2023 ICCAD CAD Contest: Problem C:
Static IR Drop Estimation Using Machine Learning

Gana Surya Prakash Kadagala and Vidya A. Chhabria

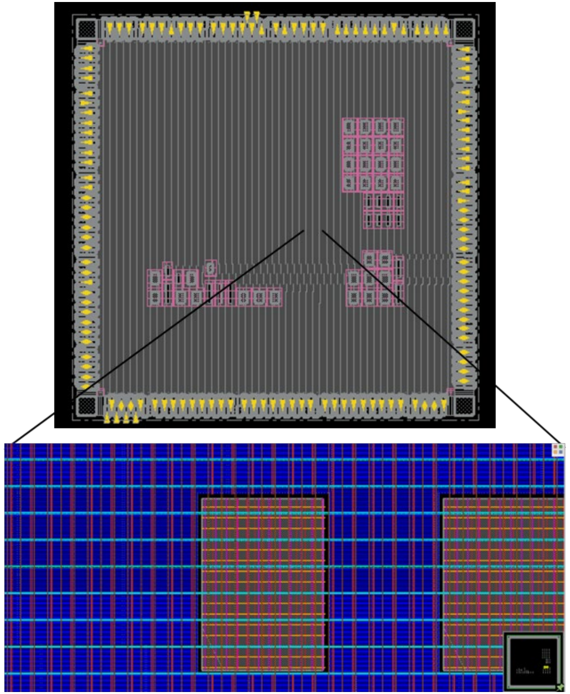
Special thanks to OpenROAD Project (UCSD) and Steel Perlot of support.

Outline

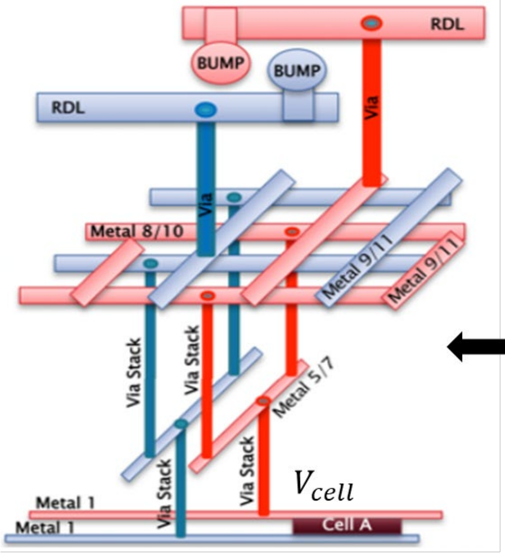
- **Introduction:**
  - Power delivery network and its model
  - Static IR drop and its challenges
  - Goals and motivation for the contest
- **The contest**
  - Problem statement
  - Data and benchmarks
  - Evaluation criteria
- **Results**

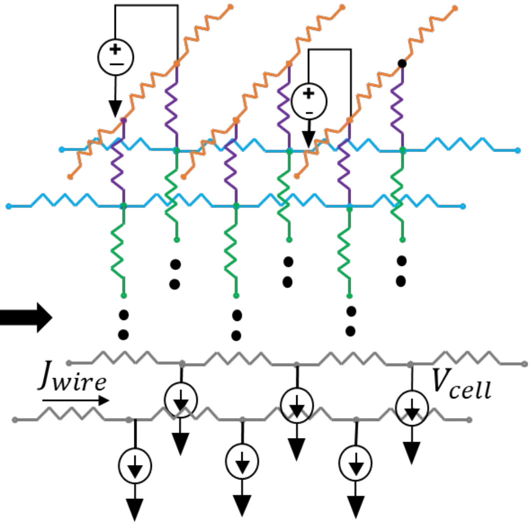
Power delivery network (PDN) and its model

12nm FinFET RISC-V core



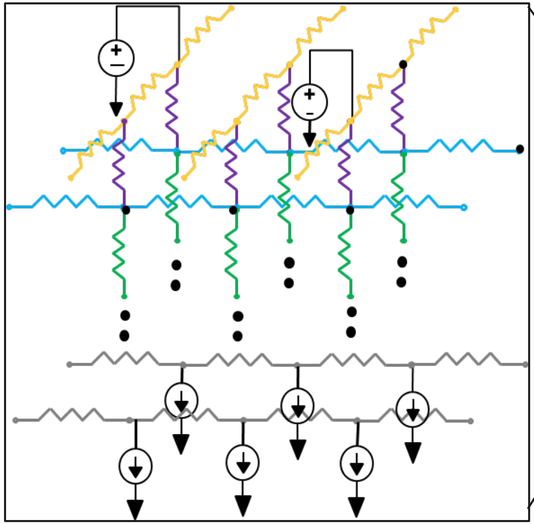
IR drop constraints	Electromigration (EM) constraints
$V_{cell} > V_{limit}$	$J_{wire} < J_{limit}$
Typical limits:	Typical limits:
5% of V_{dd}	Layer- and tech-dependent





Static IR drop estimation and its challenges

Modified nodal analysis:
Billions of nodes, Problem of “N”



Analyze IR/EM:
$$\boldsymbol{GV} = \boldsymbol{J}$$

$$V_{cell} > V_{limit}?$$
$$J_{wire} < J_{limit}?$$

12nm FinFET RISC-V core
12M nodes and 3 hours runtime
[PDNSim and commercial tool runtimes]

- Traditional techniques
  - Multigrid methods
  - Sparsity exploitation
  - Numerical and analytical techniques
- Challenge: Computationally expensive

Machine learning to the rescue (?)

PowerNet: Transferable Dynamic IR Drop Estimation via Maximum Convolutional Neural Network

Zhiyao Xie[1], Haoxing Ren[2], Brucek Khailany[2], Ye Sheng[2], Santosh Santosh[2], Jiang Hu[3], Yiran Chen[1]
[1]Duke University, [2]Nvidia Corporation, [3]Texas A&M University
{zhiyao.xie, yiran.chen}@duke.edu, {haoxingr, bkhailany, sye, santosha}@nvidia.com, jianghu@tamu.edu

GridNet: Fast Data-Driven EM-Induced IR Drop Prediction and Localized Fixing for On-Chip Power Grid Networks*

Han Zhou, Wentian Jin, and Sheldon X.-D. Tan
Department of Electrical and Computer Engineering, University of California, Riverside, CA 92521

Vector-based Dynamic IR-drop Prediction Using Machine Learning

Jia-Xian Chen[1], Shi-Tang Liu[1], Yu-Tsung Wu[1], Mu-Ting Wu[1], Chieo-Mo Li[1], Norman Chang[2], Ying-Shiun Li[2], Wen-Tze Chuang[2]
[1]*Graduate Institute of Electronics Engineering*
National Taiwan University, Taiwan
[2] *Ansys Inc.*

SpeedER: A Supervised Encoder-Decoder Driven Engine for Effective Resistance Estimation of Power Delivery Networks

Bing-Yue Wu, National Taiwan University of Science and Technology, Taipei, Taiwan, M11007411@mail.ntust.edu.tw
Shao-Yun Fang, National Taiwan University of Science and Technology, Taipei, Taiwan, syfang@mail.ntust.edu.tw
Hsiang-Wen Chang, Synopsys Taiwan Co., Ltd., Taipei, Taiwan
Peter Wei, Synopsys Taiwan Co., Ltd., Taipei, Taiwan

Thermal and IR Drop Analysis Using Convolutional Encoder-Decoder Networks

Vidya A. Chhabria[1], Vipul Ahuja[2], Ashwath Prabhu[2], Nikhil Patil[2], Palkesh Jain[2], and Sachin S. Sapatnekar[1]
[1]University of Minnesota, USA; [2]Qualcomm Technologies Inc., India

Machine-learning-based Dynamic IR Drop Prediction for ECO

Yen-Chun Fang[1], Heng-Yi Lin[1], Min-Yan Su[1], Chien-Mo Li[1], Eric Jia-Wei Fang[2]
[1]Graduate Institute of Electronics Engineering
National Taiwan University, Taipei 106, Taiwan
[2]MediaTek Inc., Hsinchu 300, Taiwan

Fast Prediction of Dynamic IR-Drop Using Recurrent U-Net Architecture

Yonghwi Kwon, Korea Advanced Institute of Science and Technology, Daejeon, Korea, yh.kwon@kaist.ac.kr
Youngsoo Shin, Korea Advanced Institute of Science and Technology, Daejeon, Korea, youngsoo@kaist.edu

IncPIRD: Fast Learning-Based Prediction of Incremental IR Drop

Chia-Tung Ho[2] and Andrew B. Kahng[1,2]
[1]CSE and [2]ECE Departments, UC San Diego, La Jolla, CA, USA
{c2ho, abk}@ucsd.edu

Motivation and goals for the contest

- Apples-to-apples comparisons across different ML techniques
- Update existing public domain PDN benchmarks
  - Previous PDN benchmarks are from IBM, released in 2007/2008
- Evaluate the synthetically generated training data as a proxy
- Drive innovative feature engineering
- Lower the barrier-to-entry to chip design problems through ML

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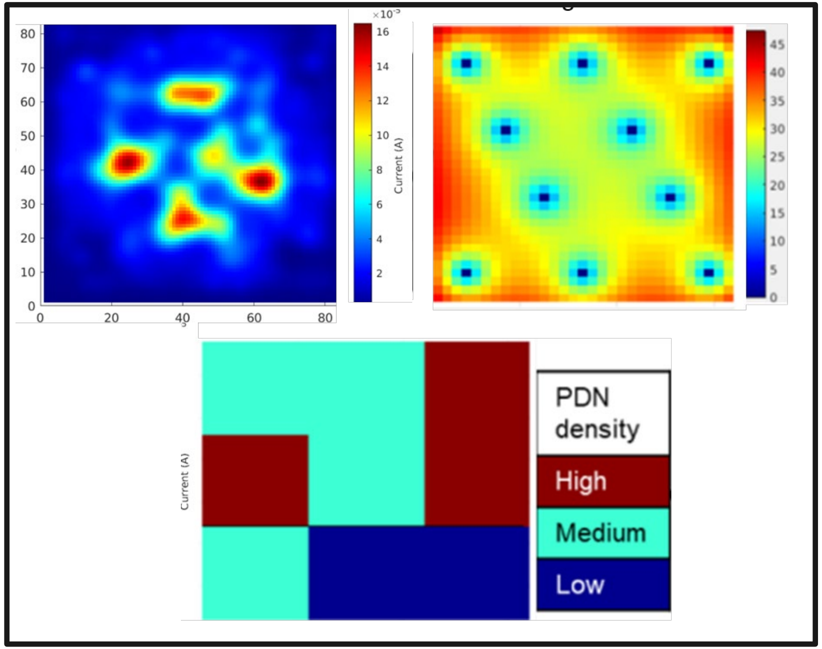
The contest: Problem statement

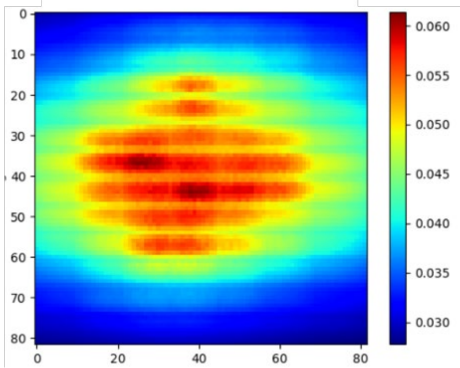
Contest goal: Predict the IR drop distribution of the chip

Input Option A: Image-based data

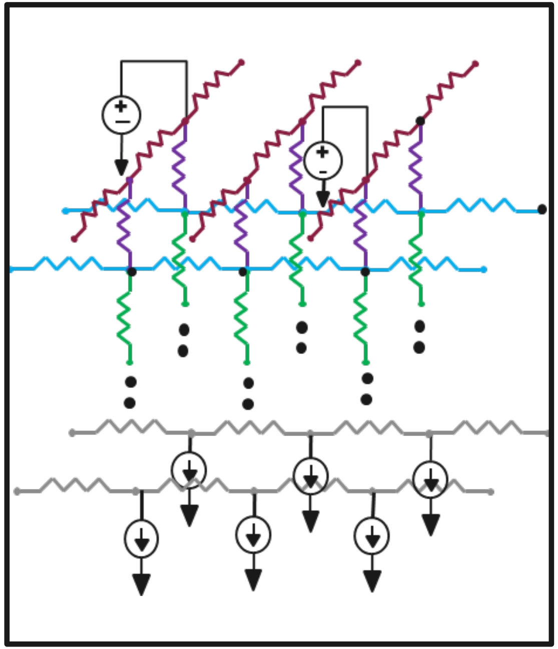


Required Output

IR drop map



Input Option B: SPICE netlist



The contest: Data format

- Input Option A: Images are in matrix-based CSVs where every pixel represents a 1μm^2 region on the chip of the three features and the IR drop

2.91E-02	2.95E-02	2.99E-02	3.02E-02	. . . .	3.07E-02
2.91E-02	2.96E-02	3.00E-02	3.03E-02	. . . .	3.08E-02
2.92E-02	2.97E-02	3.00E-02	3.04E-02	. . . .	3.09E-02
2.93E-02	2.97E-02	3.01E-02	3.05E-02	. . . .	3.10E-02
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
2.93E-02	2.98E-02	3.02E-02	3.06E-02	. . . .	3.11E-02

- Input Option B: SPICE netlist with node coordinate information embedded

```
R645 n1_m1_108000_17920 n1_m1_102600_179200 0.14
R646 n1_m1_113400_179200 n1_M3_113400_179200 4.23
I7 n1_m1_113400_179200 0 4.24901e-08
V0 n1_m7_81000_106230 0 1.1
```

The generic convention is <electric component> <node1> <node2> <value>.

The node is defined using the following convention:
<netname>__<layer-idx>_<x-cordinate>_<y-cordinate>

The contest: Benchmarks

Differences between real and fake circuit data

Feature	Real circuit data
Power map	OpenROAD-flow-scripts after placement
Power delivery network (PDN)	Template-based and regular PDNs in OpenROAD-flow-scripts
Voltage source	Vary voltage source distribution in OpenROAD
SPICE netlist	Extracted from OpenROAD (PDNSim)
IR drop map	SPICE simulation and interpolation

V. A. Chhabria, K. Kunal, M. Zabihi and S. S. Sapatnekar, "BeGAN: Power Grid Benchmark Generation Using a Process-portable GAN-based Methodology," ICCAD 2021.

The contest: Benchmarks summary

Real circuit data

- Twenty real-circuit testcases: Nangate45 technology nodes

Hidden testcases

Test case	# V	# R	# I	# Templates	Area (mm^2)
7	16	94,590	24,988	4	0.361
8	16	89,562	24,988	1	0.361
9	36	186,291	64,064	4	0.697
10	36	172,877	64,064	1	0.697
13	4	17,183	11,864	3	0.066
14	4	16,535	11,864	1	0.066
15	16	64,120	44,117	4	0.239
16	16	59,560	44,117	1	0.239
19	36	201,902	63,347	4	0.757
20	36	188,475	63,347	1	0.757

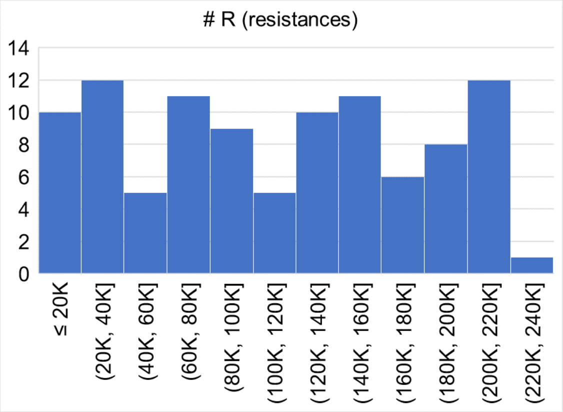
Visible testcases

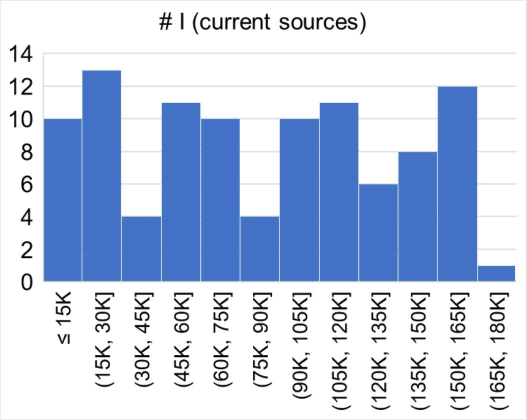
Test case	# V	# R	# I	# Templates	Area (mm^2)
1	4	24,088	11599	4	0.089
2	4	22,328	11599	1	0.089
3	49	228440	101684	4	0.865
4	49	214890	101684	1	0.865
5	25	110466	38934	4	0.411
6	25	102526	38934	1	0.411
11	4	10860	7718	3	0.042
12	4	10408	7718	1	0.042
17	16	84045	59078	4	0.320
18	16	80039	59078	1	0.320

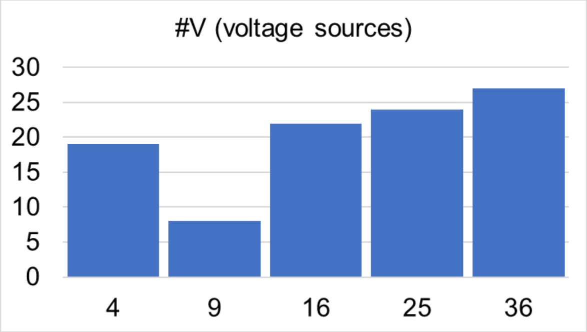
The contest: Benchmarks summary

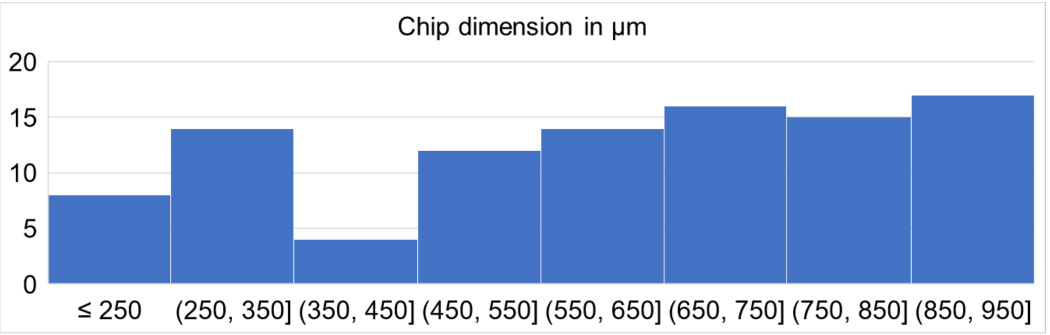
Fake circuit data

- 100 data points released for contest
- Additional thousands of datapoint on BeGAN repository





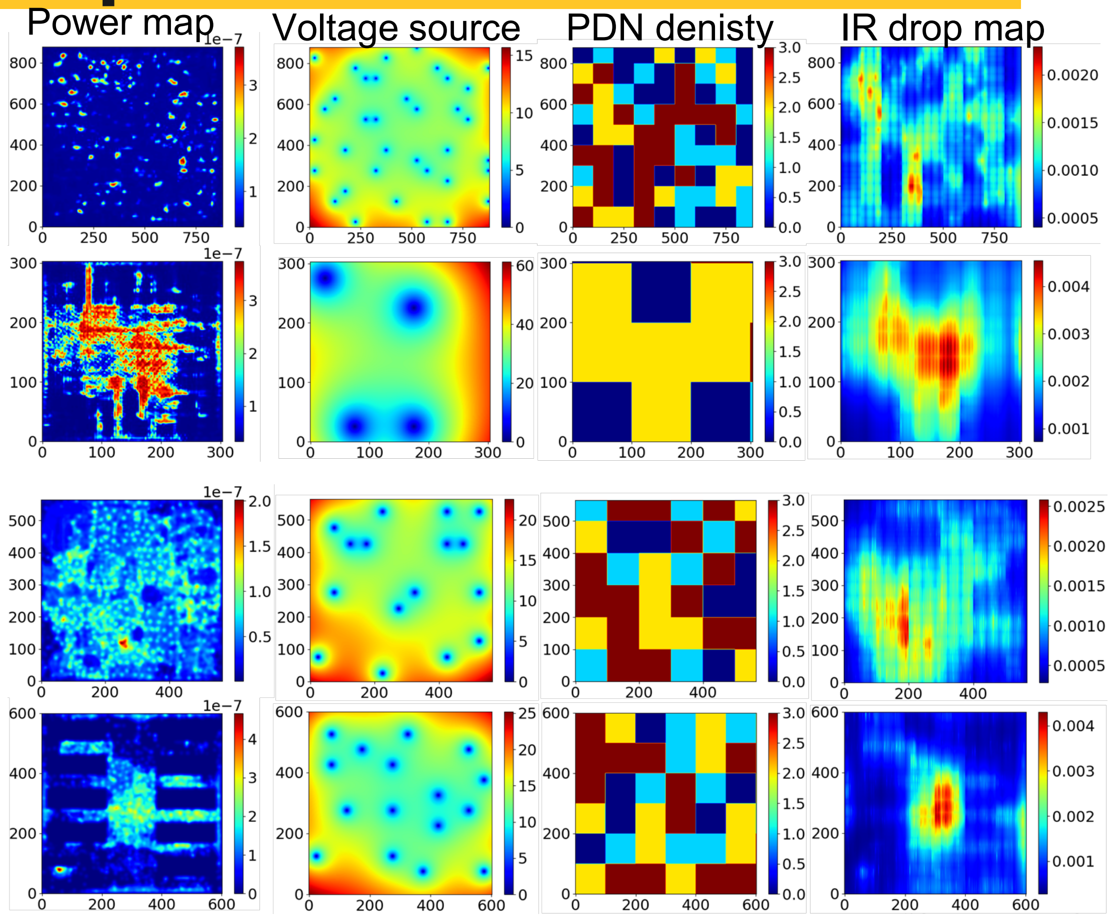




The contest: Example benchmark dataset

Fake circuit data

Real circuit data



The contest: Evaluation criteria

- **Mean absolute error (MAE):** Element wise differences between predicted IR drop and golden IR drop matrices
- **F1 score:** Binary classification using the 10% of the worst-case IR drop in the golden data as the positive class
    - F1 score = 2 * Precision * Recall / (Precision + Recall)
    - Precision = TP / (TP + FP)
    - Recall = TP / (TP + FN)
- **Runtime**: Inference time for a single datapoint
- **Total score per testcase:** 60% to MAE + 30% to F1 + 10% to Runtime
    - Team with the least MAE gets 60 points for the testcase, highest F1 score 30 points for the testcase and least runtime get 10 points for the testcase
    - All other teams scores relative to the maximum metric of the testcase

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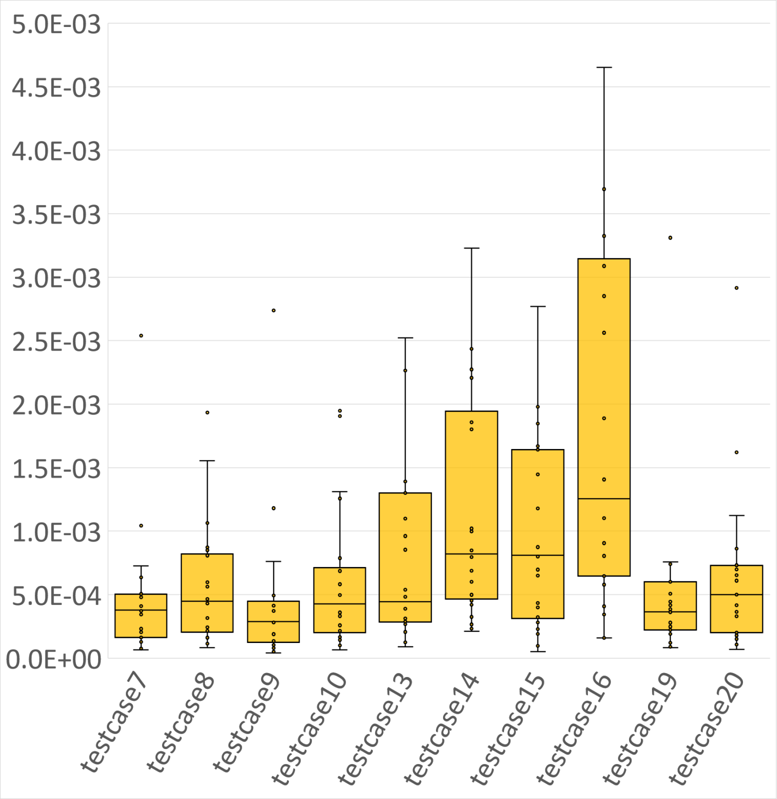
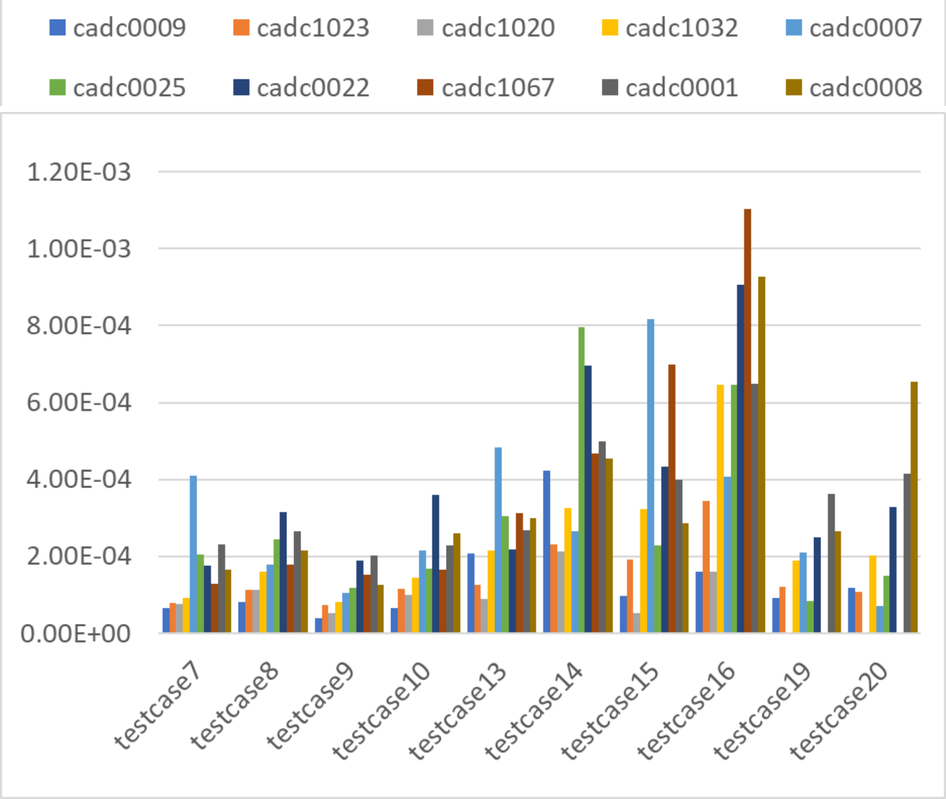
Results: Number of teams

- Total number of teams registered = 72
- Number of teams submitted **alpha** submission = 24
- Number of teams submitted **beta** submission = 25
- Number of teams submitted **final** submission = 27

Results: Mean absolute error (MAE)

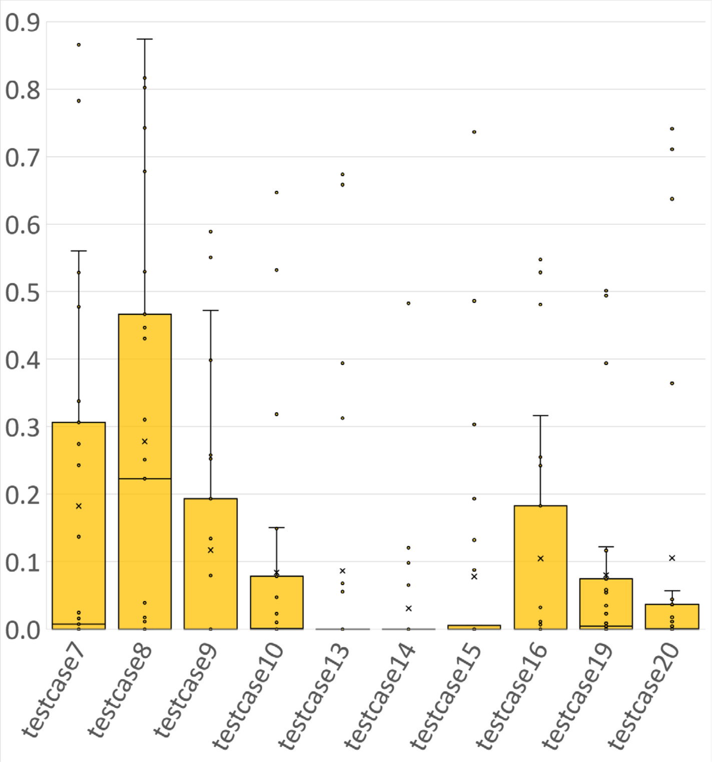
Top 10 teams MAE in volts and distribution for each hidden real circuit testcase

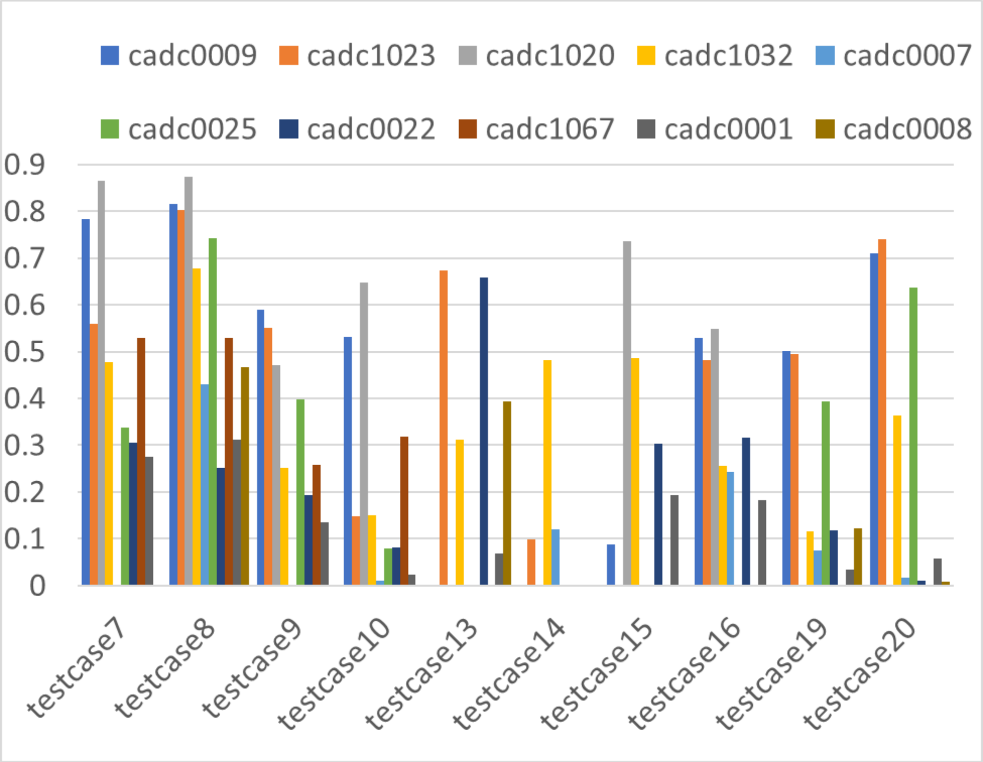




Results: F1 scores

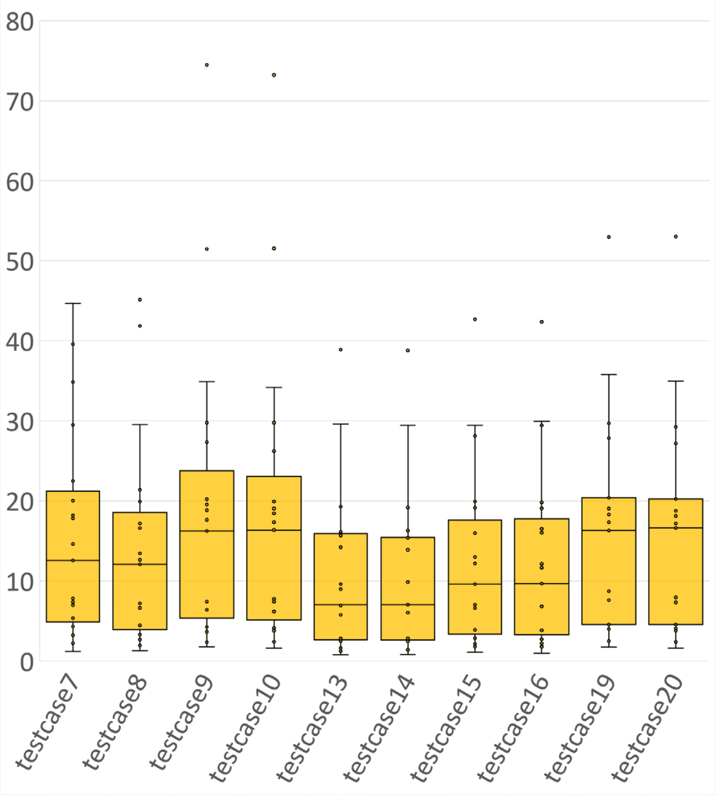
Top 10 teams F1 score and distribution for each hidden real circuit testcase

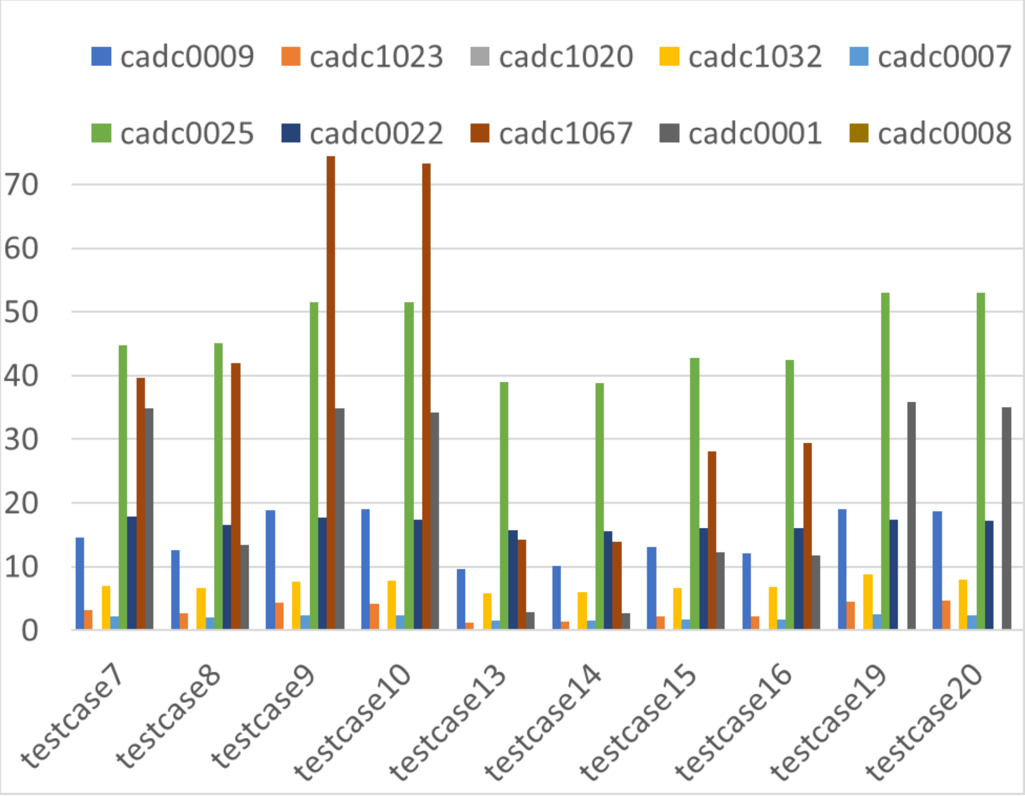




Results: Runtimes

Top 10 teams runtime in seconds and distribution for each testcase





Results: Overall score

Top 10 teams score per testcase and final score

Testcase	Testcase 7	Testcase 8	Testcase 9	Testcase 10	Testcase 13	Testcase 14	Testcase 15	Testcase 16	Testcase 19	Testcase 20	Final score	Rank
cadc0009	87.94	89.05	90.93	85.53	26.98	30.92	36.69	89.78	85.83	65.20	**688.84**	**1**
cadc1023	73.76	75.55	65.65	45.49	79.43	66.66	21.26	58.87	74.69	72.83	**634.19**	**2**
cadc1020	82.54	72.86	71.60	69.46	60.00	60.00	90.00	89.71	0.00	0.00	**596.17**	**3**
cadc1032	61.36	55.54	45.37	36.51	40.45	70.38	31.10	30.30	35.08	37.58	**443.65**	**4**
cadc0007	14.91	49.02	30.80	25.62	16.15	60.48	9.87	42.54	34.89	67.61	**351.88**	**5**
cadc0025	31.07	45.85	41.22	27.67	17.99	16.16	13.87	15.09	83.90	53.94	**346.76**	**6**
cadc0022	33.69	24.89	23.71	15.69	54.77	18.79	20.24	28.54	28.09	14.14	**262.56**	**7**
cadc1067	49.43	46.01	29.26	38.99	17.89	27.71	4.86	9.05	0.00	0.00	**223.19**	**8**
cadc0001	26.87	30.19	19.32	18.86	26.04	28.42	16.60	25.69	16.25	12.86	**221.10**	**9**
cadc0008	23.90	38.78	19.37	15.27	35.59	27.99	10.89	10.36	26.07	6.72	**214.94**	**10**

Conclusion

- The contest had 27 final submissions
- Innovative solutions with novel feature engineering techniques from participants resulting in high F1 and low MAE values
- Release of synthetic benchmarks and real circuit benchmarks:
    - ICCAD Contest benchmarks and benchmark generation scripts: https://github.com/ASU-VDA-Lab/ML-for-IR-drop
    - Additional BeGAN benchmarks: https://github.com/UMN-EDA/BeGAN-benchmarks

Winners!

ICCAD23 Problem C: Static IR drop prediction using machine learning

- **Third place:** Congratulations!

Problem C		Contributing authors	School
3rd Place	Advisors	Prof. Roman Solovyev	Institute for Design Problems in Microelectronics of Russian Academy of Sciences
		Prof. Dmitry Telpukhov	National Research University of Electronic Technology
	Students	Ilya Shafeev	National Research University of Electronic Technology
		Evgeny Demidov	Institute for Design Problems in Microelectronics of Russian Academy of Sciences

ICCAD23 Problem C: Static IR drop prediction using machine learning

- **Second place:** Congratulations!

Problem C		Contributing authors	School
2nd Place	Advisors	Prof. Zhifeng Lin	Fuzhou University
		Prof. Jianli Chen	Fudan University
		Prof. Jun Yu	Fudan University
	Students	Yilu Chen	Fuzhou University
		Min Wei	Fudan University
		Xingyu Tong	Fudan University
		Zhijie Cai	Fudan University
		Guohao Chen	Fudan University

ICCAD23 Problem C: Static IR drop prediction using machine learning

- **First place:** Congratulations!

Problem C		Contributing authors	School
1st Place	Advisors	Prof. Hung-Ming Chen	National Yang Ming Chiao Tung University
	Students	Yu-Tung Liu	National Yang Ming Chiao Tung University
		Yu-Hao Cheng	National Yang Ming Chiao Tung University
		Shao-Yu Wu	National Yang Ming Chiao Tung University

ICCAD23 Problem C: Static IR drop prediction using machine learning

- **Honorable mention:** Congratulations!

Problem C		Contributing authors	School
Honorable Mention	Advisors	Prof. Zhaori Bi	Fudan University
	Students	Yuan Meng	Fudan University
		Ruiyu Lv	Fudan University
		Wangzhen Li	Fudan University
		Aidong Zhao	Fudan University