Vertical Interconnect Accesses (VIAs), placement site types, etc.
- **design.def** includes design-specific logical and physical such as net-list connectivity, grouping information, physical constraints, cell locations and orientations, routing geometry data, P/G mesh, etc.
- **placement.constraints** is a text file including some other constraints such as maximum target utilization or the maximum displacement. Any constraint defined in this file is considered a soft constraint.

Benchmark Design Suites

- The designs were created from the ISPD 2014 and 2015 Placement Contest benchmarks.
- The global placements were generated by Eh?Placer.
- Two sets of benchmarks were used for the final evaluation results:
  - Released design suite includes 8 designs provided for the participants.
  - Hidden design suite includes 8 designs used for blind evaluation.
  - Both suites were equally weighted for the final evaluation
- **If a team could not generate a legal placement in a specified time (30 mins), the respective score is set to 1+e6**.

Released Benchmark Suite

Design	#Rows	#Macros	#Cells	#Nets	#Fence Regions	#I/O	% cell types				utilization
							1xH	2xH	3xH	4xH	
des_perf_b_md1	300	0	112679	122951	12	374	94.8	5.2	0	0	54.98
des_perf_b_md2	300	0	112679	122951	12	374	90.47	6.02	2.01	1.5	64.69
edit_dist_1_md1	361	0	130661	133223	0	2574	90.31	6.12	2.04	1.53	67.47
edit_dist_a_md2	400	6	127414	134051	1	2574	90.31	6.12	2.04	1.53	59.42
fft_2_md2	171	0	32281	33307	0	3010	89.62	6.56	2.18	1.64	83.12
fft_a_md2	400	6	30625	32090	0	3010	89.57	6.59	2.19	1.65	32.41
fft_a_md3	400	6	30625	32090	0	3010	93.42	2.19	2.19	2.19	31.24
pci_bridge32_a_md1	200	4	29533	34058	3	361	90.39	6.07	2.02	1.52	49.57

Hidden Benchmark Suite

Design	#Rows	#Macros	#Cells	#Nets	#Fence Regions	#I/O	% cell types				utilization
							1xH	2xH	3xH	4xH	
des_perf_1	222	0	112644	112880	0	374	100.00	0.00	0.00	0.00	90.64
des_perf_a_md1	450	4	103589	115187	4	374	95.66	4.34	0.00	0.00	55.11
des_perf_a_md2	450	4	103589	115187	4	374	96.99	1.00	1.00	1.00	55.92
edit_dist_a_md3	400	6	119626	134051	1	2574	93.88	2.04	2.04	2.04	57.22
pci_bridge32_a_md2	200	4	29533	34058	3	361	85.51	7.08	4.04	3.37	57.72
pci_bridge32_b_md1	400	6	26134	32546	3	361	90.38	6.07	2.02	1.52	28.68
pci_bridge32_b_md2	400	6	26134	32546	3	362	97.97	1.01	1.01	1.01	19.72
pci_bridge32_b_md3	400	6	26134	32546	3	363	94.94	1.01	2.02	2.02	23.98

Contest Results

Teams

- 11 final submissions from Brazil, China, Germany, Hong Kong, Taiwan, and the USA.
- 8 out of 11 teams could generate at least one legal solution.
- The ranking was ***significantly*** impacted by the number of legal solutions generated by the teams.

Released Suite Scores

- cada005, cada012, cada040, cada041, and cada053 generated legal solutions for all designs of the released suite within the 30-min allotted time.

Team	Score	#Failures
cada001	100018.68	1
cada005	**10.50**	**0**
cada006	800000.00	8
cada012	**4.86**	**0**
cada021	800000.00	8
cada036	800000.00	8
cada040	**9.22**	**0**
cada041	**7.64**	**0**
cada045	100008.20	1
cada053	**6.75**	**0**
cada099	800000.00	8

Hidden Suite Scores

- **Only** two teams generated legal solutions for all designs in the suite within the allotted 30-min time

Team	Score	#Failures
TBA	6913.44	0
TBA	201640.75	2
TBA	800000.00	8
TBA	117.34	0
TBA	800000.00	8
TBA	800000.00	8
TBA	512841.70	4
TBA	100762.61	1
TBA	700001.07	7
TBA	600001.75	6
TBA	718655.40	7

And Now, Introducing the Top 6 Winning Teams!

The Winners!

Released Benchmark Scores (runtime adjusted)

	des_perf_b_md1			des_perf_b_md2			edit_dist_1_md1			edit_dist_a_md2		
Team	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score
cada001	100000.00	--	100000.00	0.88	4.80	0.82	11.55	5.14	10.71	4.42	4.79	4.07
cada005	1.32	9.34	1.31	1.52	23.23	1.59	1.23	25.00	1.28	1.22	27.07	1.27
cada012	0.63	6.59	0.61	0.72	6.26	0.68	0.73	8.58	0.70	0.53	7.59	0.50
cada040	1.05	34.28	1.13	0.97	56.47	1.07	1.58	67.10	1.76	0.74	108.00	0.84
cada041	1.27	10.85	1.27	0.92	18.01	0.94	0.82	20.60	0.84	0.78	31.50	0.83
cada045	100000.00	--	100000.00	0.75	3.93	0.69	0.78	4.14	0.71	4.35	4.46	3.98
cada053	0.97	12.08	0.98	0.91	12.65	0.91	0.86	14.14	0.86	0.62	14.36	0.62
cada099	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00

	fft_2_md2			fft_a_md2			fft_a_md3			pci_bridge32_a_md1		
Team	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score
cada001	1.06	1.08	0.95	0.63	1.13	0.58	0.50	1.11	0.47	1.14	1.24	1.08
cada005	2.01	6.34	2.06	0.70	4.03	0.71	0.56	3.30	0.57	1.64	4.51	1.71
cada012	0.79	1.60	0.74	0.53	1.41	0.50	0.42	1.36	0.39	0.76	1.43	0.73
cada040	1.81	27.42	2.05	0.61	5.07	0.64	0.47	4.53	0.49	1.15	7.40	1.24
cada041	1.47	30.64	1.68	0.53	2.50	0.52	0.41	2.45	0.41	1.15	2.51	1.15
cada045	1.01	0.93	0.90	0.56	11.53	0.62	0.43	10.39	0.47	0.90	0.94	0.84
cada053	1.21	4.35	1.21	0.63	3.16	0.63	0.49	2.95	0.49	1.05	2.75	1.05
cada099	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00

Hidden Benchmark Scores (runtime adjusted)

Rank	TEAM	des_perf_b_md1			des_perf_b_md2			edit_dist_1_md1			edit_dist_a_md2		
		Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime
1	cada053	0.93	14.84	0.93	0.87	15.39	0.87	0.80	17.42	0.80	0.64	21.02	0.64
2	cada012	0.79	8.27	0.75	0.85	9.35	0.82	1.66	11.93	1.61	0.69	12.10	0.66
3	cada005	2.36	52.83	2.57	3.97	35.62	4.21	4.92	38.19	5.20	1.99	39.84	2.09
-	cada040	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--
-	cada001	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--
-	cada099	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--

Rank	TEAM	fft_2_md2			fft_a_md2			fft_a_md3			pci_bridge32_a_md1			Total Scores	
		Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	with Runtime
1	cada053	0.95	4.02	0.95	0.58	6.42	0.58	0.45	6.35	0.45	1.00	3.90	1.00	6.22	6.22
2	cada012	1.24	2.47	1.19	0.57	1.83	0.51	0.44	1.79	0.40	1.01	1.58	0.94	7.23	6.89
3	cada005	2.98	7.21	3.10	1.99	8.49	2.04	3.03	8.50	3.10	3.30	8.38	3.48	24.55	25.79
-	cada040	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--	--	--
-	cada001	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--	--	--
-	cada099	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--	--	--

Impact of Hidden Benchmark on Final Scores

- Only **two teams,** cada001 and cada012, could generate legal solutions for all 8 designs within the allotted time (30 min).
- The runtime for some legalizers was significantly affected by the maximum movement constraints. This was especially deleterious for teams cada040 and cada053's final scores.
- Team cada012 performed best on these benchmarks.

Team	Score	#Failures
cada001	6913.44	0
cada005	201640.75	2
cada006	800000.00	8
cada012	117.34	0
cada021	800000.00	8
cada036	800000.00	8
cada040	512841.70	4
cada041	100762.61	1
cada045	700001.07	7
cada053	600001.75	6
cada099	718655.40	7

Top 6 Teams

- 1st place: **122.20**
- 2nd place: **100770.25**
- 3rd place: **106932.12**
- 4th place: **201651.26**
- 5th place: **512850.92**
- 6th place: **600008.51**

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Honorable Mention ☺

Team cada053: RippleLG

The Chinese University of Hong Kong

Hong Kong

Haocheng Li, Wing-Kai Chow, Gengjie Chen,

Prof. Evangeline F. Y. Young, Prof. Bei Yu

Honorable Mention ☺

Team cada040: TU Dresden

Dresden University of Technology

Germany

Tilman Horst, Andreas Krinke, Steve Bigalke, Robert Fischbach,

Arthur Nothdurft, Sergii Osmolovskyi, Mohamed Sabra, Matthias Thiele,

Prof. Jens Lienig

Honorable Mention ☺

Team cada005: NCKU_95416

National Cheng Kung University

Taiwan

Tai-Ting Chen, You-Lun Deng, Yi-Wen Wang, Prof. Jai-Ming Lin

3rd Place ☺

Team cada001: Ophidian

Federal University of Santa Catarina

Brazil

Renan Netto, Tiago Augusto Fontana, Sheiny Fabre,

Thiago Barbato, Chrystian Guth,

Prof. Jose Luis Guntzel, Prof. Laercio Lima Pilla

2nd Place ☺

Team cada041: ColdNoodle

National Taiwan University

Taiwan

Shih-Wei Hsieh, Shao-Chun Hung

Prof. Yao-Wen Chang

1st Place ☺

Team cada012: C_TI

Fuzhou University

China

Ziran Zhu, Yuhang Chen, Ye Huang, Xingquan Li,

Prof. Jianli Chen, Prof. Wenxing Zhu, Prof. Genghua Fan

Released Benchmark Scores (runtime adjusted)

Team	des_perf_b_md1			des_perf_b_md2			edit_dist_1_md1			edit_dist_a_md2		
	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score
cada001	100000.00	--	100000.00	0.88	4.80	0.82	11.55	5.14	10.71	4.42	4.79	4.07
cada005	1.32	9.34	1.31	1.52	23.23	1.59	1.23	25.00	1.28	1.22	27.07	1.27
cada012	0.63	6.59	0.61	0.72	6.26	0.68	0.73	8.58	0.70	0.53	7.59	0.50
cada040	1.05	34.28	1.13	0.97	56.47	1.07	1.58	67.10	1.76	0.74	108.00	0.84
cada041	1.27	10.85	1.27	0.92	18.01	0.94	0.82	20.60	0.84	0.78	31.50	0.83
cada045	100000.00	--	100000.00	0.75	3.93	0.69	0.78	4.14	0.71	4.35	4.46	3.98
cada053	0.97	12.08	0.98	0.91	12.65	0.91	0.86	14.14	0.86	0.62	14.36	0.62
cada099	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00

Team	fft_2_md2			fft_a_md2			fft_a_md3			pci_bridge32_a_md1		
	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score	Raw Score	Runtime	Scaled Score
cada001	1.06	1.08	0.95	0.63	1.13	0.58	0.50	1.11	0.47	1.14	1.24	1.08
cada005	2.01	6.34	2.06	0.70	4.03	0.71	0.56	3.30	0.57	1.64	4.51	1.71
cada012	0.79	1.60	0.74	0.53	1.41	0.50	0.42	1.36	0.39	0.76	1.43	0.73
cada040	1.81	27.42	2.05	0.61	5.07	0.64	0.47	4.53	0.49	1.15	7.40	1.24
cada041	1.47	30.64	1.68	0.53	2.50	0.52	0.41	2.45	0.41	1.15	2.51	1.15
cada045	1.01	0.93	0.90	0.56	11.53	0.62	0.43	10.39	0.47	0.90	0.94	0.84
cada053	1.21	4.35	1.21	0.63	3.16	0.63	0.49	2.95	0.49	1.05	2.75	1.05
cada099	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00	100000.00	--	100000.00

Hidden Benchmark Scores (runtime adjusted)

Rank	TEAM	des_perf_b_md1			des_perf_b_md2			edit_dist_1_md1			edit_dist_a_md2		
		Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime
1	cada053	0.93	14.84	0.93	0.87	15.39	0.87	0.80	17.42	0.80	0.64	21.02	0.64
2	cada012	0.79	8.27	0.75	0.85	9.35	0.82	1.66	11.93	1.61	0.69	12.10	0.66
3	cada005	2.36	52.83	2.57	3.97	35.62	4.21	4.92	38.19	5.20	1.99	39.84	2.09
-	cada040	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--
-	cada001	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--
-	cada099	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--

Rank	TEAM	fft_2_md2			fft_a_md2			fft_a_md3			pci_bridge32_a_md1			Total Scores	
		Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	Runtime (sec)	Score with runtime	Raw Score	with Runtime
1	cada053	0.95	4.02	0.95	0.58	6.42	0.58	0.45	6.35	0.45	1.00	3.90	1.00	6.22	6.22
2	cada012	1.24	2.47	1.19	0.57	1.83	0.51	0.44	1.79	0.40	1.01	1.58	0.94	7.23	6.89
3	cada005	2.98	7.21	3.10	1.99	8.49	2.04	3.03	8.50	3.10	3.30	8.38	3.48	24.55	25.79
-	cada040	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--	--	--
-	cada001	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--	--	--
-	cada099	Not legal	--	--	Not legal	--	--	Not legal	--	--	Not legal	--	--	--	--

ICCAD-2017 CAD Contest for Multi-Deck Standard Cell Legalization: Problem Description, Benchmarks, and Results

Nima Karimpour Darav **Ismail Bustany** **Andrew Kennings**

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