Open3DBench: 3D-IC Backend Implementation Flow

Yunqi Shi
Nanjing University
Email: shiyq@lamda.nju.edu.cn

github:

arXiv:

Why Open3DBench?

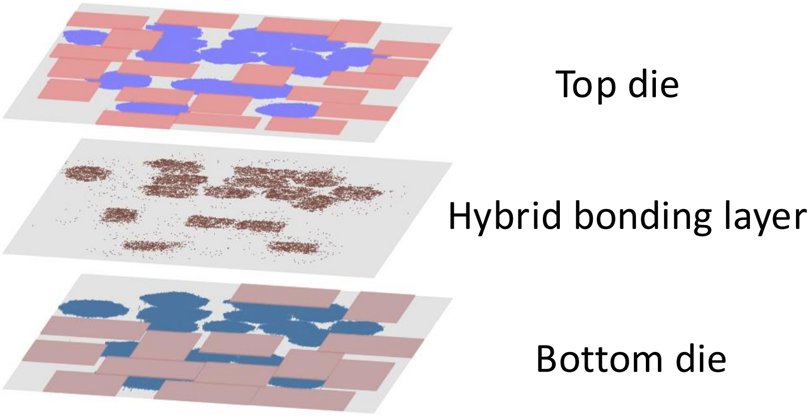
- 3D-IC physical design research has attracted tremendous attention these years.
- We want to test our 3D algorithms in a **standardized** and **reliable** way.

Taking 3D placement as an example:

Contest benchmarks:

- 3D Placement with D2D Vertical Connections @ ICCAD’22 Contest
- 3D Placement with Macros @ ICCAD’23 Contest

[1]



- Such contest benchmarks provide standardized comparison. But the host did not provide any implementation details (including valid PDK or design RTLs), narrowing the use of test cases.

[1] Zhao, Yuxuan, et al. "Analytical Heterogeneous Die-to-Die 3D Placement with Macros." TCAD 2024.

Why Open3DBench?

- 3D-IC physical design research has attracted tremendous attention these years.
- We want to test our 3D algorithms in a **standardized** and **reliable** way.

Taking 3D placement as an example:

Workaround by 2D backend flow:

- Macro-3D [1], Pin-3D [2], 3D Net-to-Pad Assignment [3] use Innovus to perform 3D backend flow.
- TA-3D [4] builds a 3D timing model using 2D tool OpenSTA.

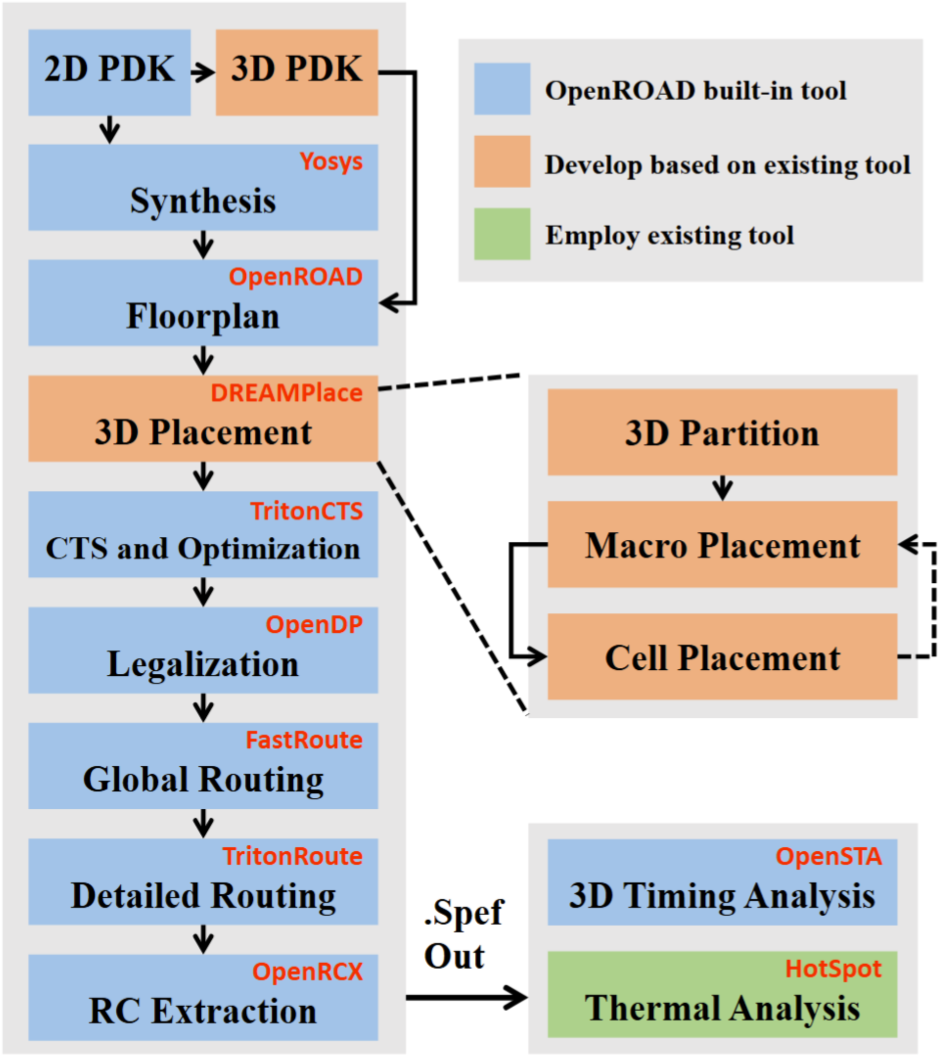
- Commercial tools and commercial PDKs prevent replicable comparisons due to license issue.
- Building our own workaround flow may be time consuming and sometimes not reliable enough.

[1] Bamberg, Lennart, et al. "Macro-3D: A physical design methodology for face-to-face-stacked heterogeneous 3D ICs." DATE 2020.
[2] Pentapati, Sai Surya Kiran, et al. "Pin-3D: A physical synthesis and post-layout optimization flow for heterogeneous monolithic 3D ICs." ICCAD 2020.
[3] Vanna-iampikul, Pruek, et al. "Placement-Aware 3D Net-to-Pad Assignment for Array-Style Hybrid Bonding 3D ICs. " ISPD 2025.
[4] Kim, Donggyu, et al. "TA3D: Timing-Aware 3D IC Partitioning and Placement by Optimizing the Critical Path." MLCAD 2024

What is Open3DBench?

- **Main purpose:**

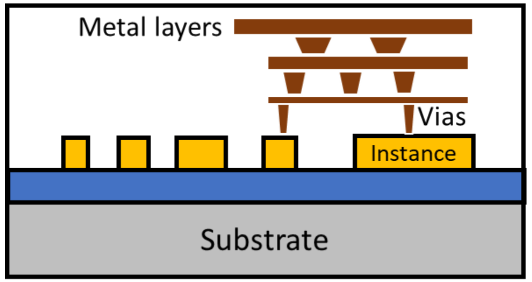
  Benchmarking everything in 3D backend flow

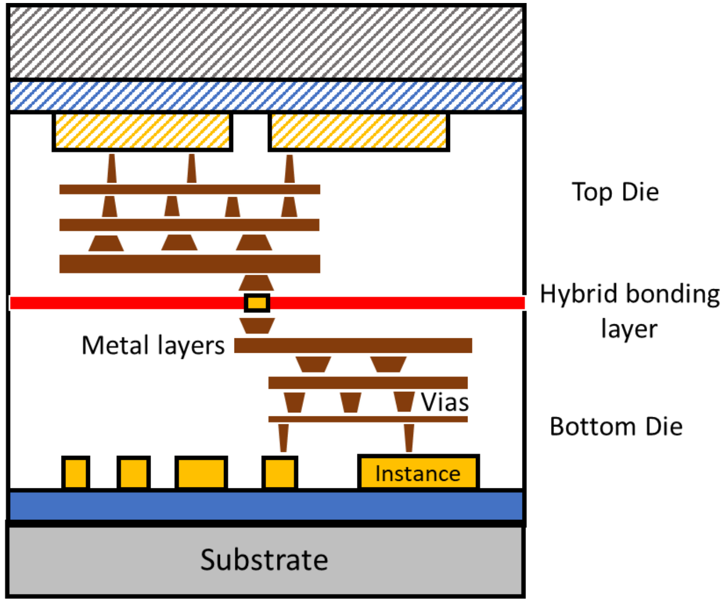


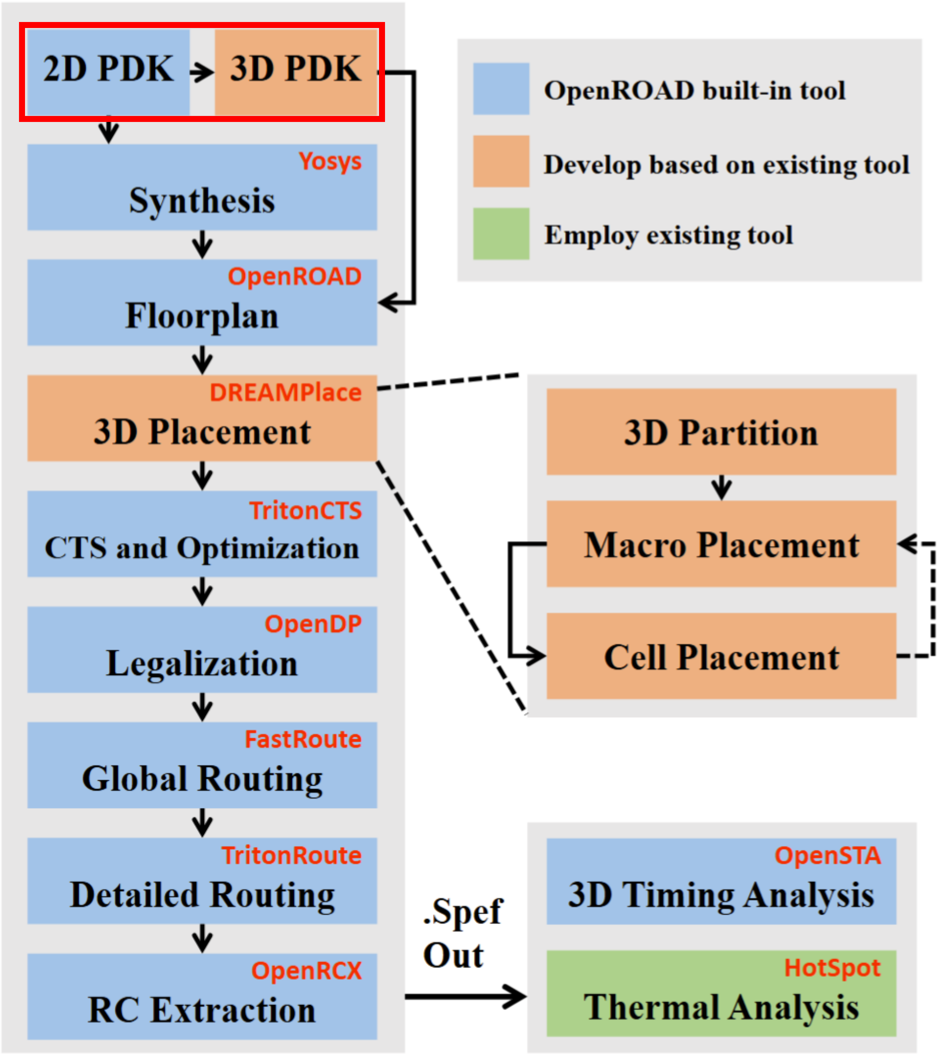
What is Open3DBench?

- **Key idea:**

  Double the original 2D metal layers and implement the 3D design on one die (like Macro-3D [1]).



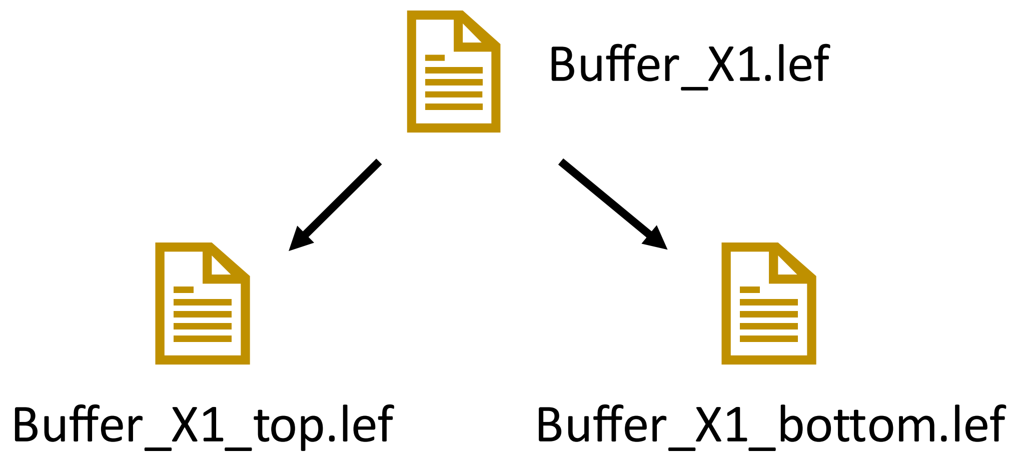


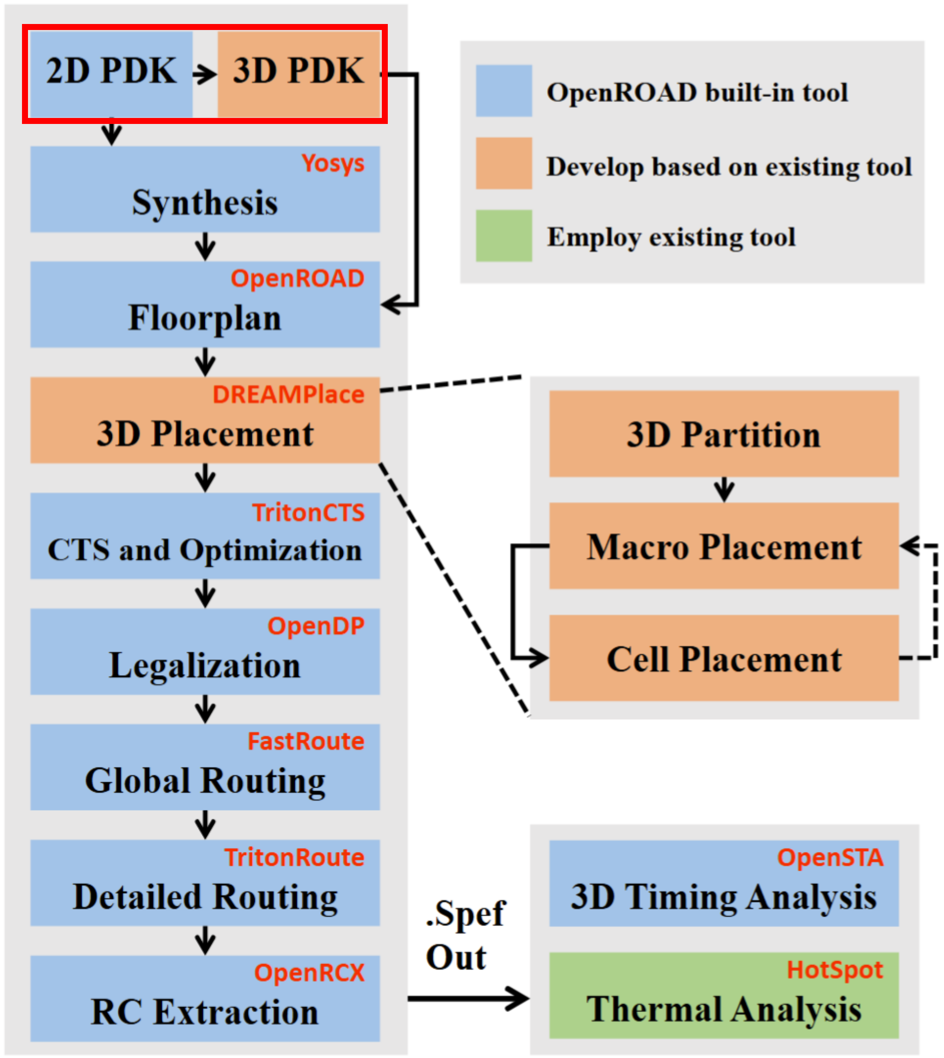


[1] Bamberg, Lennart, et al. "Macro-3D: A physical design methodology for face-to-face-stacked heterogeneous 3D ICs." DATE 2020.

What is Open3DBench?

- **PDK preparation:** Modify NG45 to NG45_3D
  - Duplicate the metal layer in *techlef*
  - Duplicate the instance *lef* and *lib* to distinguish top and bottom die

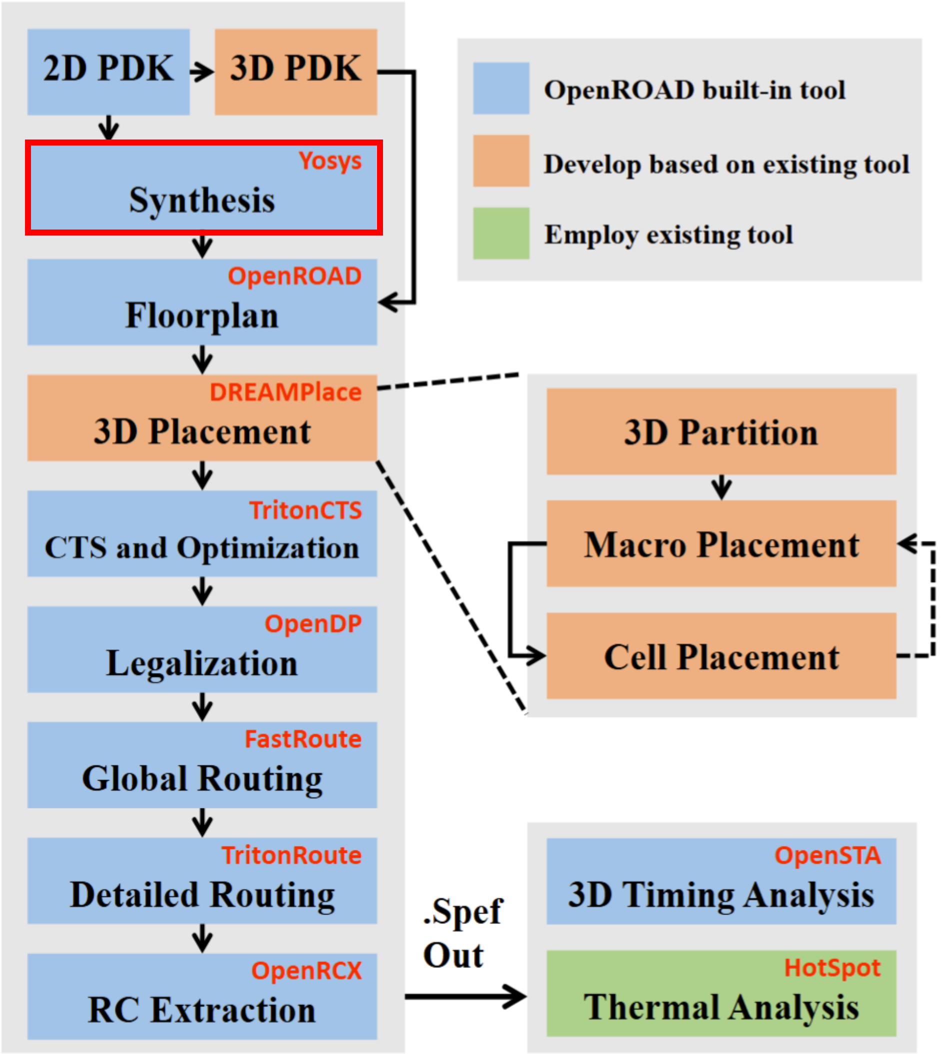




What is Open3DBench?

- **Design preparation:**

  Any 2D design (RTL / netlist) supported by OpenROAD-flow-scripts

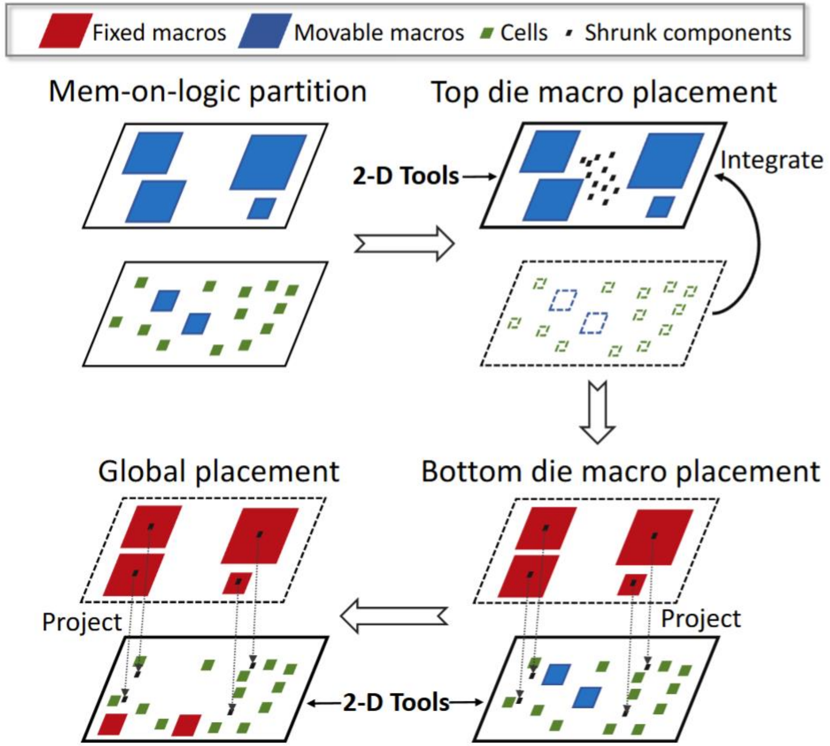


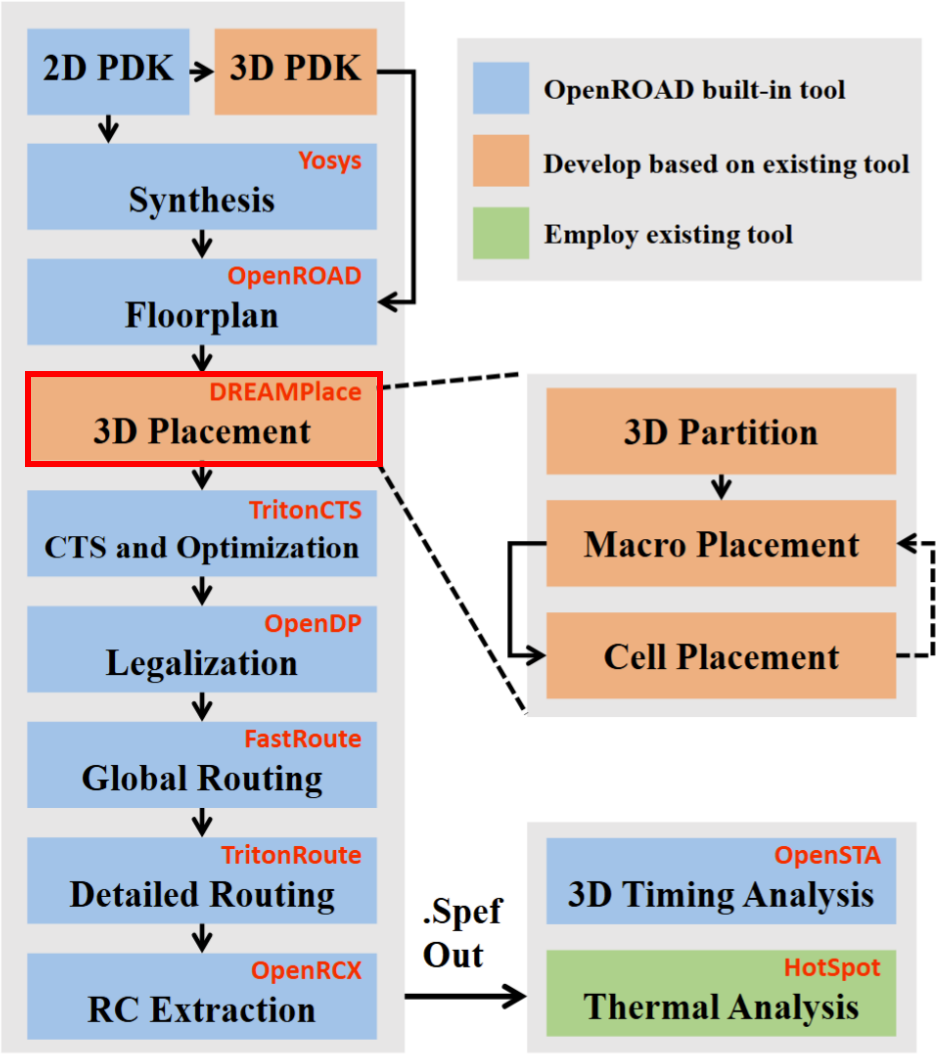
[1] Bamberg, Lennart, et al. "Macro-3D: A physical design methodology for face-to-face-stacked heterogeneous 3D ICs." DATE 2020.

What is Open3DBench?

- **3D Placement:**

  Adopt 2D DREAMPlace [1] for workaround

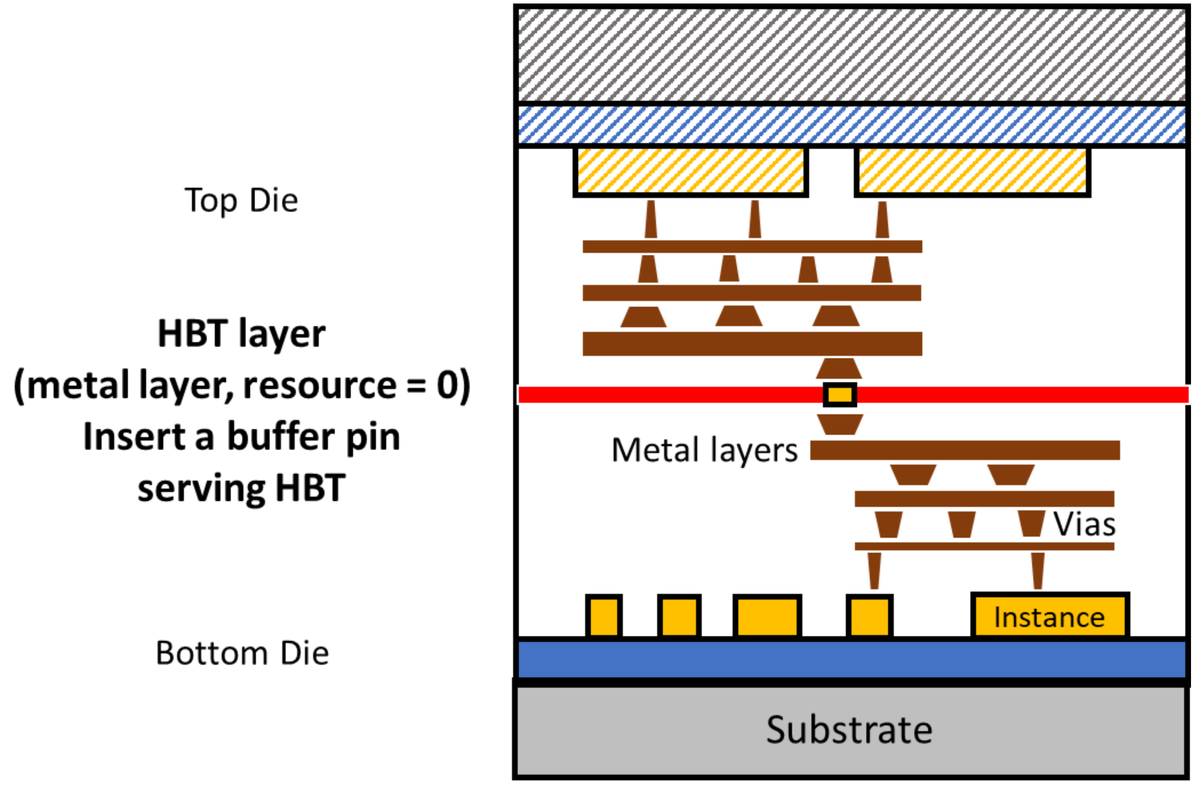


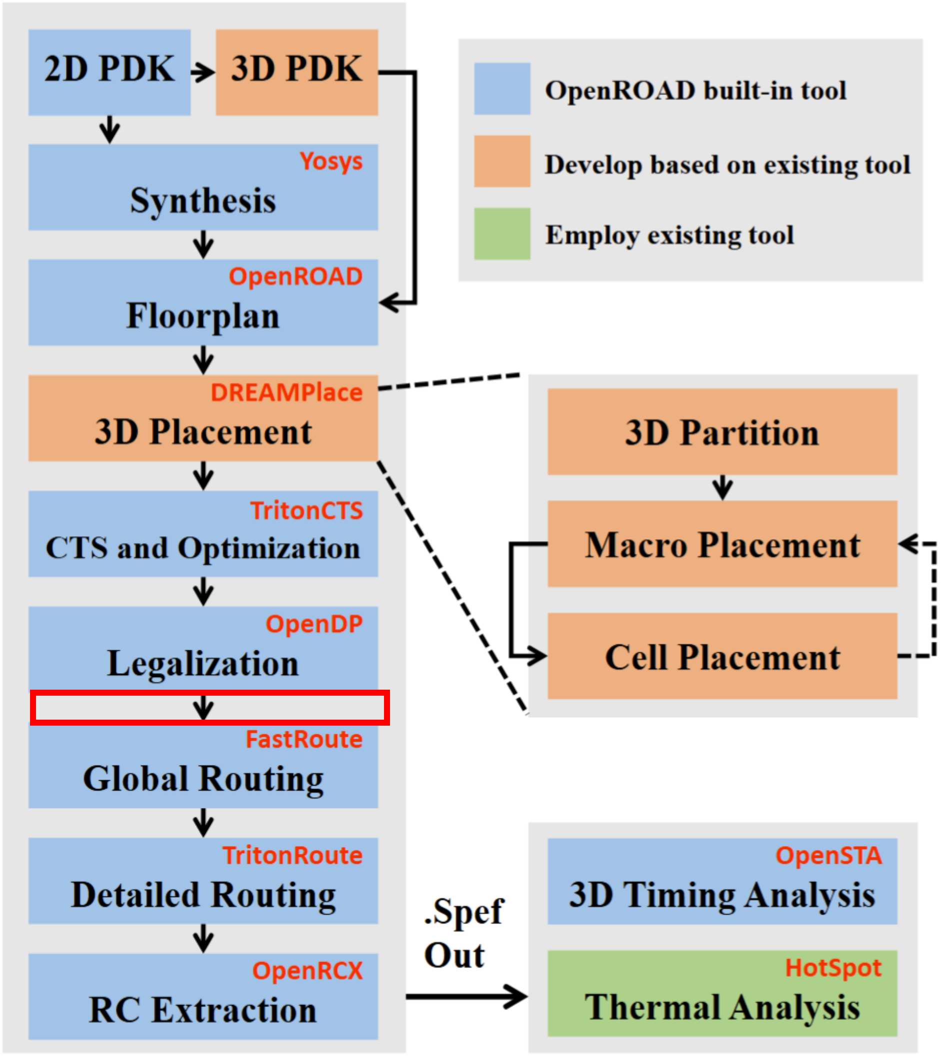


[1] Lin, Yibo, et al. "DREAMPlace: Deep learning toolkit-enabled GPU acceleration for modern VLSI placement." DAC 2019.

What is Open3DBench?

- **Hybrid Bonding Terminal (HBT)**

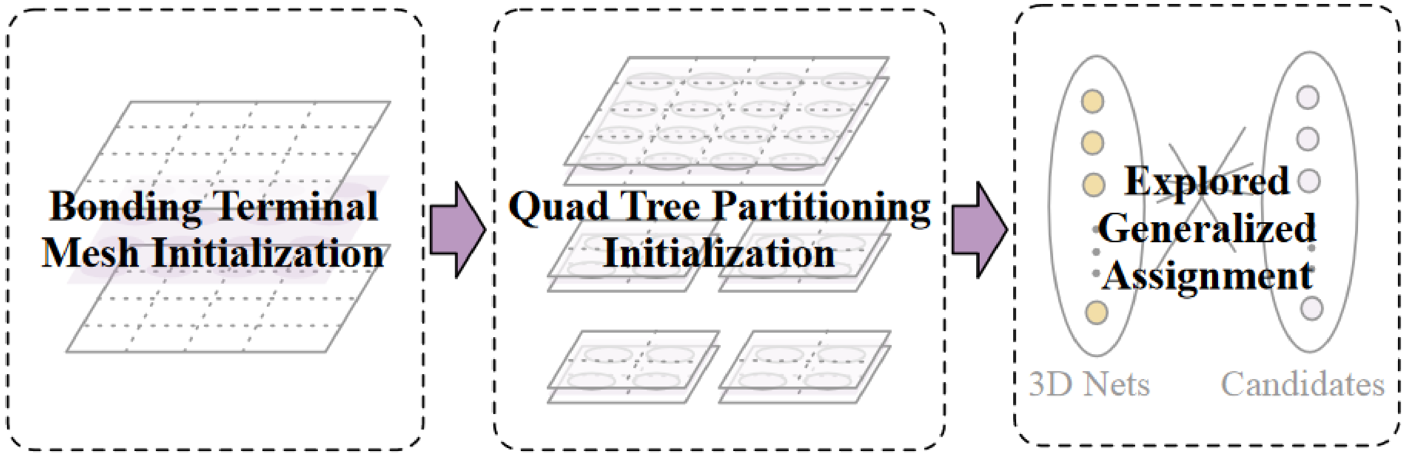


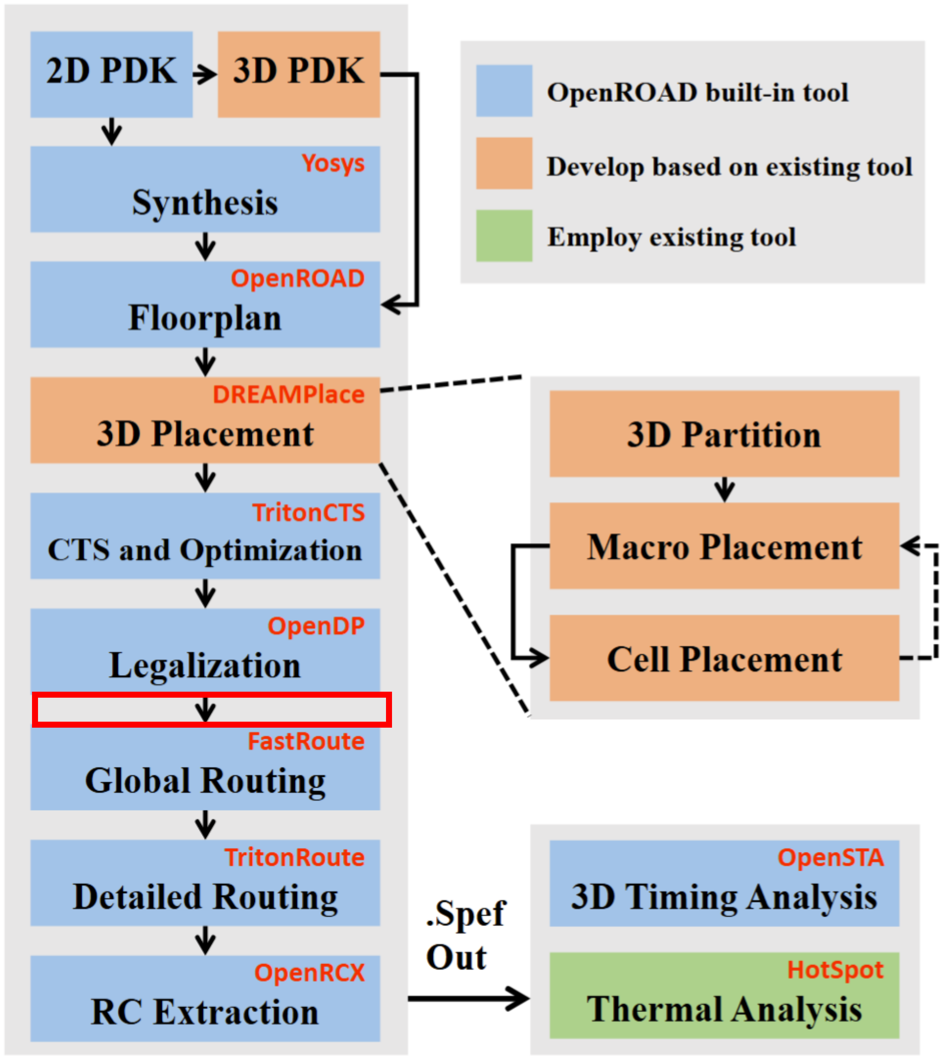


[1] Vanna-iampikul, Pruek, et al. "Placement-Aware 3D Net-to-Pad Assignment for Array-Style Hybrid Bonding 3D ICs. " ISPD 2025.

What is Open3DBench?

- **Hybrid Bonding Terminal (HBT)**





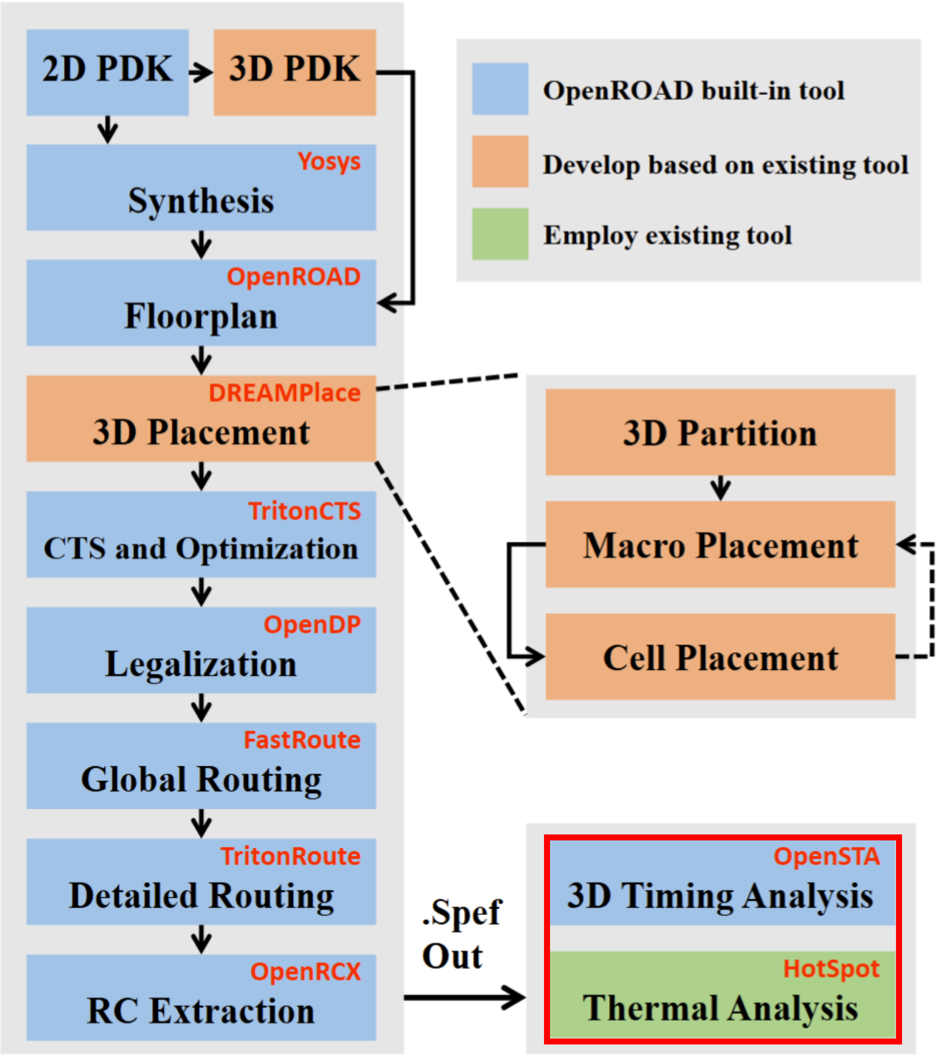
[1] Liu, Siting, et al. "Routing-aware legal hybrid bonding terminal assignment for 3D face-to-face stacked ICs." ISPD 2024.

What is Open3DBench?

- **PPA evaluation**

  Since we establish the whole design on a 2D vision, and have defined the 3D connections properly, the original 2D OpenSTA [1] can serve 3D timing analysis.

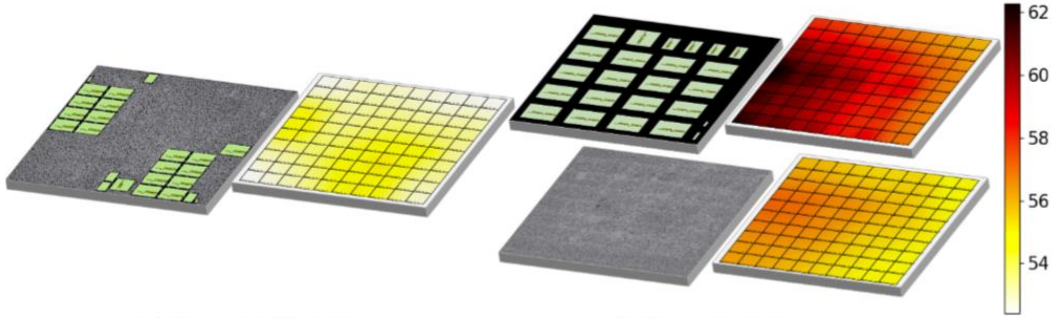
  HotSpot [2] supports 3D inherently.



[1] https://github.com/The-OpenROAD-Project/OpenSTA
[2] https://github.com/uvahotspot/HotSpot

What is Open3DBench?

- **Some evaluations**



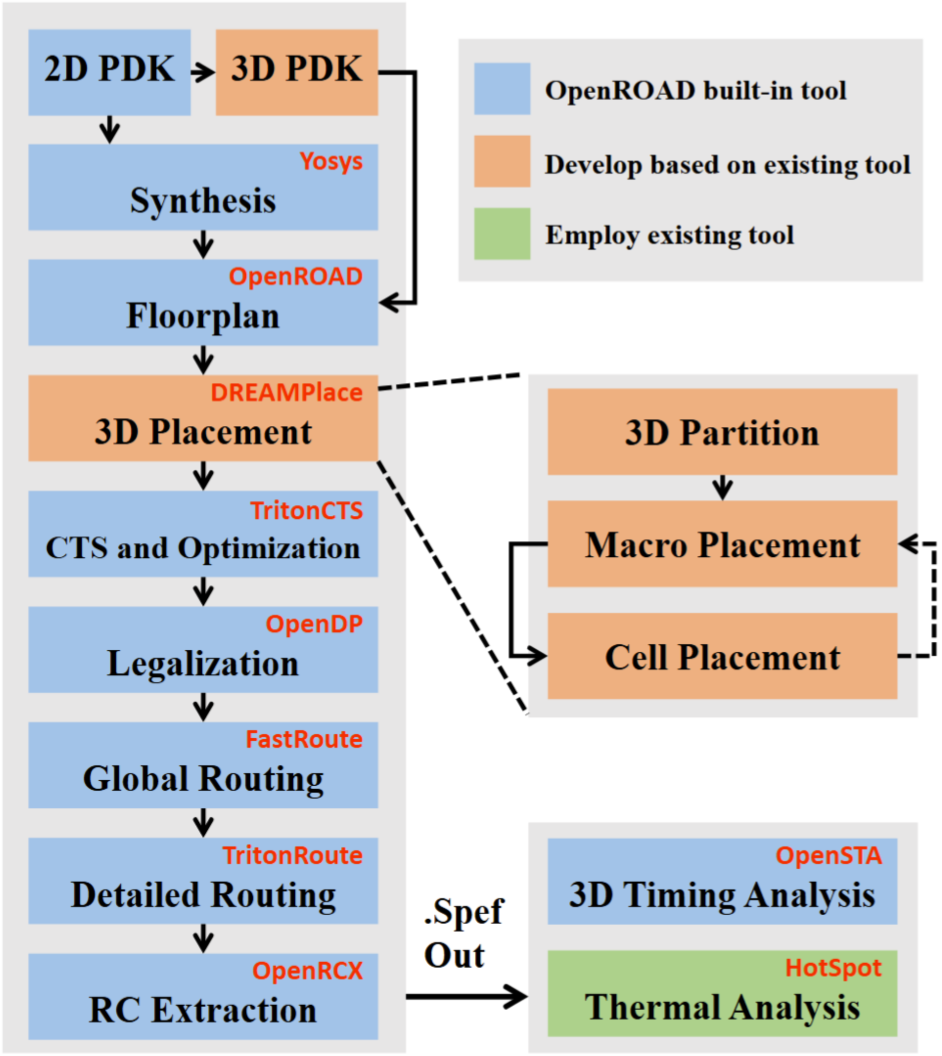
(a) Hier-RTLMP-2D
power = 0.40 w
T_{max} = **55.14 °C**

(b) Open3D-Tiling
power = **0.38 w**
$T_{max}(top)$ = 62.29 °C
$T_{max}(bottom)$ = 57.14 °C

Designs	Methods	Area (mm^2)	rWL (m)	Overflow (#)	WNS (ns)	TNS (ns)	Power (W)	T_{max} (°C)	Runtime (s)
ariane133	*Hier-RTLMP-2D*	2.25	8.20	132	-2.18	-5766.41	0.393	58.84	3667
	DREAMPlace-2D	2.25	7.18	112	-1.69	-4098.04	0.389	58.69	1556
	Open3D-Tiling	1.00	6.21	0	-1.40	-3049.41	**0.360**	58.35	1743
	Open3D-DMP	1.00	**5.59**	0	**-1.34**	**-2648.76**	**0.360**	58.21	1739
ariane136	*Hier-RTLMP-2D*	2.25	8.63	127	-2.51	-7072.67	0.514	63.40	1779
	DREAMPlace-2D	2.25	7.80	148	-2.71	-7561.23	0.508	61.14	1720
	Open3D-Tiling	1.00	6.32	0	**-2.38**	**-6125.24**	**0.471**	60.93	1791
	Open3D-DMP	1.00	**6.05**	0	-2.45	-6603.91	**0.471**	62.27	1870
black_parrot	*Hier-RTLMP-2D*	1.76	12.41	68	-6.96	-6289.17	0.398	55.14	1819
	DREAMPlace-2D	1.76	12.23	334	-6.57	-5268.85	0.399	55.26	1728
	Open3D-Tiling	0.81	8.08	0	-5.76	**-2251.30**	0.376	62.29	1895
	Open3D-DMP	0.81	**7.79**	0	**-5.67**	-4067.11	**0.374**	60.97	1920
bp_be	*Hier-RTLMP-2D*	0.56	3.00	30	-1.88	-523.27	0.152	52.63	1063
	DREAMPlace-2D	0.56	2.89	36	-1.30	-246.99	0.153	53.08	916
	Open3D-Tiling	0.30	**2.40**	0	-1.21	-188.86	**0.144**	61.17	998
	Open3D-DMP	0.30	2.42	0	**-0.89**	**-108.89**	**0.144**	59.11	1053
bp_fe	*Hier-RTLMP-2D*	0.48	1.81	6	-1.40	-942.36	0.302	64.09	449
	DREAMPlace-2D	0.48	1.73	30	-1.51	-978.59	0.305	63.62	239
	Open3D-Tiling	0.24	1.38	0	-1.53	**-729.42**	0.284	87.33	398
	Open3D-DMP	0.24	**1.30**	0	**-1.37**	-814.64	**0.283**	82.32	388
bp_multi	*Hier-RTLMP-2D*	1.21	6.20	36	-7.97	-12072.10	1.143	86.18	868
	DREAMPlace-2D	1.21	5.63	9	-8.30	-10946.20	1.126	85.50	760
	Open3D-Tiling	0.64	4.06	0	**-7.01**	**-9246.70**	1.062	112.09	883
	Open3D-DMP	0.64	**4.03**	0	-8.03	-9812.57	**1.050**	98.09	935
bp_quad	*Hier-RTLMP-2D*	12.96	46.63	3429	-3.66	-39020.00	**1.822**	66.05	8010
	DREAMPlace-2D	12.96	41.99	3968	-2.05	-31231.90	1.848	68.17	6336
	Open3D-Tiling	6.25	50.19	0	-2.62	-31124.70	1.840	69.78	7973
	Open3D-DMP	6.25	**40.39**	0	**-1.83**	**-26966.20**	1.832	66.96	7981
swerv_wrapper	*Hier-RTLMP-2D*	1.10	5.62	14428	-2.14	-1975.79	0.250	54.86	1175
	DREAMPlace-2D	1.10	5.54	9540	-1.86	-1429.90	0.254	53.48	1092
	Open3D-Tiling	0.56	3.63	0	-1.26	-972.80	**0.232**	62.17	2085
	Open3D-DMP	0.56	**3.46**	0	**-1.23**	**-958.01**	0.234	60.49	1744
3D improvements over 2D†		51.19%$\uparrow$	24.06%$\uparrow$	100%$\uparrow$	16.24%$\uparrow$	30.84%$\uparrow$	5.72%$\uparrow$	-10.04%$\downarrow$	-24.82%$\downarrow$
3D-DMP improvements over 3D-Tiling		Equal	5.96%$\uparrow$	Equal	7.22%$\uparrow$	-4.49%$\downarrow$	1.98%$\uparrow$	3.56%$\uparrow$	0.23%$\uparrow$

Limitations

- Heterogeneous
- TSV consideration
- 3D power distribution network
- 3D buffering & sizing
- …



Thank you!

Yunqi Shi
Nanjing University
Email: shiyq@lamda.nju.edu.cn

github:

arXiv: