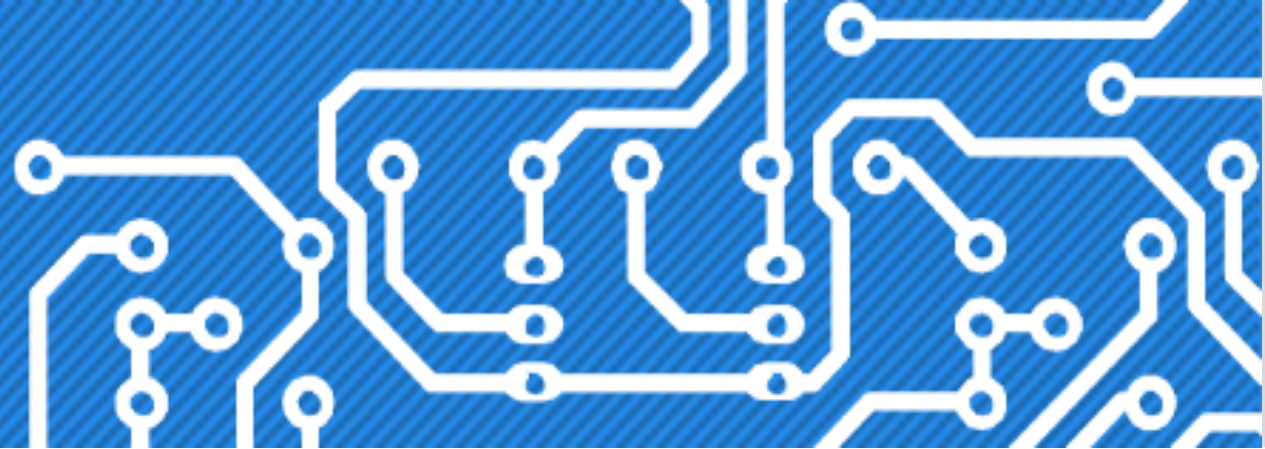


International Symposium on Physical Design



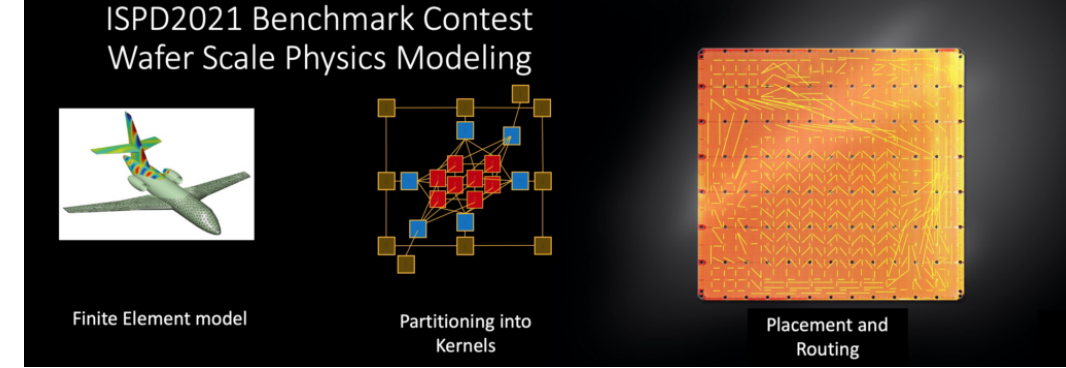
ISPD 2021 Wafer-Scale Physics Modeling
Contest: A New Frontier for Partitioning,
Placement and Routing
March 24, 2021, 9:15am PT

Patrick Groeneveld
Michael James
Vladimir Kibardin
Ilya Sharapov
Leo Wang
Marvin Tom



Program

- Welcome, ISPD's Benchmark Contest History
- CS-1 Wafer Scale Engine hardware
- The ISPD2021 challenge: wafer scale physics modeling
- Benchmarks, scoring
- Results, Reveal of the winners
- Analysis of the Results
- Short 4-min Team presentations



Questions?
Please use Zoom chat

Physical Design Benchmark Contest History

- **1988 Macro Placement**
- 2005&2006 Standard Cell Placement
- 2007&2008 Global Routing
- 2009&2010 Clock Tree Synthesis
- 2011 Congestion Driven Placement
- 2012&2013 Discrete Gate Sizing
- 2014&2015 Routing-aware placement
- 2016 Routability-driven FPGA placement
- 2017 Clock-aware FPGA Placement
- 2018&2019 Detailed Routing
- 2020 Wafer-Scale Placement for ML
- **2021 Wafer-Scale Physics modeling**

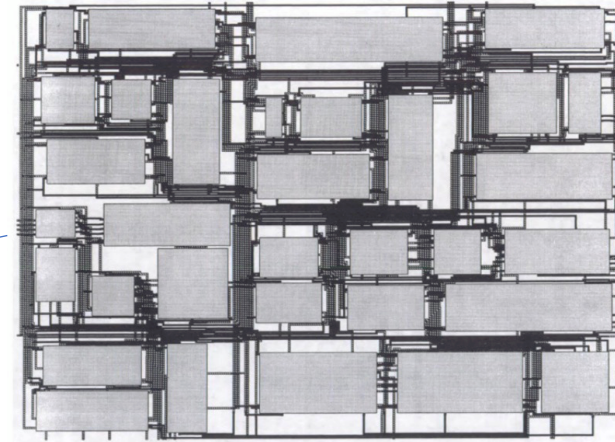
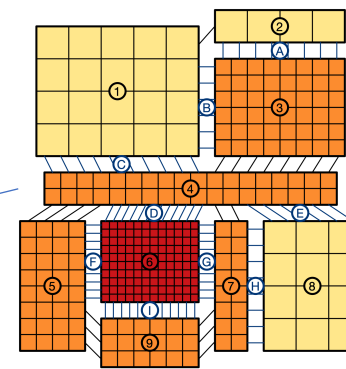
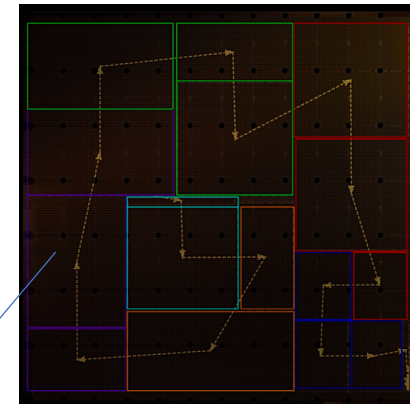


Figure 2.33. The benchmark circuit AMI33.

Table 2.3. 1988 MCNC Benchmark Results

	AMI33		XEROX	
	Area	# Vias	Area	# Vias
DELFT	2.60	967	26.57	925
SEATTLE S.	2.73	862	28.63	1235
VITAL	3.21	763	31.71	1029
MOSAICO	3.10	885	29.01	1173
BEAR	3.05	1092	28.47	1101



ISPD2021 contest: Team Locations



XDPlacer
Xidian University

LMS
Pohang Univ.

SmartFEP
Huazhong Univ.

Cerebras Systems
Toronto, Canada

FSPlanner
Univ of Utah

Cerebras Systems
Silicon Valley, CA

F4@collegestation
Texas A&M University

A-Team
CUHK

Jinkela
Nat. Tsing Hua Univ.

NTU428
Nat. Taiwan Univ.

NYCU718
Nat. Yang Ming
Chiao Tung Univ.

iPlace
Nat. Taiwan Univ.

Cerebras ISPD 2021 Team

- Patrick Groeneveld
- Michael James
- Vladimir Kibardin
- Ilya Sharapov
- Marvin Tom
- Leo Wang

ISPD 2021 Wafer-Scale Physics Modeling Contest

A New Frontier for Partitioning, Placement and Routing

Patrick Groeneveld, Michael James, Vladimir Kibardin,
Ilya Sharapov, Marvin Tom and Leo Wang
Cerebras Systems, Los Altos, CA, USA
{patrick, michael, vladimir, ilya, marvin, leo}@cerebras.net

ABSTRACT

Solving 3-D partial differential equations in a Finite Element model is computationally intensive and requires extremely high memory and communication bandwidth. This paper describes a novel way where the Finite Element mesh points of varying resolution are mapped on a large 2-D homogenous array of processors. Cerebras developed a novel supercomputer that is powered by a 21.5cm by 21.5cm Wafer-Scale Engine (WSE) with 850,000 programmable compute cores. With 2.6 trillion transistors in a 7nm process this is by far the largest chip in the world. It is structured as a regular array of 800 by 1060 identical processing elements, each with its own local fast SRAM memory and direct

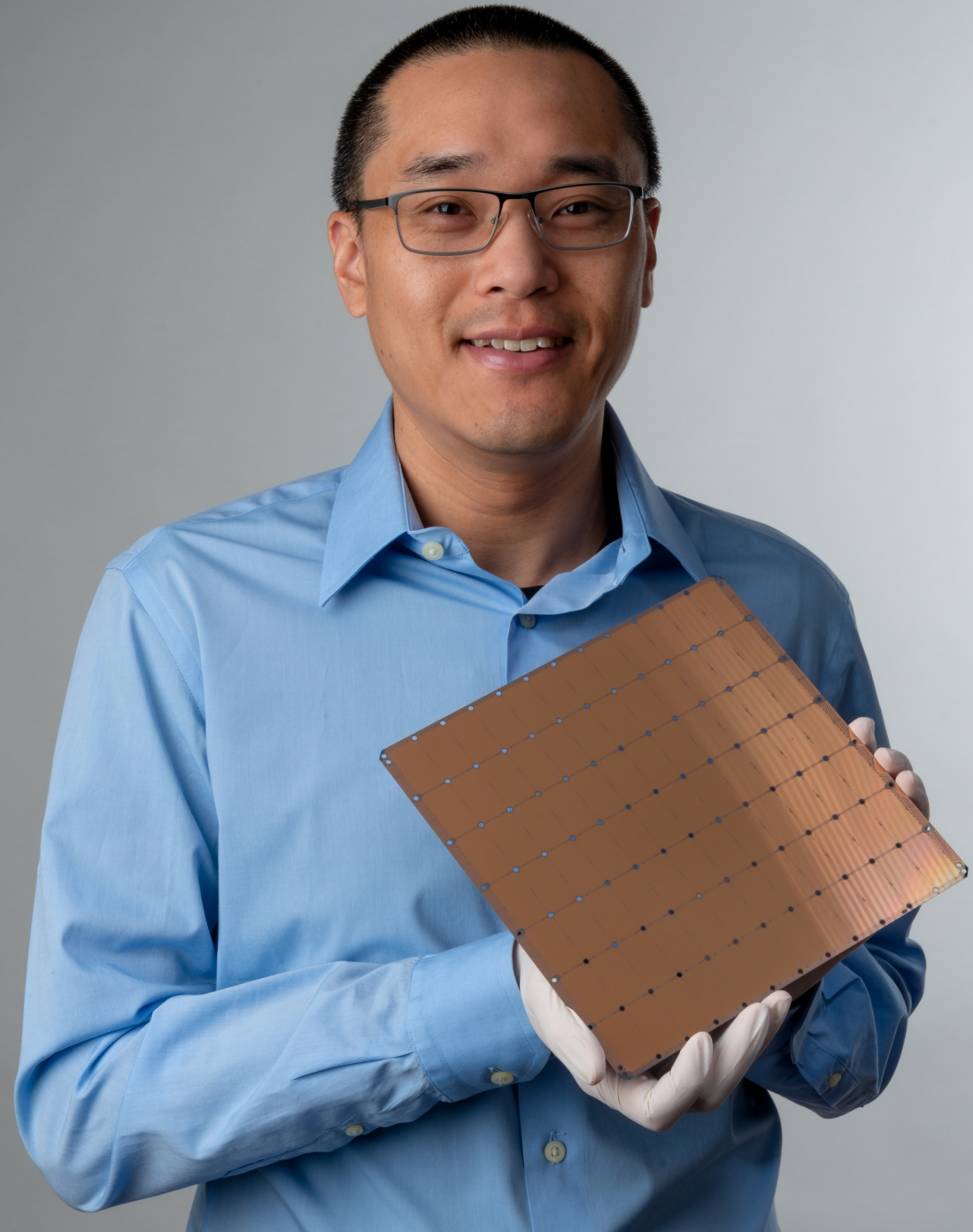
1. Introduction

Finite Element (FE) methods are widely used for solving nonlinear partial differential equations (PDE's). They use a mesh of discrete points to model a region. FE methods perform the same computational pattern uniformly at all mesh points. Fast computation of Finite Element methods has many relevant applications in engineering: from aerodynamics and structural analysis, calculating heat transfer to electromagnetic potentials. This sets up a system of equations that are solved using conjugate gradient methods, not unlike the engine in placement methods. Typically, FE methods are run on clusters of CPUs and accelerated using GPUs.

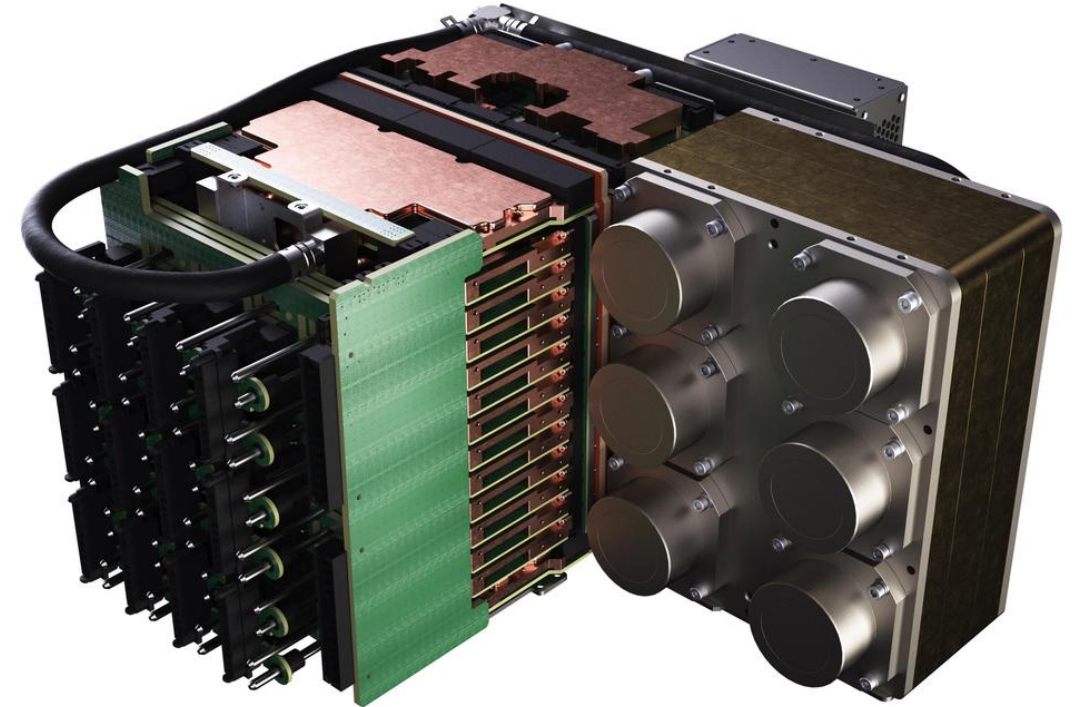
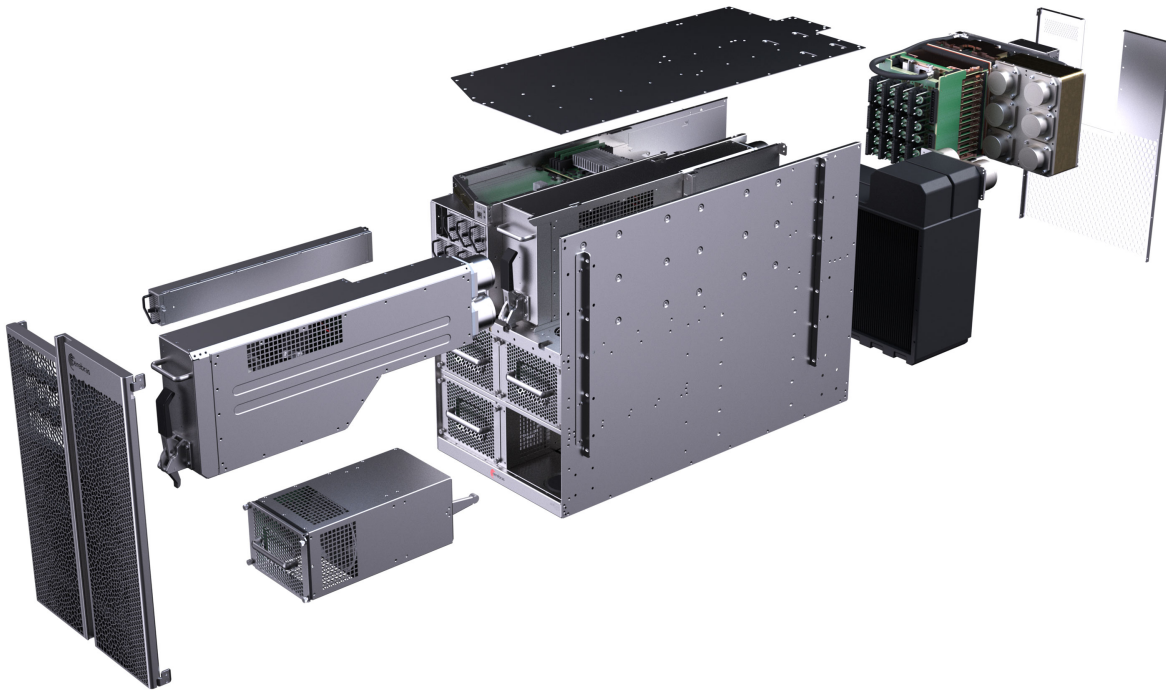


Cerebras: Largest Chip Ever Built

- 46,225 mm² silicon
- 2.6 **Trillion** transistors, 7nm TSMC
- 850,000 processor cores
- 40 Gigabytes of On-chip Memory
- 9 PByte/s memory bandwidth
- 100 Pbit/s fabric bandwidth



CS-1 Supercomputer Hardware

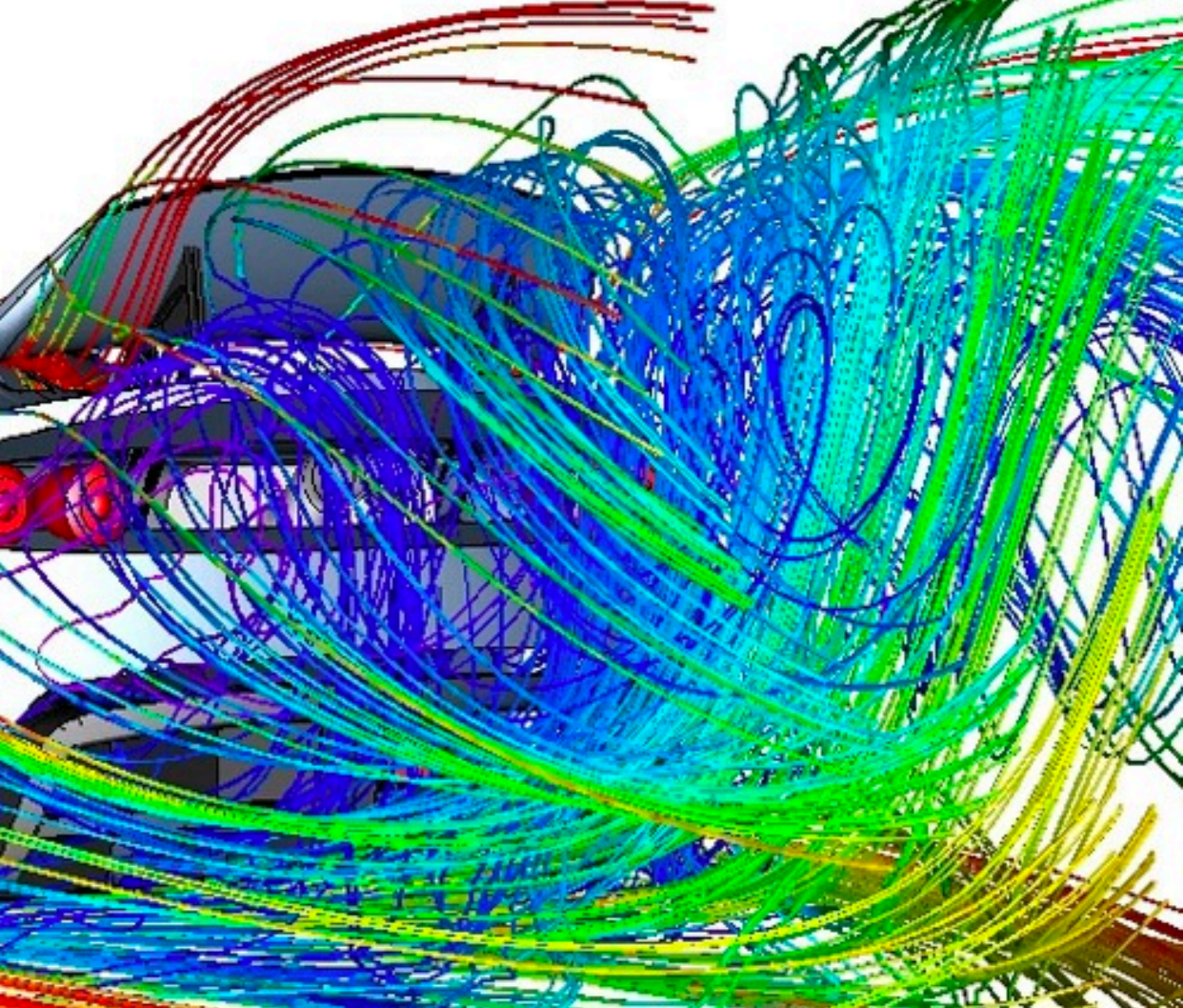
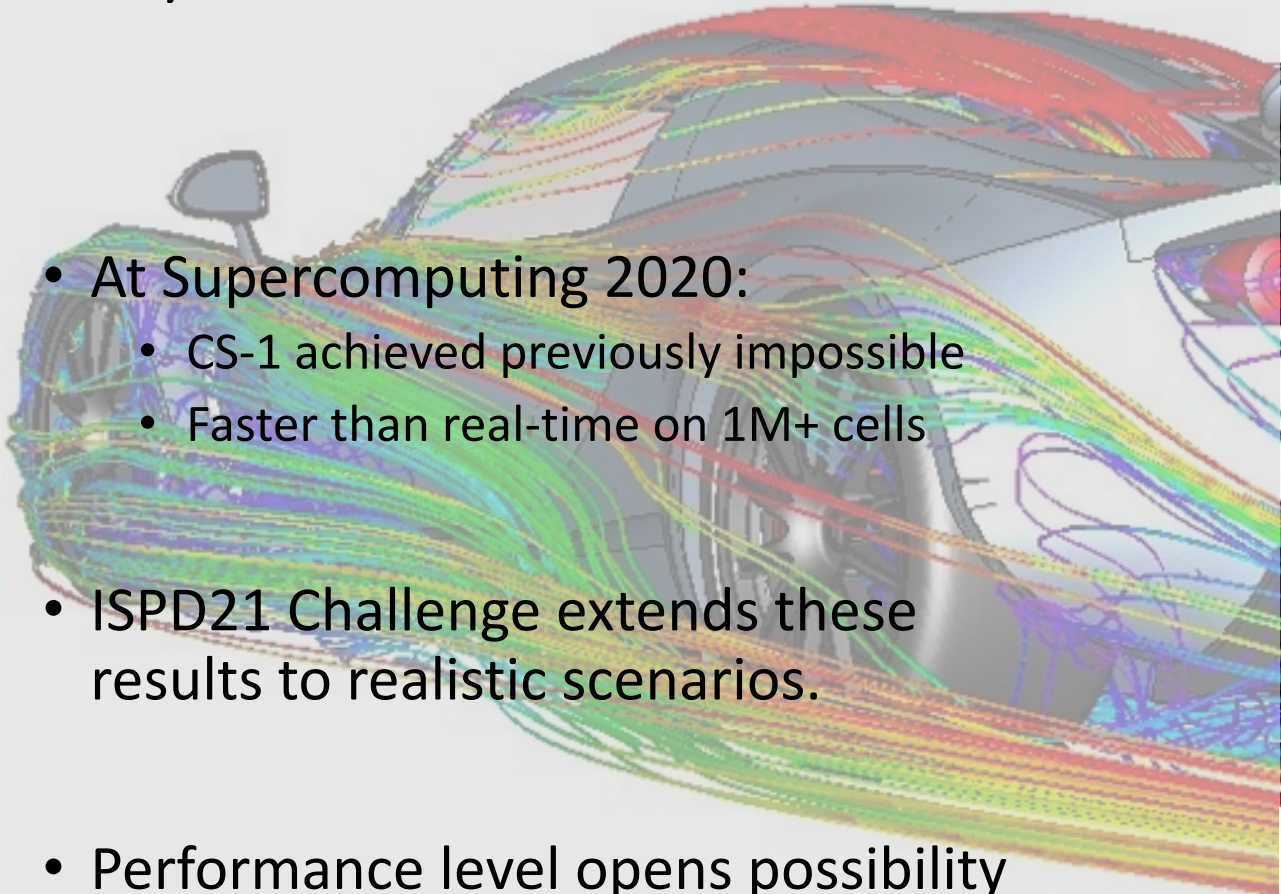


The wafer-scale physics modeling problem



Extending CS-1: Physics Simulations

- At Supercomputing 2020:
 - CS-1 achieved previously impossible
 - Faster than real-time on 1M+ cells
- ISPD21 Challenge extends these results to realistic scenarios.
- Performance level opens possibility for whole new types of computer applications.

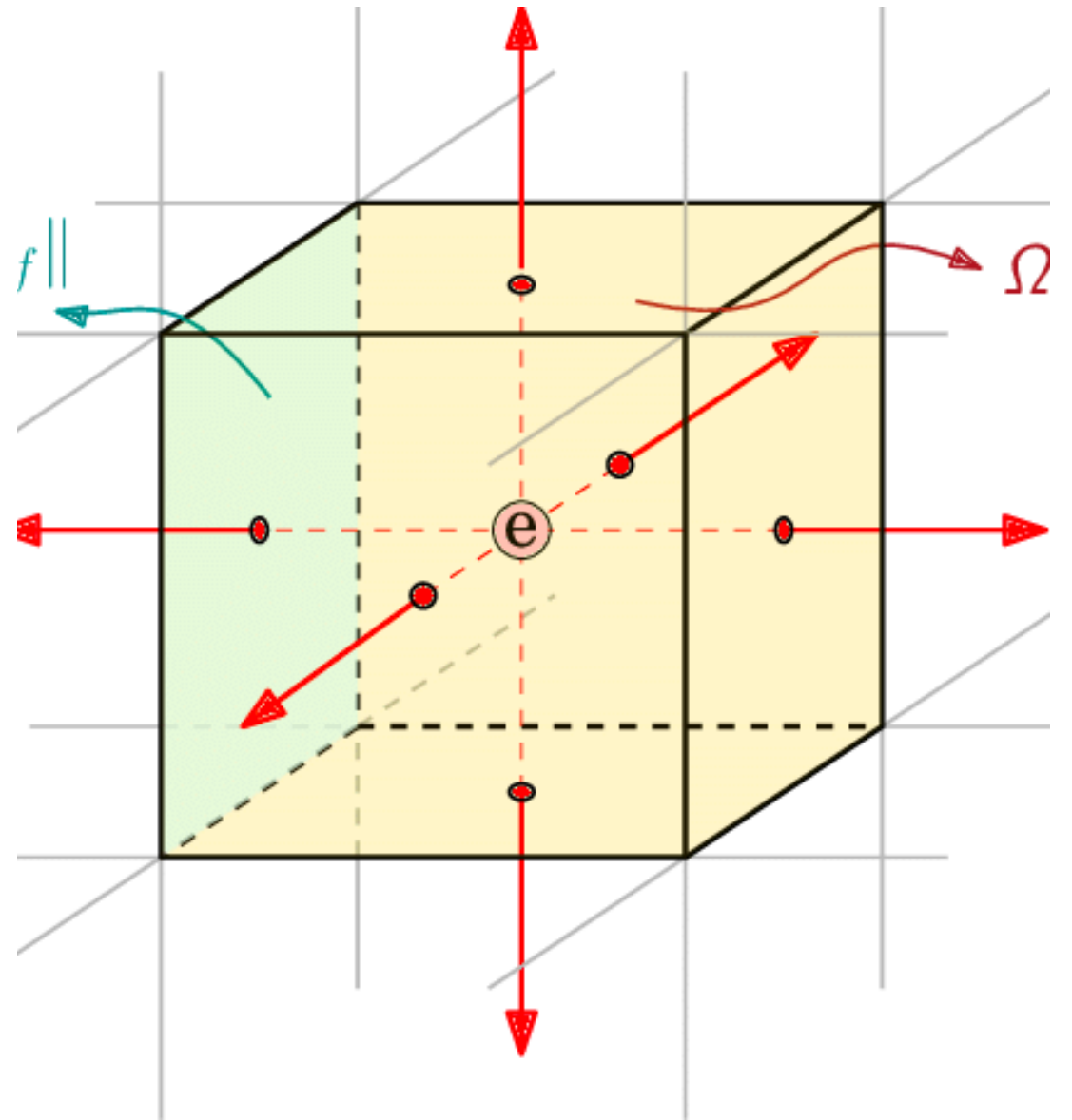


Fast Stencil-Code Computation on a Wafer-Scale Processor

Kamil Rocki*, Dirk Van Essendelft[†], Ilya Sharapov*, Robert Schreiber*, Michael Morrison*, Vladimir Kibardin*, Andrey Portnoy*, Jean Francois Dietiker^{†‡}, Madhava Syamlal[†] and Michael James*

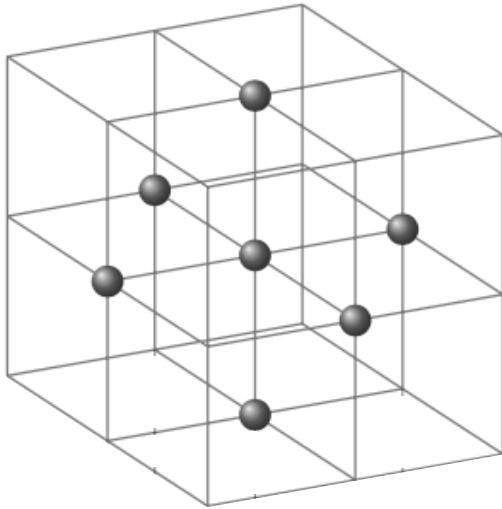
Finite Volume Method

- Dice space into many small cubic cells.
- Track pressure, velocity in each cell over time.
- Navier Stokes leads to a sparse linear systems at each time step.
- Solving provides physical quantities for next time step.

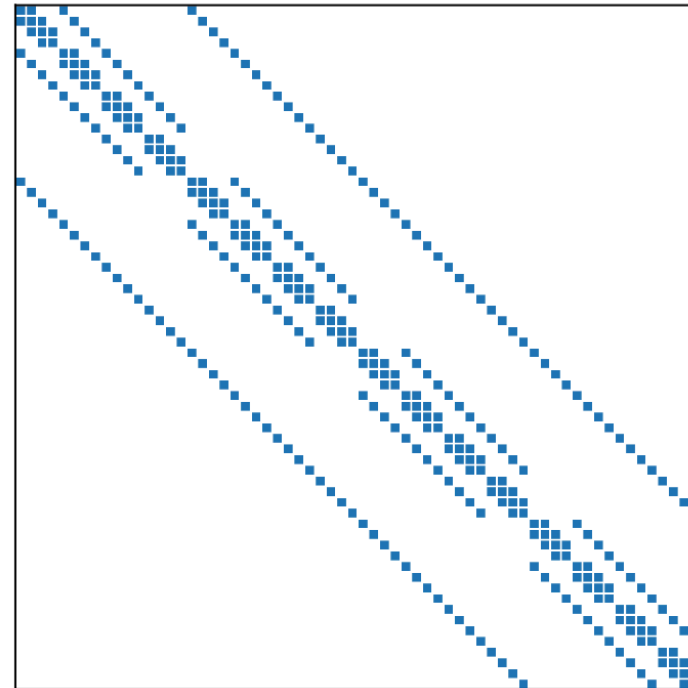


BiConjugate Gradient on CS-1

- Krylov subspace method to solve linear system $Ax = b$.
- Structured sparse A to model local interactions in 3-space



3D mesh with local interactions



Sparse Matrix A , a 7-point stencil

Inner Computation Loop

Operation	Count	FLOPS	% FLOPS
Vector Multiply-Add	6	12N	30%
Sparse Matrix-Vector	2	24N	50%
Dot Product	4	8N	20%

Function BiCGSTAB(A, b, x_0)

$r_0 \leftarrow b, p_0 \leftarrow r_0$

For $i = 0, 1, 2, \dots$ do

$s_i \leftarrow Ap_i$

$\alpha_i \leftarrow \frac{\langle r_0, r_i \rangle}{\langle r_0, s_i \rangle}$

$q_i \leftarrow r_i - \alpha_i s_i$

$y_i \leftarrow Aq_i$

$\omega_i \leftarrow \frac{\langle q_i, y_i \rangle}{\langle y_i, y_i \rangle}$

$x_i \leftarrow x_i + \alpha_i p_i + \omega_i q_i$

$r_{i+1} \leftarrow q_i - \omega_i y_i$

$\beta_i \leftarrow \frac{\alpha_i \langle r_0, r_{i+1} \rangle}{\omega_i \langle r_0, r_i \rangle}$

$p_{i+1} \leftarrow r_{i+1} + \beta_i (p_i - \omega_i s_i)$

End for

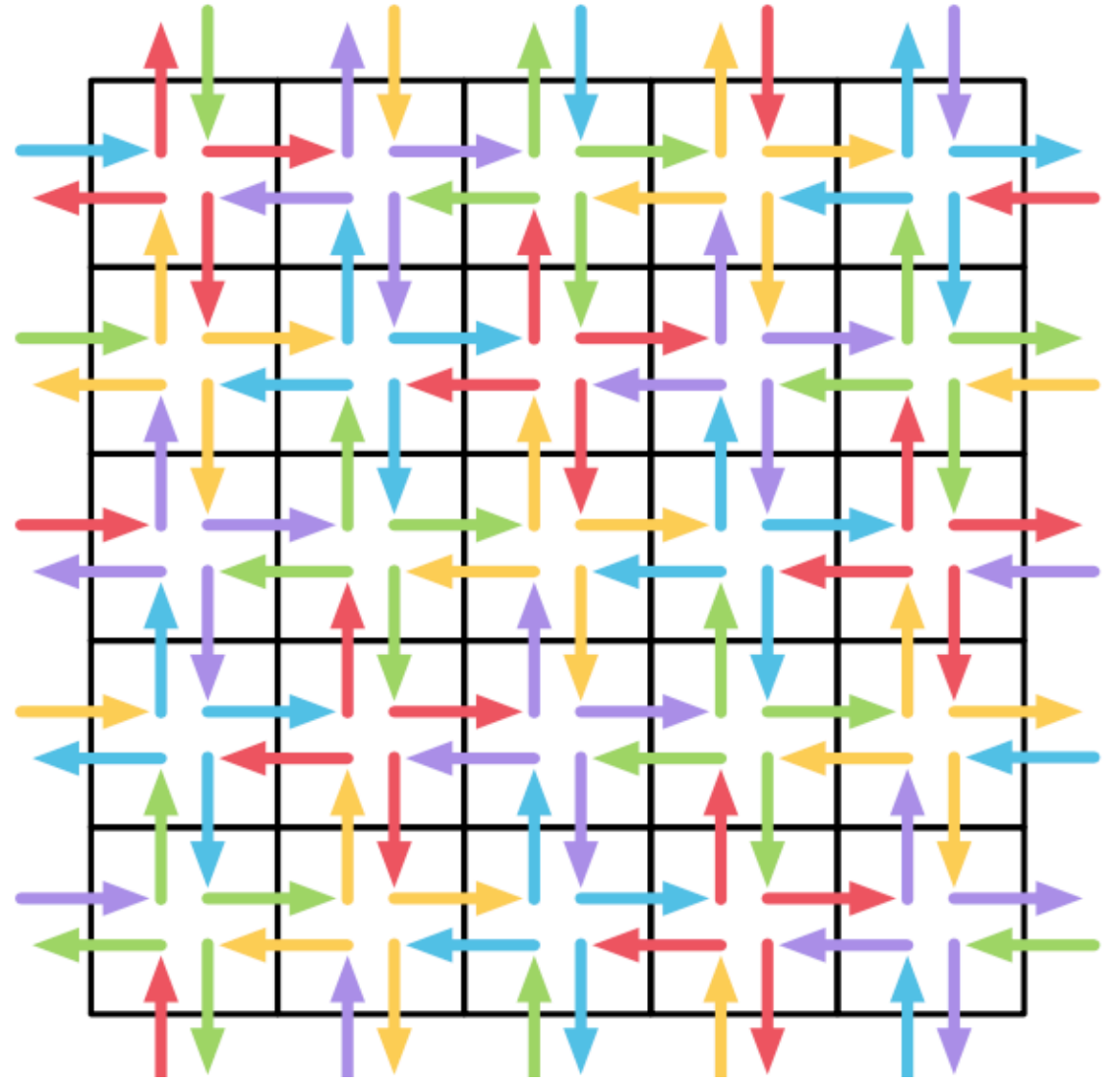
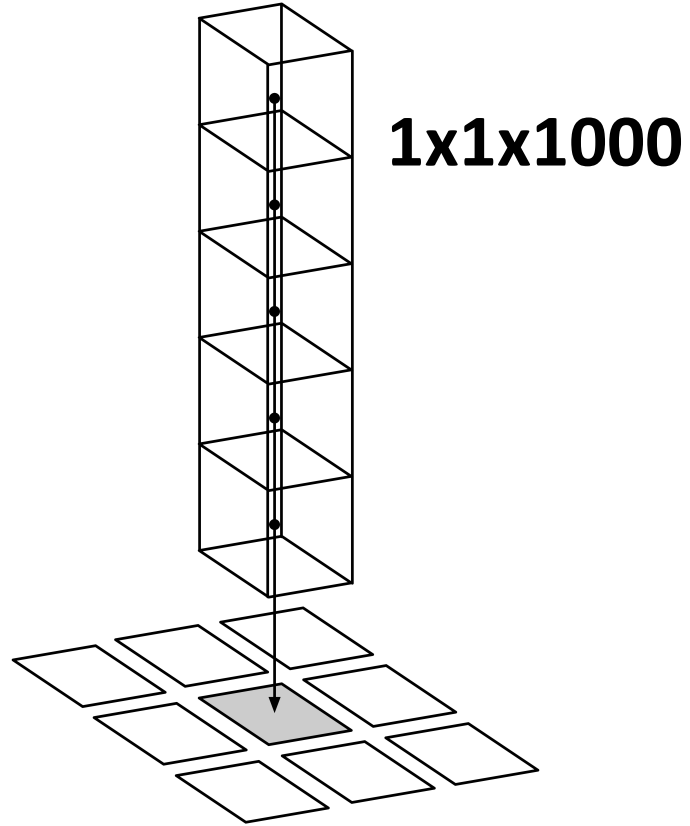
End function

Requires Huge Memory Bandwidth

Operation	FLOPS	READS	WRITES	FLOP : IO	Pattern
Vector Multiply-Add	2N	2N	N	2:3	Local
Sparse Matrix-Vector	12N	7N	N	3:2	Neighbor
Dot Product	2N	2N	0	1:1	All Reduce

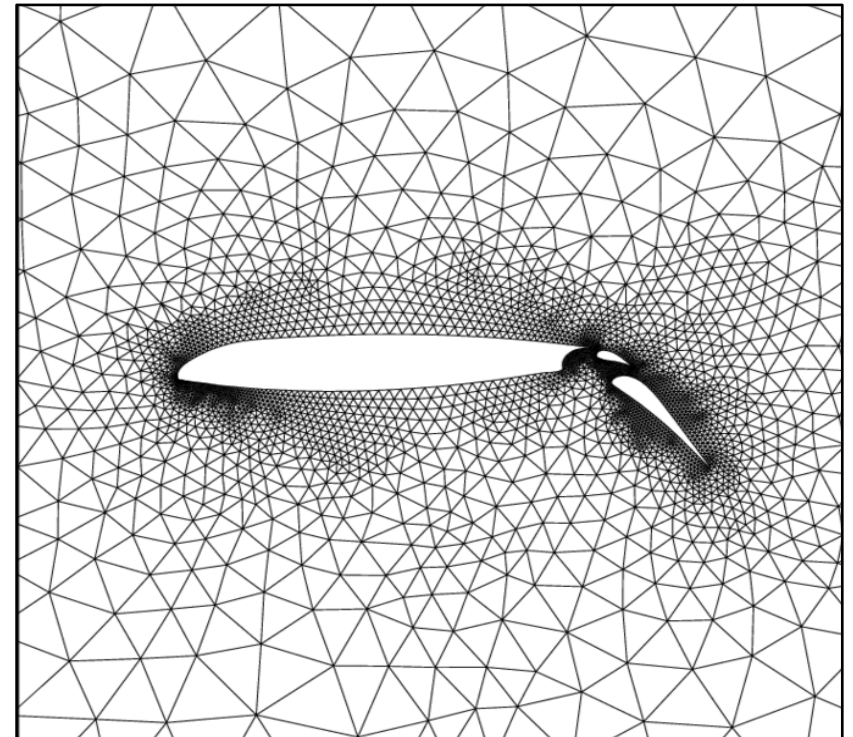
Processor	FLOP : IO
GPU	1000:1
CPU	200:1
CS-1	$\frac{2}{3}$:1

Sparse Matrix - Vector Communication Pattern



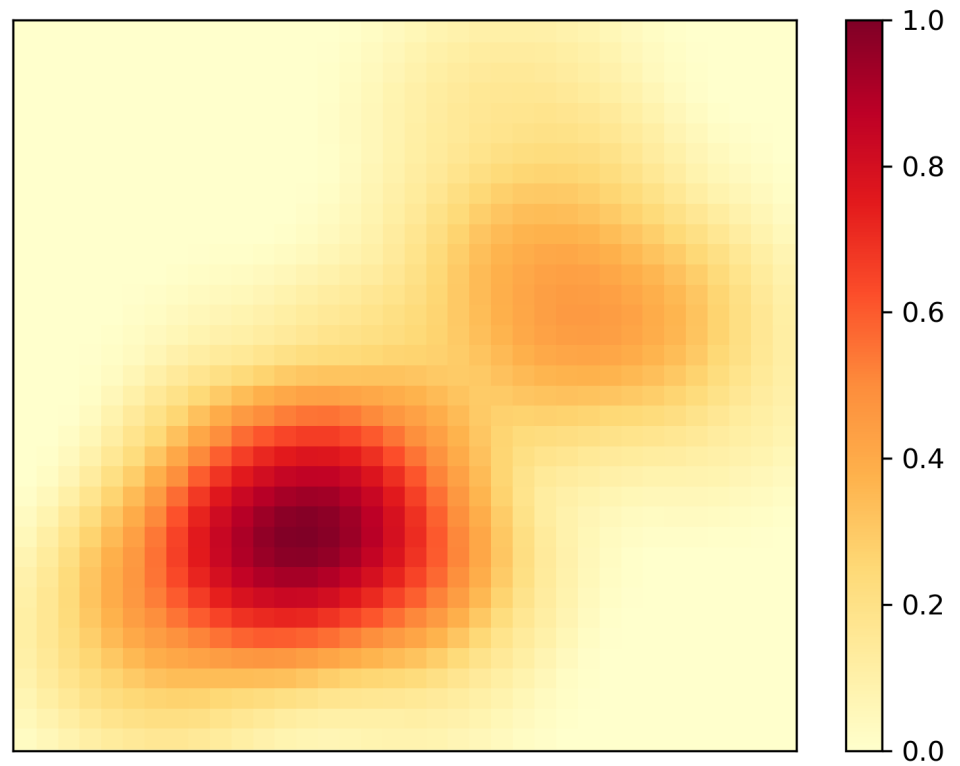
ISPD 2021 Challenge

- Real simulations use irregular mesh!
- Extend kernels:
 - Each tile holds **10x10x10** grid points.
 - Adapters perform 2x2:1 interpolation.
- Formulate placement & routing problem.



Density Function

- Map from 3D space to desired resolution.



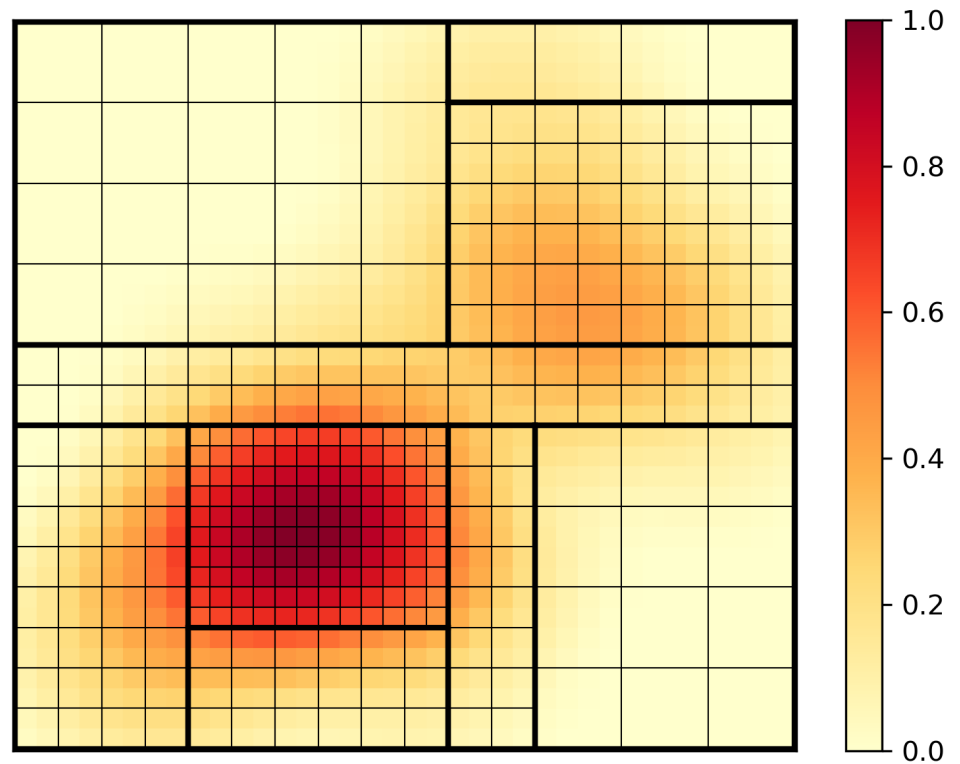
Partitioning

Solutions partition into fixed resolution regions.

Resolutions are powers of 2.

Approximate target density.

Sub-meshes must align.



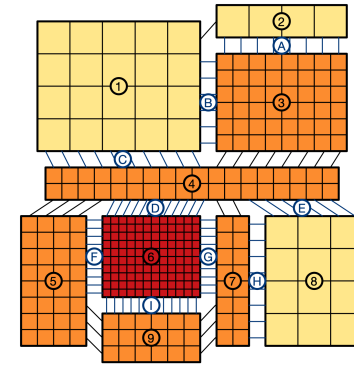
Placement

Place all compute tiles in a region.

Place adapters between regions.

Connectivity score:

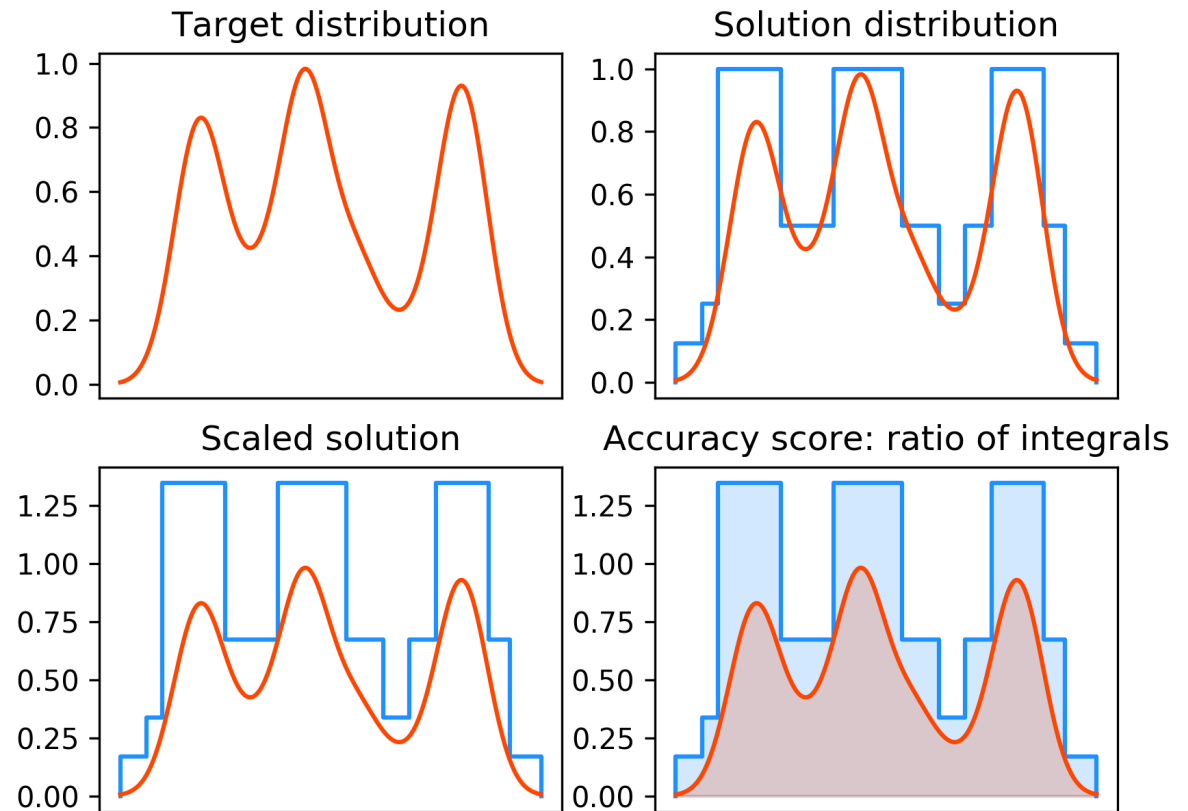
Minimize $L_{1.5}$ wire-length.



1	1	1	1	1	B	B	2	A	A	2	A	A	2	A	A	2	A	3	
1	1	1	1	1	B	3	A	3	3	3	3	3	3	3	3	3	3	3	3
1	1	1	1	1	B	B	3	3	3	3	3	3	3	3	3	3	3	3	3
1	1	1	1	1	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3
C	C	C	C	C	C	C	C	C	C	3	3	3	3	3	3	3	3	3	3
					4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
					D	4	D	4	D	4	D	4	D	4	D	4	4	4	4
4	4		F	6	D	6	D	6	D	6	D	6	D	6	D	E	E	E	4
4	4	4	F	6	6	6	6	6	6	6	6	6	6	6	6	G	7	7	E
4	4	4	F	6	6	6	6	6	6	6	6	6	6	6	6	G	7	7	7
5	5	5	F	6	6	6	6	6	6	6	6	6	6	6	6	G	7	7	7
5	5	5	F	6	6	6	6	6	6	6	6	6	6	6	6	G	G	7	E
5	5	5	F	6	6	6	6	6	6	6	6	6	6	6	6	G	G	7	7
5	5	5	F	6	6	6	6	6	6	6	6	6	6	6	6	7	H	H	E
5	5	5	F	6	6	6	6	6	6	6	6	6	6	6	6	G	H	8	8
5	5	5	F	6	6	6	6	6	6	6	6	6	6	6	6	7	H	8	8
5	5	5		I	6	I	6	I	6	I	6	I	6	I	6	G	H	8	8
5	5	5	5	9	I	9	I	9	I	9	I	9	I	9	I	7	H	8	8
5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	7	H	8	8
5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	7	H	8	8

Scoring

- Accuracy score
 - Scale solution distribution to exceed the target
 - Score: number of grid points that are under target
- Overall score: minimum of Accuracy and Connectivity
 - Need to optimize both metrics

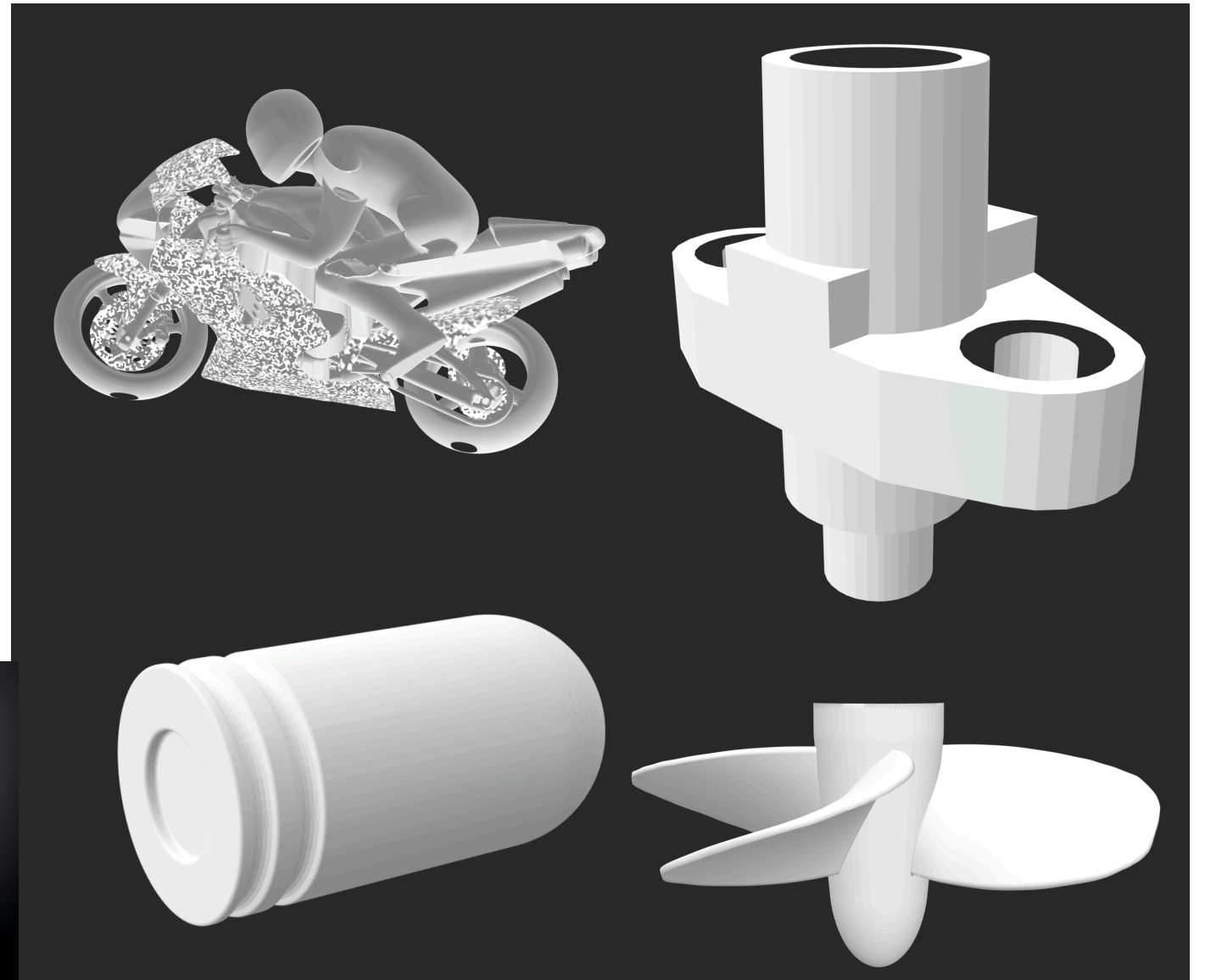


Meet the Teams in the ISPD2021 Contest!

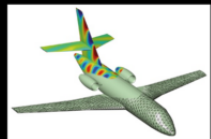
Team	Affiliation	Country	Members
A-Team	The Chinese University of Hong Kong	Hong Kong	Jinwei Liu, Xiaopeng Zhang, Xinshi Zang, Shiju Lin, Jingsong Chen, Bentian Jiang, Lixin Liu, Fangzhou Wang, Evangeline F.Y. Young , Martin D.F. Wong
F4@CollegeStation	Texas A&M	USA	Yishuang Lin, Hailiang Hu, Rongjian Liang, Yaguang Li, Jiang Hu
FSPlanner	University of Utah	USA	Cheng-Hsiang Chiu, Dian-Lun Lin, Tsung-Wei Huang
iPlace	National Taiwan University	Taiwan	Chun-Yu Yang, Yi-Ting Hsieh, Jhu-Lin Lan, Yu-Quan Chen, Iris Hui-Ru Jiang
Jinkela	National Tsing Hua University	Taiwan	YUNG-YUAN Lan, Chao-Yuan Huang, HSIU-CHU Hsu, Yu-Yu Li, Zhi-Hong Li, Ye-Chih Lin, CHieh-Yu Cheng, Ting-Chi Wang
NTU428	National Taiwan University	Taiwan	Yu-Ching Huang, Yen-Hsiang Huang, Hao-Yun Chang, Yao-Wen Chang
NYCU718	National Yang Ming Chiao Tung University	Taiwan	Hong-Wen Chiou, Chun-Wei Lai, Yu-Teng Chang, Yu-Min Lee
SmartFEP	Huazhong University of Science and Technology	China	Zhouxing Su, Canhui Luo, Qingyun Zhang, Yan Gao, Zhipeng Lü
XDPlacer	Xidian University	China	Benzheng Li, Zhengguang Tang, Xiyi He, Dingcheng Liu, Guangxin Guo, Hailong You , Zhongdong Qi

Benchmark Set

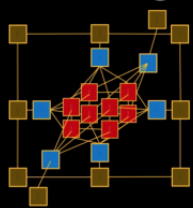
- Bullet
- Flange
- Motorbike
- Propeller



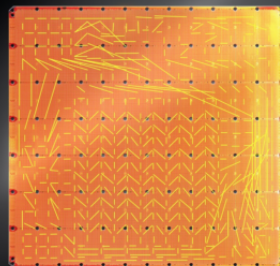
ISPD2021 Benchmark Contest
Wafer Scale Physics Modeling



Finite Element model
heatmap



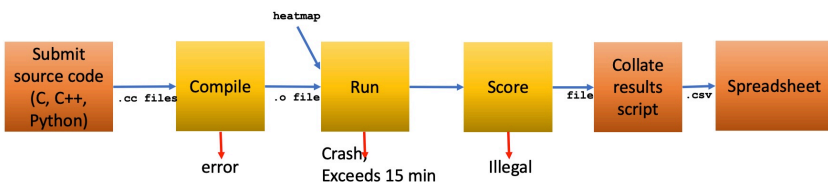
Partitioning into
Kernels



Placement and
Routing

ISPD2021 Framework: Software

- **Custom Software:**
 - Parsing, Benchmark Generation, scoring, visualization
- **Google Forms, Sheets, Docs:**
 - Submission, Team administration, final scoring
 - Yet Another Mail Merge
- **Github repository:**
 - Testcases, scoring and evaluation tool
- **Piazza:**
 - Communication with teams, Q&A
- **DOMJudge:**
 - Submission of results
- **Amazon AWS server:**
 - Scoring results



2. The special session on the contest is on **Wednesday March 24th at 9:15am Pacific Time**. Unfortunately, this is 12:15am for some of you.

3. **Prepare a 4-minute recorded video presentation** about your work. We will play this during the session. Hit the following:

- Your team name, members, and where you are from
- The outline with the methods of your approach
- A few nice details, results and pictures
- What you took away from this contest.

4. The final scores will be announced.

5. We will make certificates for all team members.

6. There will be award plaques and \$3000 worth of prizes to the top-3 winning teams.

We are very much looking forward to your result and the ISPD special session next week!

Kind regards on behalf of the Cerebras ISPD2020 team,

Patrick

A peek at the score that we see until now (Wednesday March 17th). Note: we cannot disclose details here without giving away Blue = normalized accuracy score, Red = normalized connectivity score.

Propeller Tip Scores (accuracy, connectivity)

Team	Blue (Accuracy)	Red (Connectivity)
team1	High	Medium
team2	High	Low
team3	Low	Low
team4	High	Low
team5	Low	Low
team6	High	Medium
team7	Low	Low

DOMjudge | judgehosts | clarifications | submissions | rejudgets | scoreboard | admin | ispd-

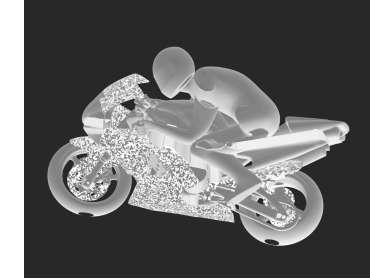
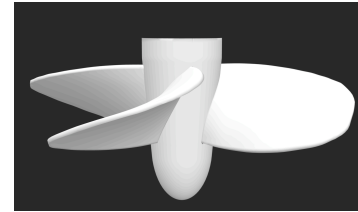
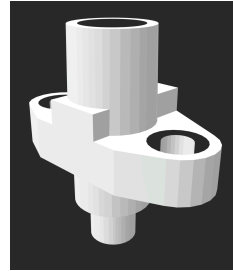
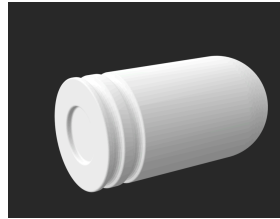
ISPD 2021

The public scoreboard was frozen with 0 minutes remaining

Filter

RANK	TEAM	SCORE	BULLET [1 POINT]	FLANGE [1 POINT]	HOLLOW SPHERE [1 POINT]	LARGE TORUS [1 POINT]	MOTORBIKE [1 POINT]	PROPELLER TIP [1 POINT]	SIMPLE TEST [0 POINTS]
1	A-Team The Chinese University of Hong Kong	7 186434	30545 2 tries	31087 5 tries	15472 1 try	16528 2 tries	31088 5 tries	30542 2 tries	15471 1 try
2	SmartFEP Huazhong University of Science and Technology	7 195745	30869 6 tries	30875 1 try	21031 3 tries	21034 1 try	30871 5 tries	30750 1 try	8897 3 tries
3	NTU428 National Taiwan University	7 206229	30623 3 tries	31035 18 tries	21994 22 tries	27843 2 tries	30626 2 tries	29495 1 try	11760 2 tries
4	F4@CollegeStation Texas A&M University	7 209281	30118 1 try	31744 13 tries	21351 1 try	21349 1 try	31744 4 tries	30118 1 try	21209 1 try
5	XDPlacer Xidian University	7 248280	33930 6 tries	38422 8 tries	26841 3 tries	26841 1 try	38384 30 tries	29421 1 try	26768 1 try
6	IPlace National Taiwan University	7 294255	41571 3 tries	41571 3 tries	36421 2 tries	42490 6 tries	42696 6 tries	41570 3 tries	11094 4 tries
7	Jinkela National Tsing Hua University	7 303341	43937 3 tries	45251 11 tries	33961 1 try	33961 1 try	43937 3 tries	33984 2 tries	33945 4 tries
8	NYCU718 National Yang Ming Chiao Tung University	7 309596	38741 19 tries	40519 33 tries	36870 2 tries	36870 1 try	41300 173 tries	36831 6 tries	36828 13 tries
9	FSP1anner University of Utah	4 226478	3 tries	3 tries	46010 2 tries	46268 2 tries	3 tries	46424 3 tries	41654 2 tries

Scoring Results for the 4 Final Benchmarks



Rank	4-design	Bullet			Flange			Propeller Tip			Motorbike		
	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score
1	2.4370	0.6140	0.7917	0.6140	0.4614	0.5810	0.4614	0.7089	0.7245	0.7089	0.6528	0.7706	0.6528
2	2.3642	0.5194	0.6771	0.5194	0.4689	0.6994	0.4689	0.7089	0.8102	0.7089	0.6670	0.8764	0.6670
3	2.0033	0.4756	0.5063	0.4756	0.3883	0.7599	0.3883	0.7088	0.4905	0.4905	0.6516	0.6489	0.6489
4	1.8033	0.2608	0.7777	0.2608	0.4743	0.5814	0.4743	0.6539	0.6536	0.6536	0.5555	0.4146	0.4146
5	1.5919	0.3648	0.5685	0.3648	0.3849	0.5341	0.3849	0.5585	0.5618	0.5585	0.2837	0.8539	0.2837
6	0.5241	0.1655	0.1636	0.1636	0.1889	0.1789	0.1789	0.1049	0.4163	0.1049	0.3116	0.0767	0.0767
7	0.1581	0.0354	2.2755	0.0354	0.0001	0.0513	0.0001	0.0004	71.4239	0.0004	0.1222	0.9741	0.1222
8	0.1264	0.0340	0.0645	0.0340	0.2629	0.0220	0.0220	0.2897	0.0317	0.0317	0.0959	0.0387	0.0387
9	0.0363							0.0363	0.0682	0.0363			

And now The Winners!!

1st place: \$1500

2nd place: \$1000

3rd place: \$500



Third Place

Third Place

Third Place

Third Place



2021 ACM International Symposium on Physical Design

Wafer-Scale Physics Modeling Contest

THIRD PLACE

Team SmartFep

Canhui Luo, Zhouxing Su, Zhipeng Lü, Qingyun Zhang, Yan
Gao

Huazhong University of Science and Technology

Jens Lienig
General Chair
ISPD2021

Laleh Behjat
Technical Program Chair
ISPD2021

Patrick Groeneveld, Michael James,
Vladimir Kibardin, Ilya Sharapov,
Marvin Tom, Leo Wang,
Cerebras

Second Place

Second Place

Second Place

Second Place



2021 ACM International Symposium on Physical Design

Wafer-Scale Physics Modeling Contest

SECOND PLACE

Team A-Team

Jinwei Liu, Xiaopeng Zhange, Shiju Lin, Xinshi Zang,
Evangeline F.Y. Young, Martin D.F. Wong

The Chinese University of Hong Kong

Jens Lienig
General Chair
ISPD2021

Laleh Behjat
Technical Program Chair
ISPD2021

Patrick Groeneveld, Michael James,
Vladimir Kibardin, Ilya Sharapov,
Marvin Tom, Leo Wang,
Cerebras

First Place

First Place

First Place

First Place



2021 ACM International Symposium on Physical Design

Wafer-Scale Physics Modeling Contest

FIRST PLACE

Team F4@Collegestation

Yishuang Lin, Hailiang Hu, Rongjian Liang, Yaguang Li,
Jiang Hu

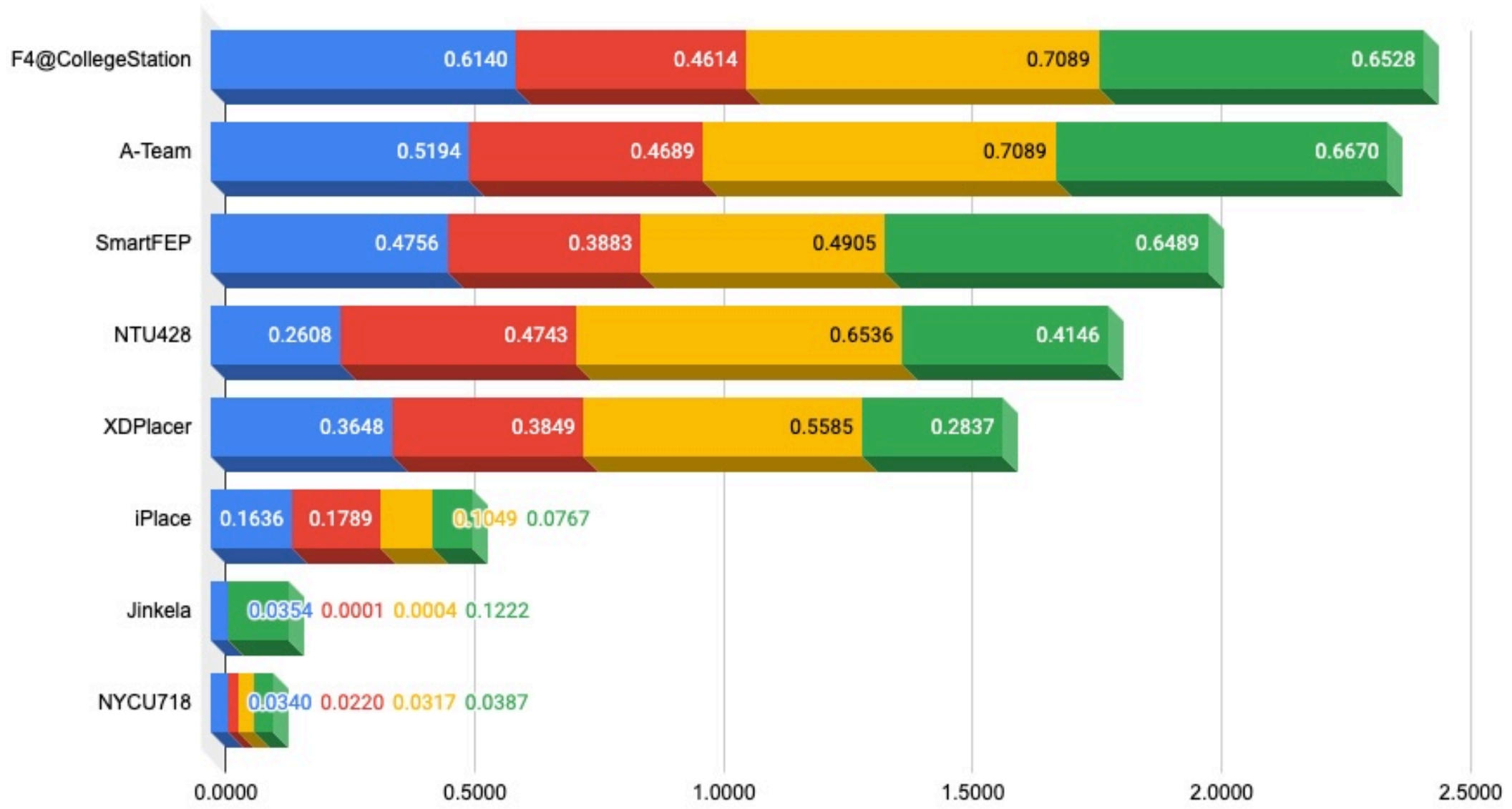
Texas A&M University

Jens Lienig
General Chair
ISPD2021

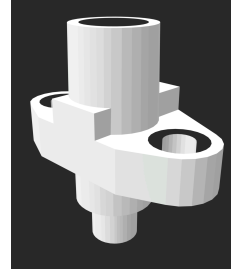
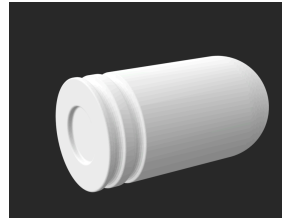
Laleh Behjat
Technical Program Chair
ISPD2021

Patrick Groeneveld, Michael James,
Vladimir Kibardin, Ilya Sharapov,
Marvin Tom, Leo Wang,
Cerebras

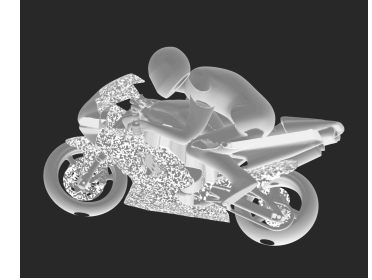
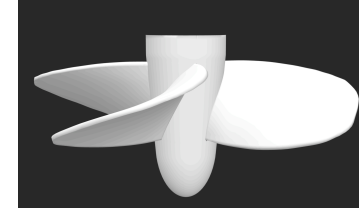
Total score for designs Bullet, Flange, Propeller Tip, Motorbike



Results



(public)



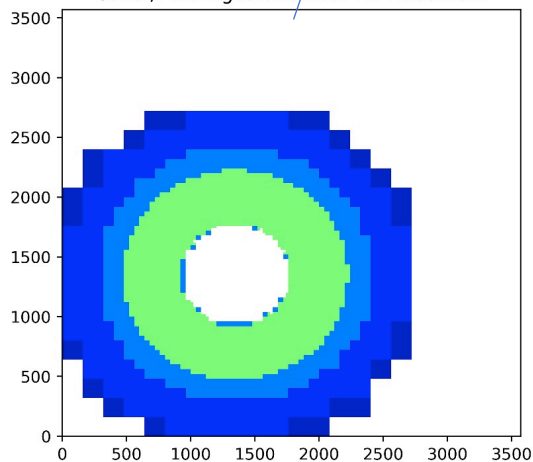
Team Name	Rank	4-design Score	Bullet			Flange			Propeller Tip			Motorbike		
			Accuracy	Connectivity	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score
F4@CollegeStation	1	2.4370	0.6140	0.7917	0.6140	0.4614	0.5810	0.4614	0.7089	0.7245	0.7089	0.6528	0.7706	0.6528
A-Team	2	2.3642	0.5194	0.6771	0.5194	0.4689	0.6994	0.4689	0.7089	0.8102	0.7089	0.6670	0.8764	0.6670
SmartFEP	3	2.0033	0.4756	0.5063	0.4756	0.3883	0.7599	0.3883	0.7088	0.4905	0.4905	0.6516	0.6489	0.6489
NTU428	4	1.8033	0.2608	0.7777	0.2608	0.4743	0.5814	0.4743	0.6539	0.6536	0.6536	0.5555	0.4146	0.4146
XDPlacer	5	1.5919	0.3648	0.5685	0.3648	0.3849	0.5341	0.3849	0.5585	0.5618	0.5585	0.2837	0.8539	0.2837
iPlace	6	0.5241	0.1655	0.1636	0.1636	0.1889	0.1789	0.1789	0.1049	0.4163	0.1049	0.3116	0.0767	0.0767
Jinkela	7	0.1581	0.0354	2.2755	0.0354	0.0001	0.0513	0.0001	0.0004	71.4239	0.0004	0.1222	0.9741	0.1222
NYCU718	8	0.1264	0.0340	0.0645	0.0340	0.2629	0.0220	0.0220	0.2897	0.0317	0.0317	0.0959	0.0387	0.0387
FSPlanner	9	0.0363							0.0363	0.0682	0.0363			

Results: Heat Map Accuracy

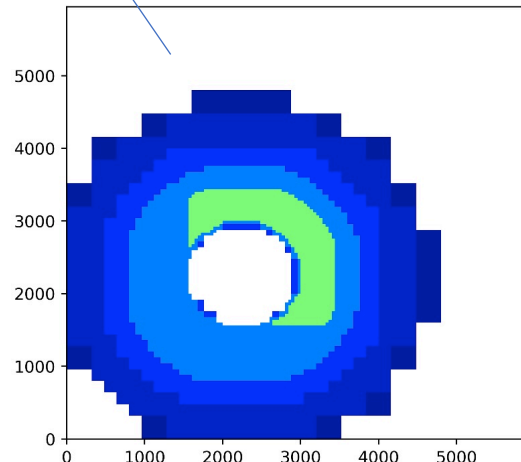
(public)

Team Name	Rank	4-design Score	Bullet			Flange			Propeller Tip			Motorbike		
			Accuracy	Connectivity	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score	Accuracy	Connectivity	Score
F4@CollegeStation	1	2.4370	0.6140	0.7917	0.6140	0.4614	0.5810	0.4614	0.7089	0.7245	0.7089	0.6528	0.7706	0.6528
A-Team	2	2.3642	0.5194	0.6771	0.5194	0.4689	0.6994	0.4689	0.7089	0.8102	0.7089	0.6670	0.8764	0.6670
SmartFEP	3	2.0033	0.4756	0.5063	0.4756	0.3883	0.7599	0.3883	0.7088	0.4905	0.4905	0.6516	0.6489	0.6489
NTU428	4	1.8033	0.2608	0.7777	0.2608	0.4743	0.5814	0.4743	0.6539	0.6536	0.6536	0.5555	0.4146	0.4146
XDPlacer	5	1.5919	0.3648	0.5685	0.3648	0.3849	0.5341	0.3849	0.5585	0.5618	0.5585	0.2837	0.8539	0.2837
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FSPlanner	9	0.0363							0.0363	0.0682	0.0363			

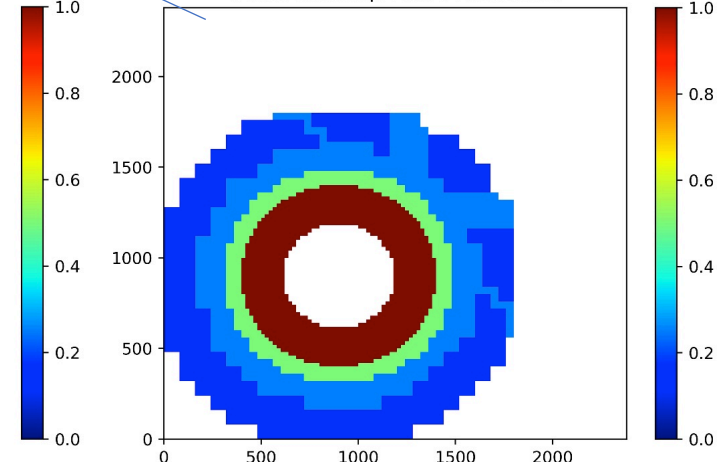
bullet/f4collegestation.out PE Placement



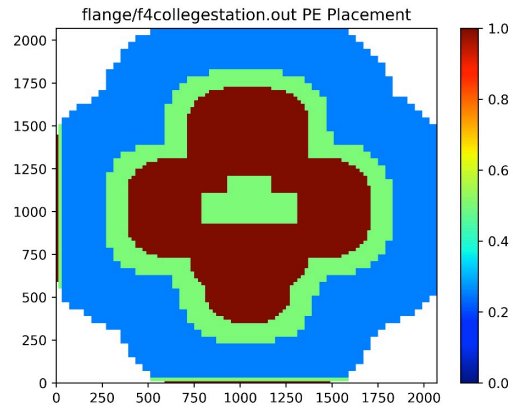
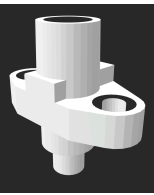
bullet/ateam.out PE Placement



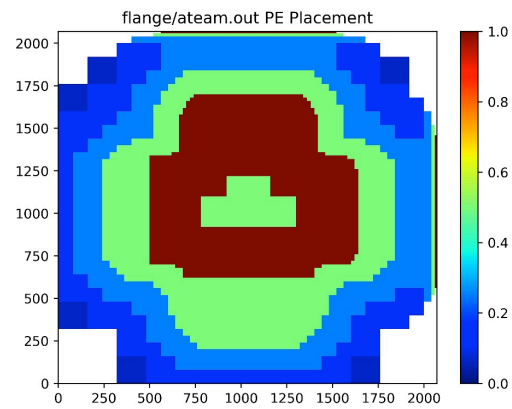
bullet/smartfep.out PE Placement



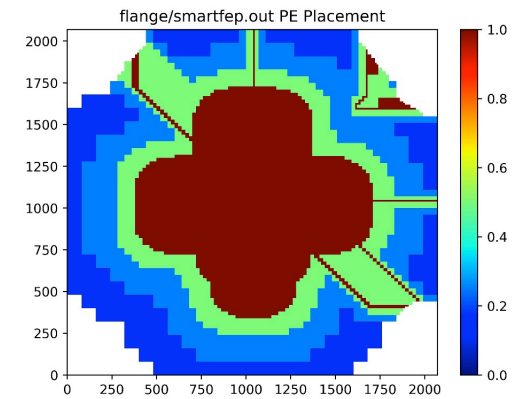
A Look at the Results (Flange)



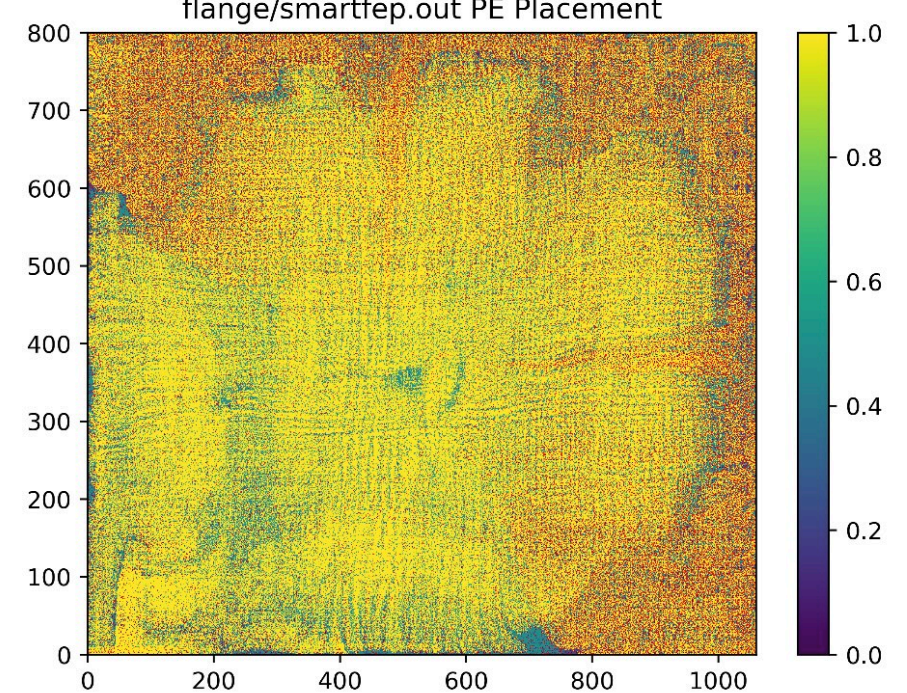
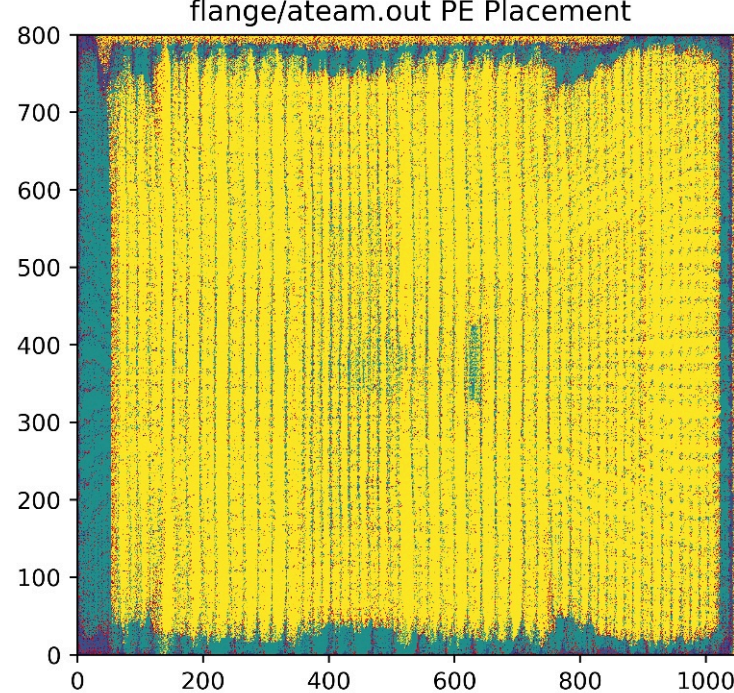
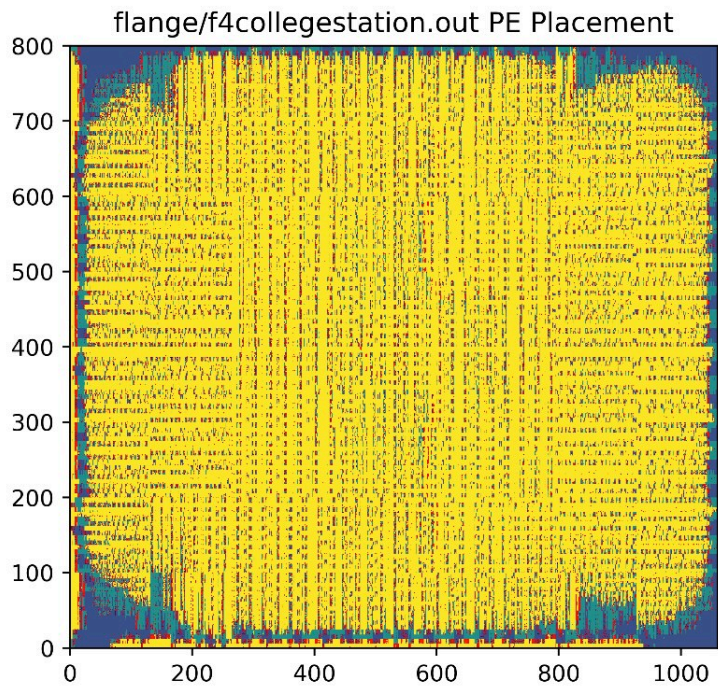
A: 0.4614 C: 0.5810



A: 0.4689 C: 0.6994



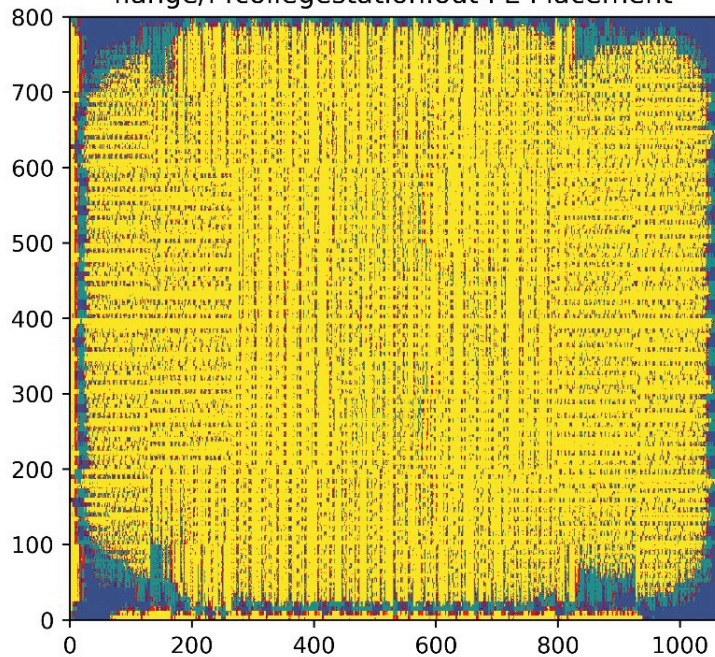
A: 0.2883 C: 0.7577



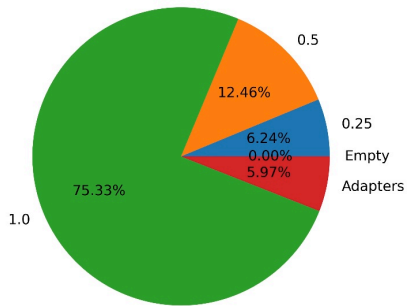
A Look at the Results (Flange)

A: 0.4614 C: 0.5810

flange/f4collegestation.out PE Placement

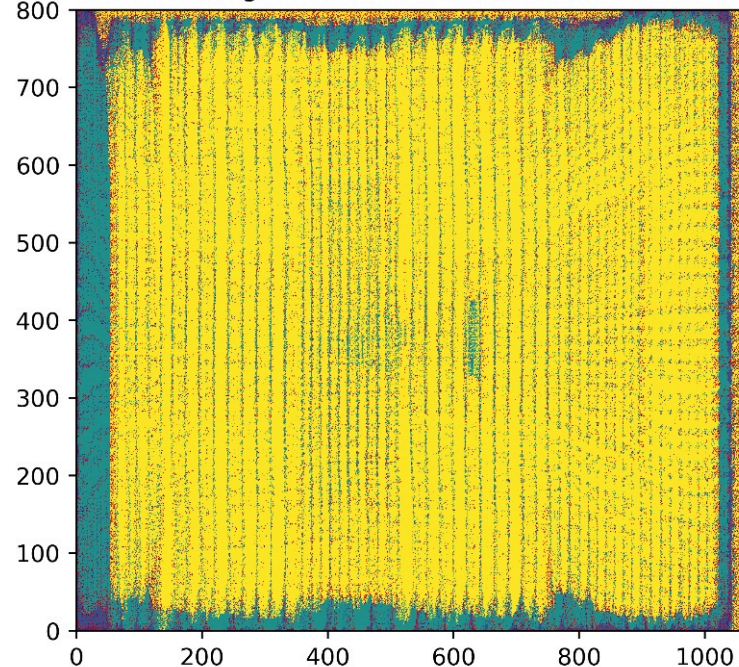


flange/f4collegestation.out PE Breakdown

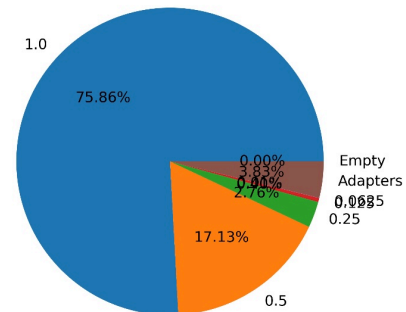


A: 0.4689 C: 0.6994

flange/ateam.out PE Placement

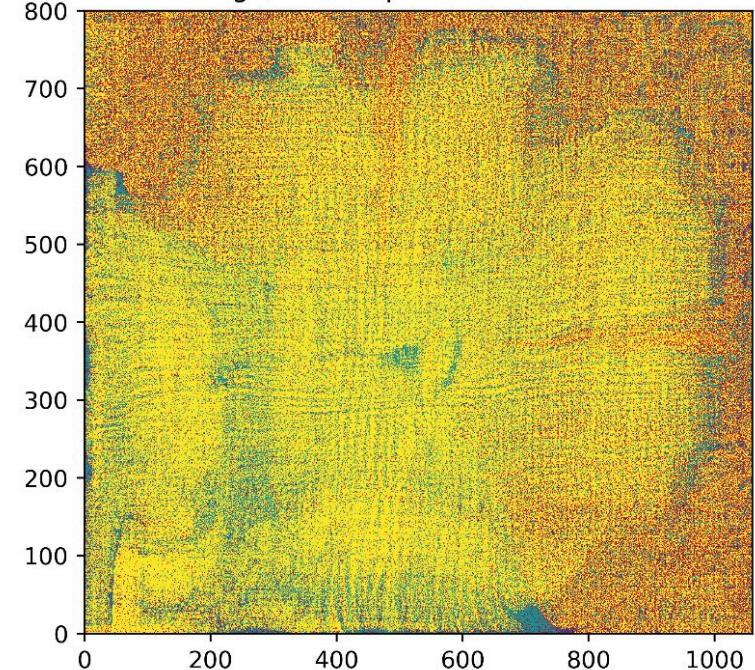


flange/ateam.out PE Breakdown

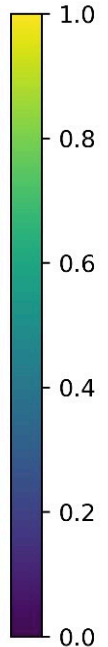
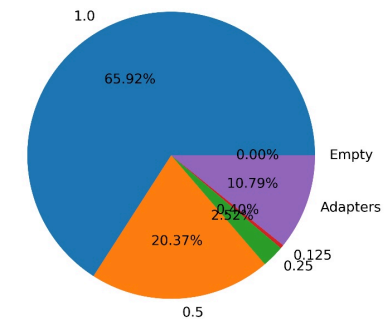


A: 0.2883 C: 0.7577

flange/smartfep.out PE Placement

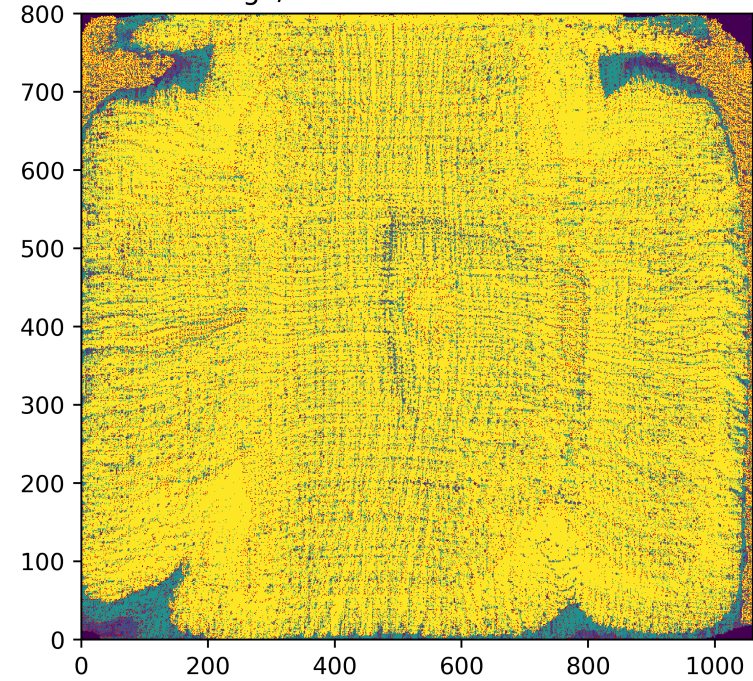


flange/smartfep.out PE Breakdown

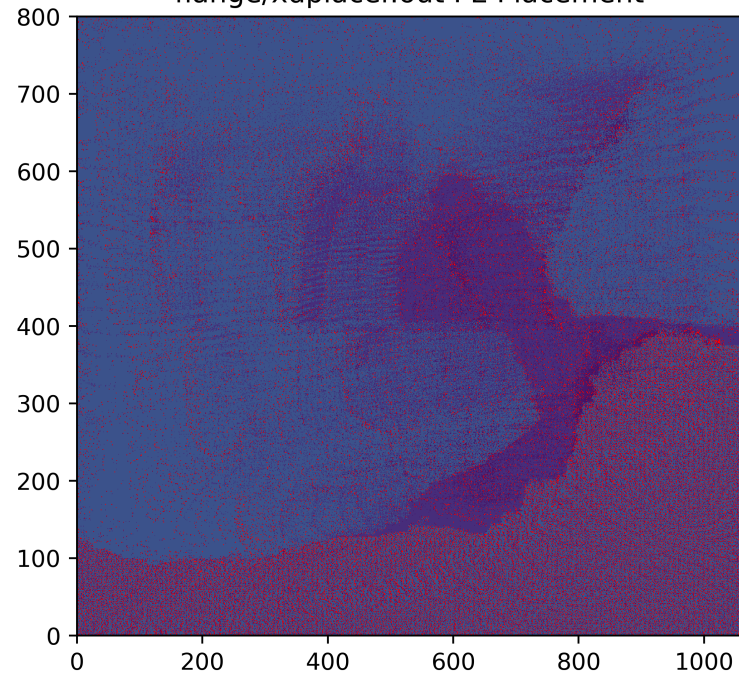


More Teams (Flange)

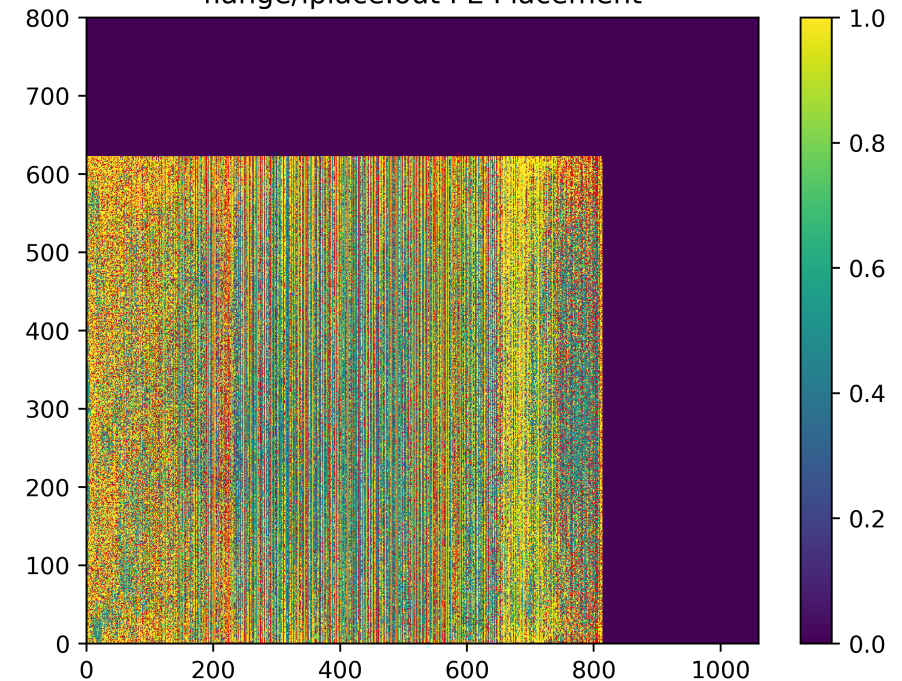
flange/ntu428.out PE Placement



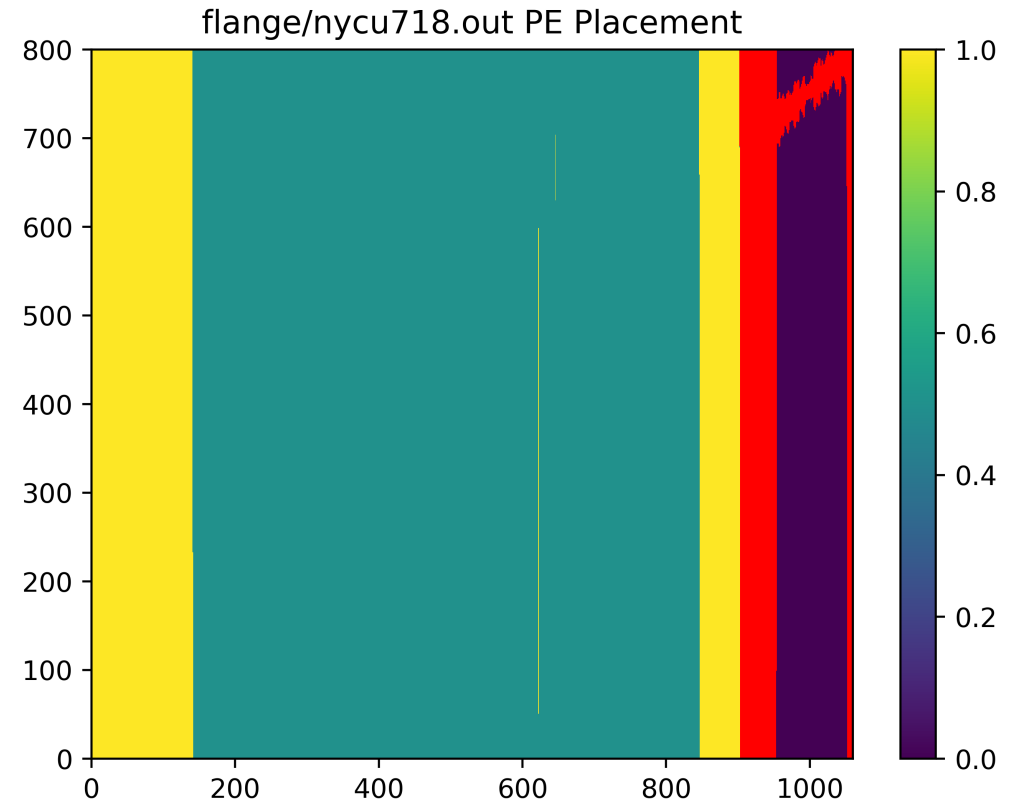
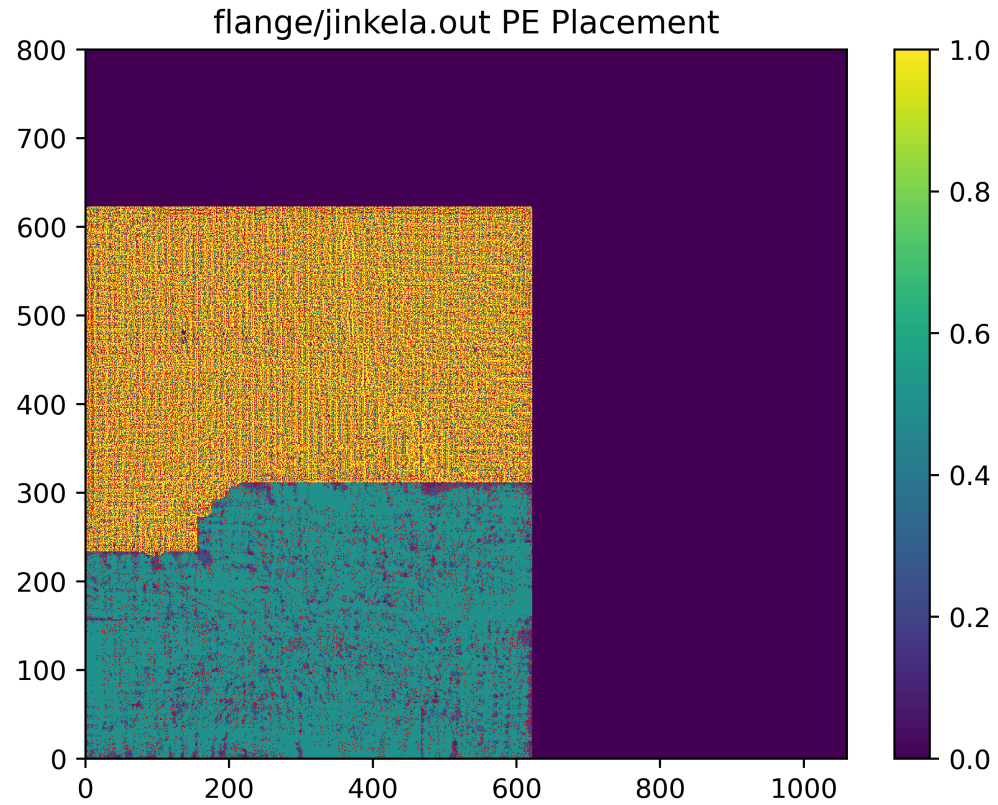
flange/xdplacer.out PE Placement



flange/iplace.out PE Placement



More results (Flange)



Thank You!

