ASP-DAC 2025

30th Asia and South Pacific Design Automation Conference

An MIP-based Force-directed Large Scale Placement Refinement Algorithm

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Outline

- Background and Related Works
- Algorithms
- Experiments
- Conclusion

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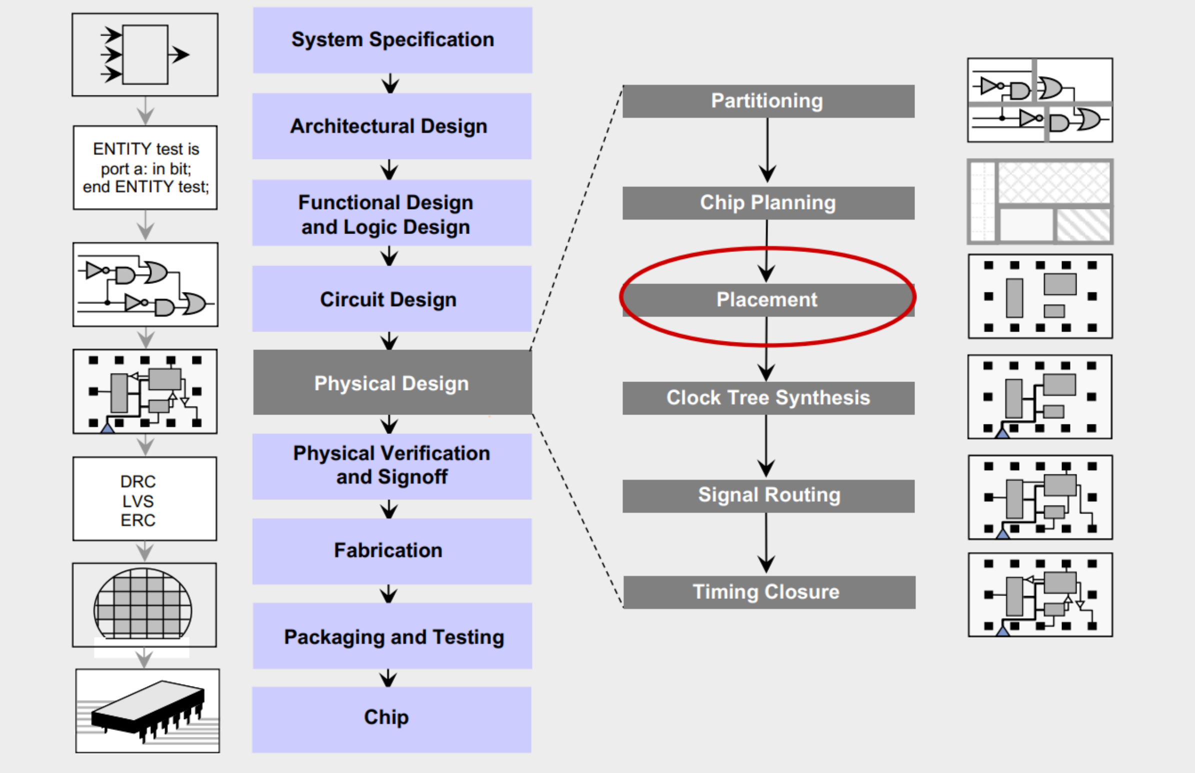
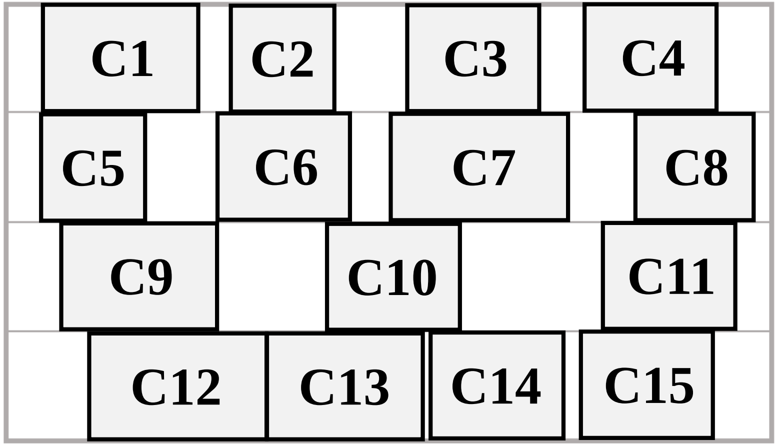
Background



ENTITY test is
port a: in bit;
end ENTITY test;
DRC
LVS
ERC
System Specification
Architectural Design
Functional Design and Logic Design
Circuit Design
Physical Design
Physical Verification and Signoff
Fabrication
Packaging and Testing
Chip
Partitioning
Chip Planning
Placement
Clock Tree Synthesis
Signal Routing
Timing Closure

Background

- Given an **initial placement**, move the standard cells again
- **Legality:** stay within bounds; no overlap; row/site alignment
- **Objective:** minimize total wirelength



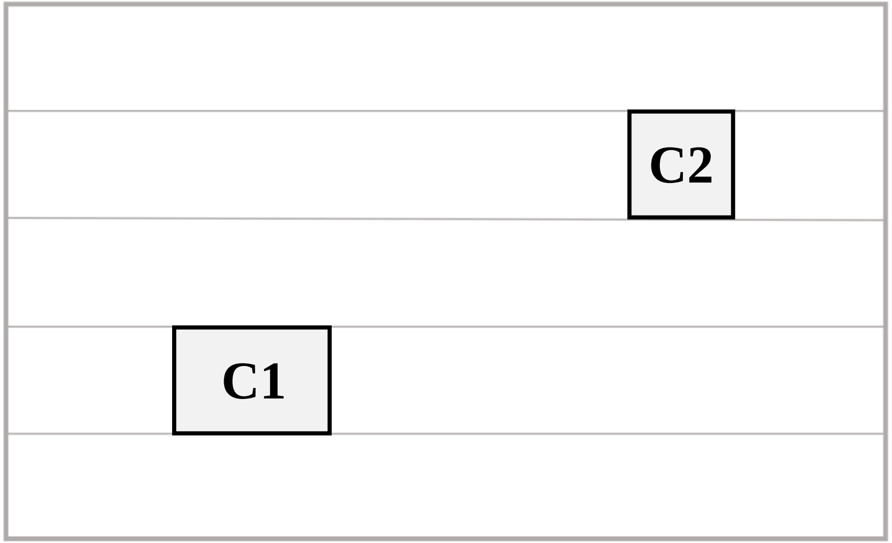
Background

- **Mixed Integer Programming (MIP)**
  - Linear programming with integer variables
  - Formulate the problem flexibly
  - Precise refinement

- **Challenges**
  - Too many integer variables slow down the speed
  - How to model wirelength? HPWL? RSMT?

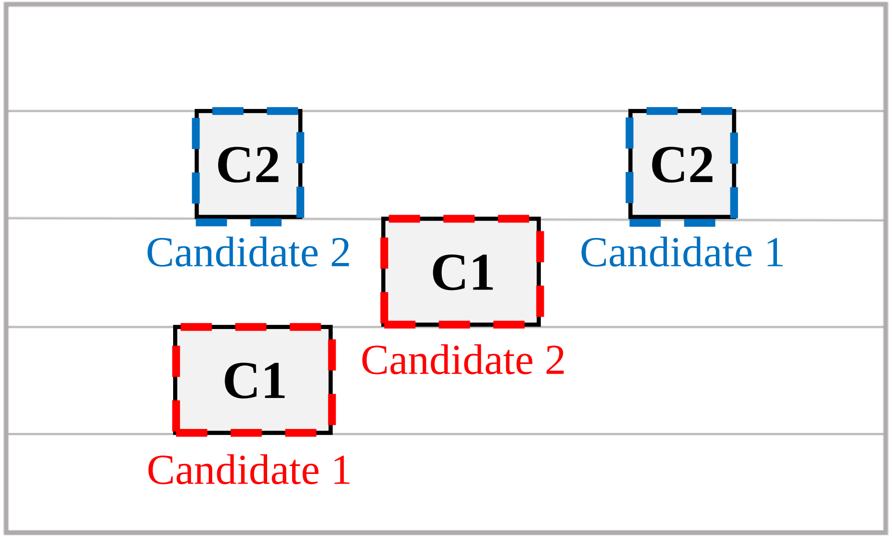
Related Work

- Every cell can move **everywhere** in the boundary.



Related Work

- **CRP**: generate discrete candidate positions for each cell



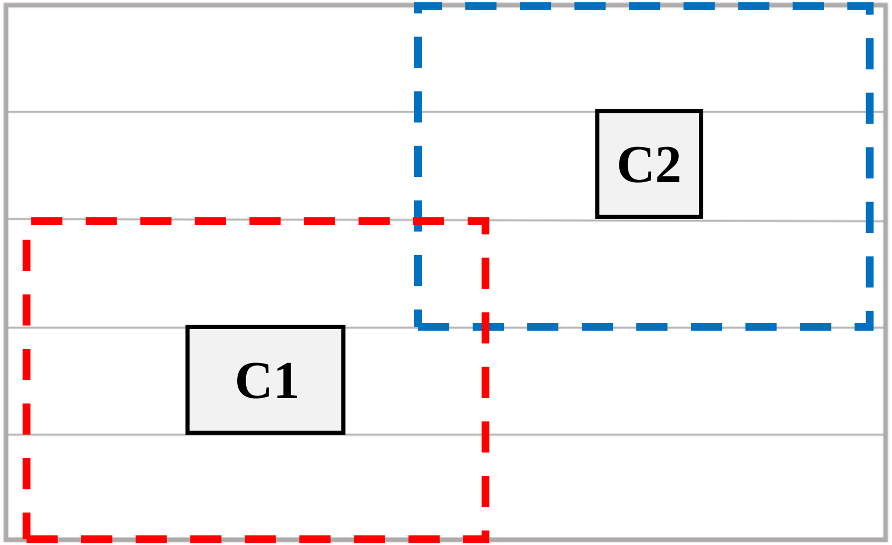
Too small search space

Limit the optimization level

[1] Erfan Aghaeekiasaraee et al. 2023. CRP2.0: A Fast and Robust Cooperation between Routing and Placement in Advanced Technology Nodes. ACM Transactions on Design Automation of Electronic Systems 28, 5 (2023), 1–42.

Related Work

- **Displacement**: generate a potential region for each cell



How to draw this region?

[2] Ke Tang et al. 2024. Mixed Integer Programming based Placement Refinement by RSMT Model with Movable Pins. ACM Transactions on Design Automation of Electronic Systems 29, 2 (2024), 1–18

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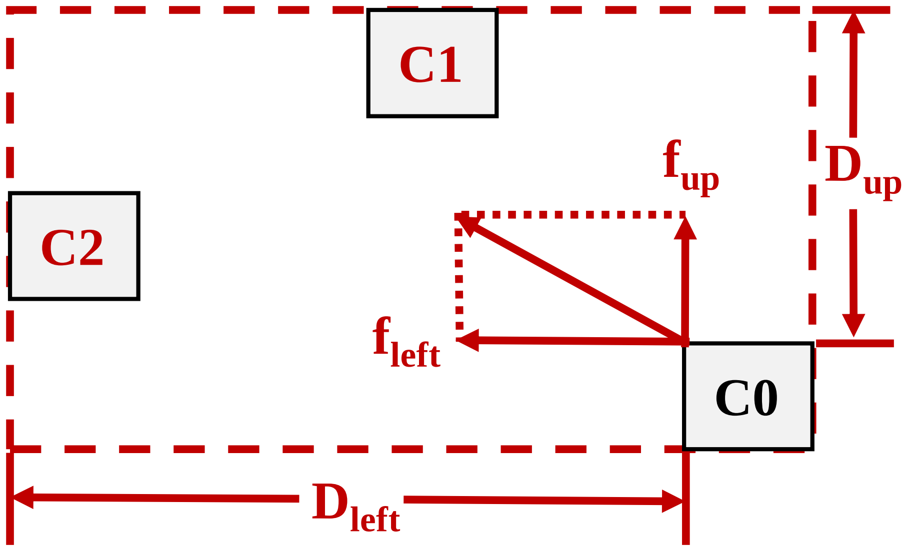
  - **Force-directed Potential Region Assignment**
  - **Centroid-based Wirelength Prediction**
- Experiments
- Conclusion

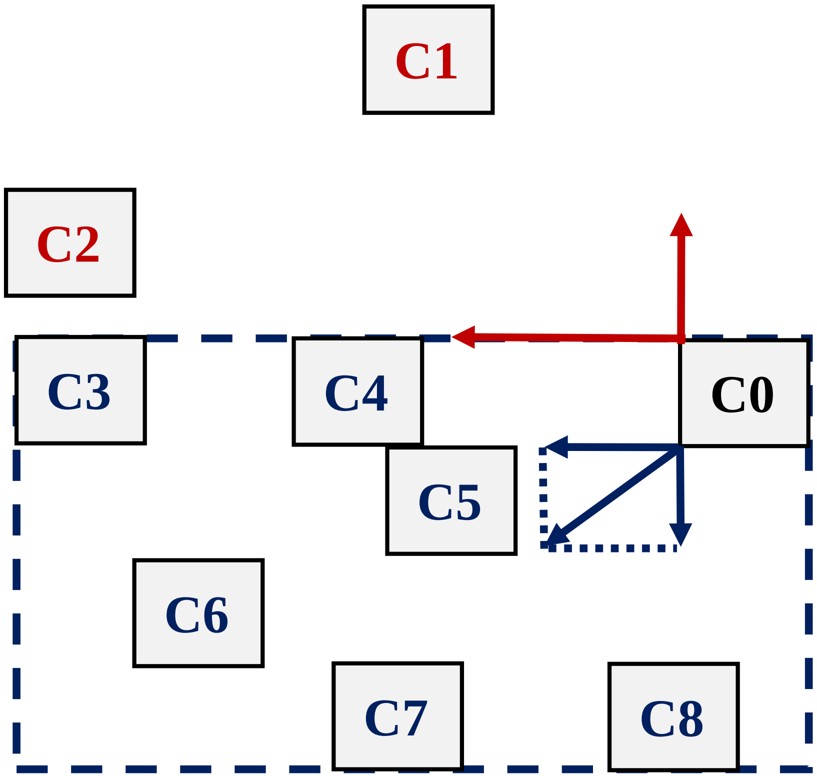
Force-directed Potential Region Assignment



Quantify the direction of force

- The force in each direction is proportional to the distance between this cell and the bounding box on this direction

Force-directed Potential Region Assignment



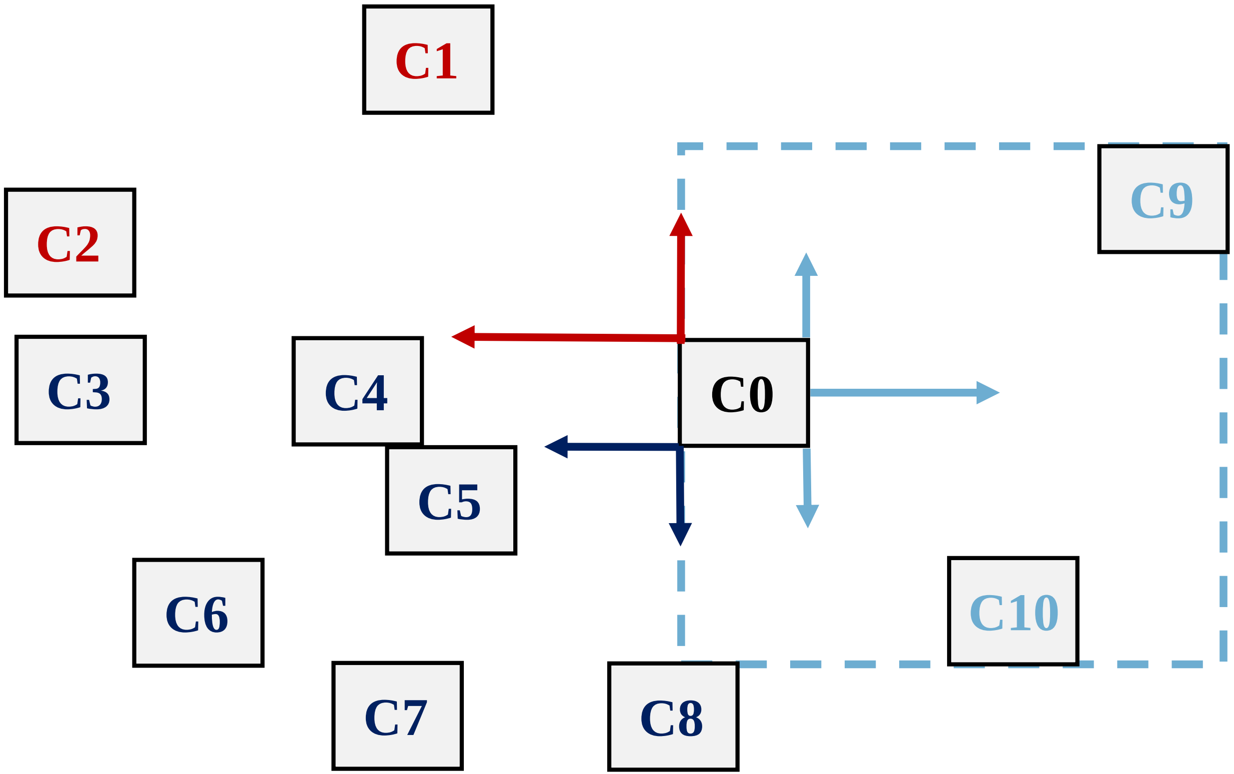
Higher density

Lower potential

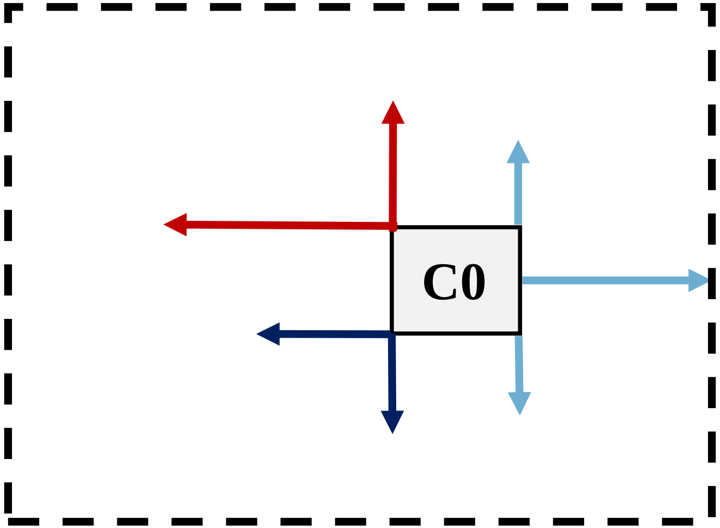
Smaller force

Quantify the magnitude of force

Force-directed Potential Region Assignment

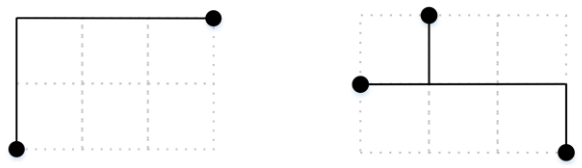


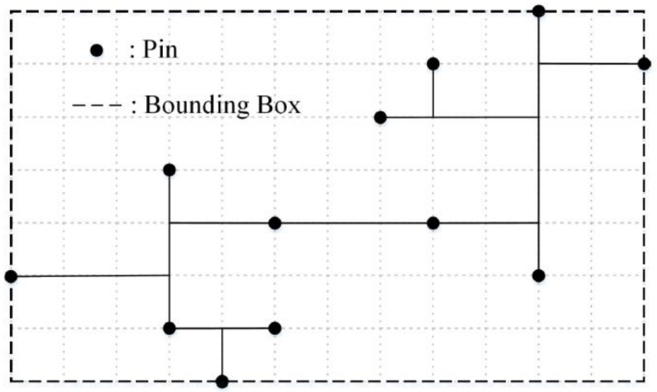
Force-directed Potential Region Assignment



- The **resultant force** forms the potential region

Centroid-based Wirelength Prediction





Objective Function

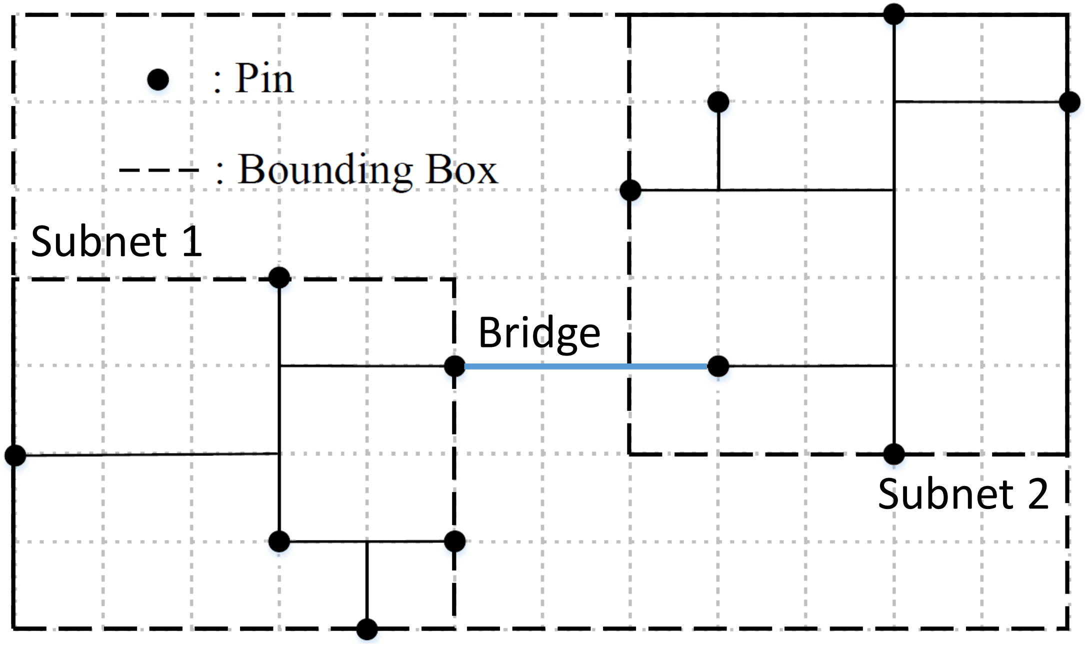
- HPWL is a popular choice
- Easy to calculate, but inaccurate especially in **high-degree nets**

$$wl_n = 27$$
$$HPWL_n = 12 + 7 = 19$$

- Inaccuracy comes from **neglecting** details inside the bounding box

Centroid-based Wirelength Prediction

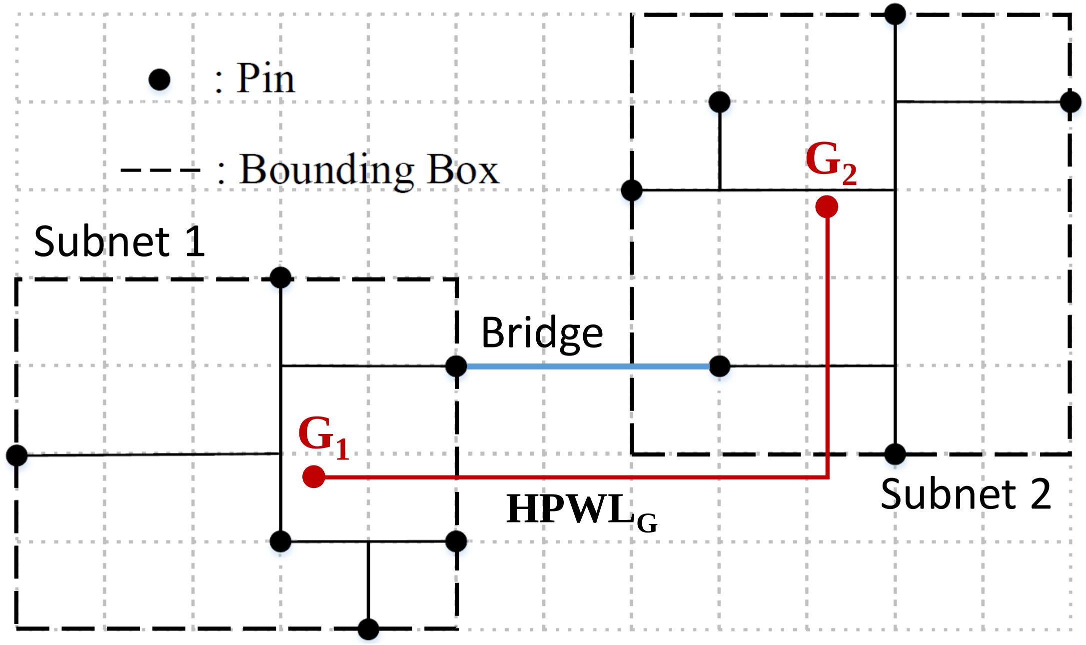
- Divide a high-degree net into subnets



$$wl_n = wl_{S_1} + wl_{S_2} + wl_{bridge}$$
$$= \mathbf{11} + \mathbf{13} + \mathbf{3} = 27$$

Centroid-based Wirelength Prediction

- **Centroid** is the geometric center of a subnet, noted as G

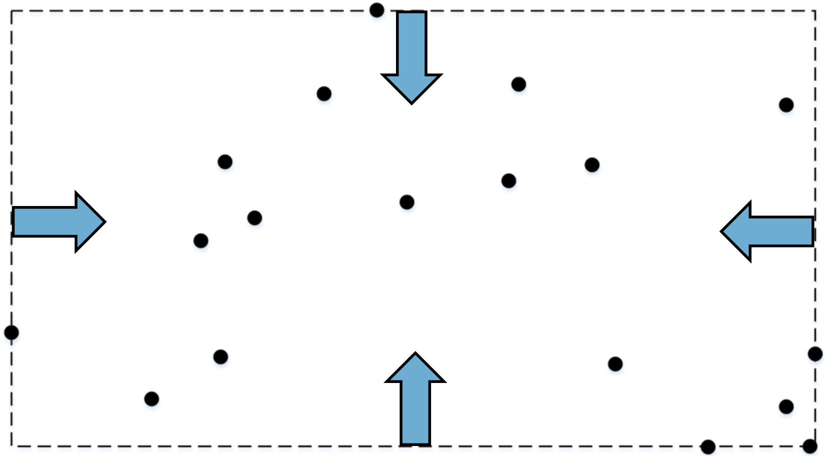


$$wl_n = wl_{S_1} + wl_{S_2} + wl_{bridge}$$
$$= \mathbf{11} + \mathbf{13} + \mathbf{3} = 27$$

$$\mathbf{WL}_n = \mathbf{HPWL}_{S_1} + \mathbf{HPWL}_{S_2} + \mathbf{HPWL}_G$$
$$= \mathbf{9} + \mathbf{10} + \mathbf{8.83} = \mathbf{27.83}$$

Centroid-based Wirelength Prediction

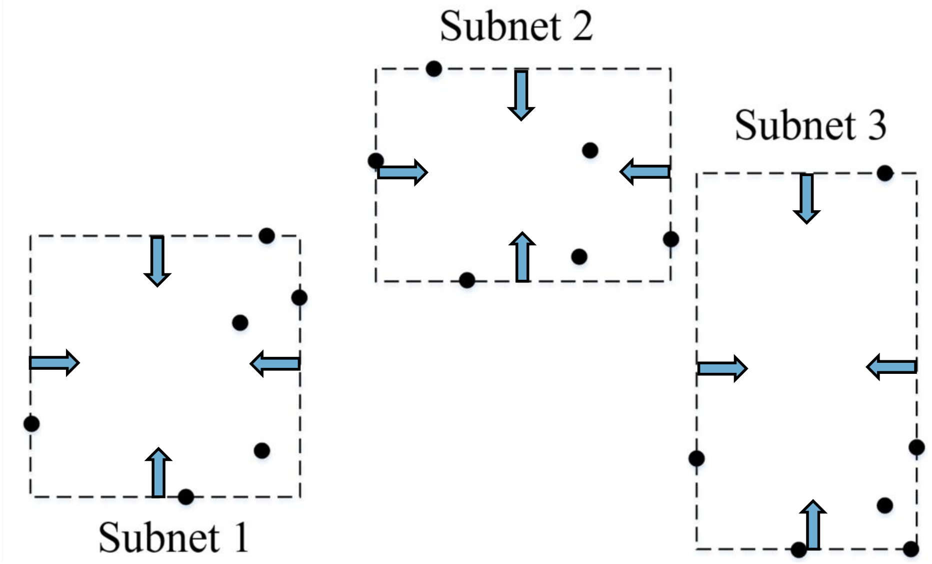
$$\mathbf{WL}_n = HPWL_{\mathrm{n}} \quad \Rightarrow \quad \mathbf{WL}_n = \sum_{\boldsymbol{S_i \in n}} HPWL_{\boldsymbol{S_i}} + HPWL_{\boldsymbol{G}}$$



$\boldsymbol{HPWL_n}$ only encourages the cells on the boundary to move inward

Centroid-based Wirelength Prediction

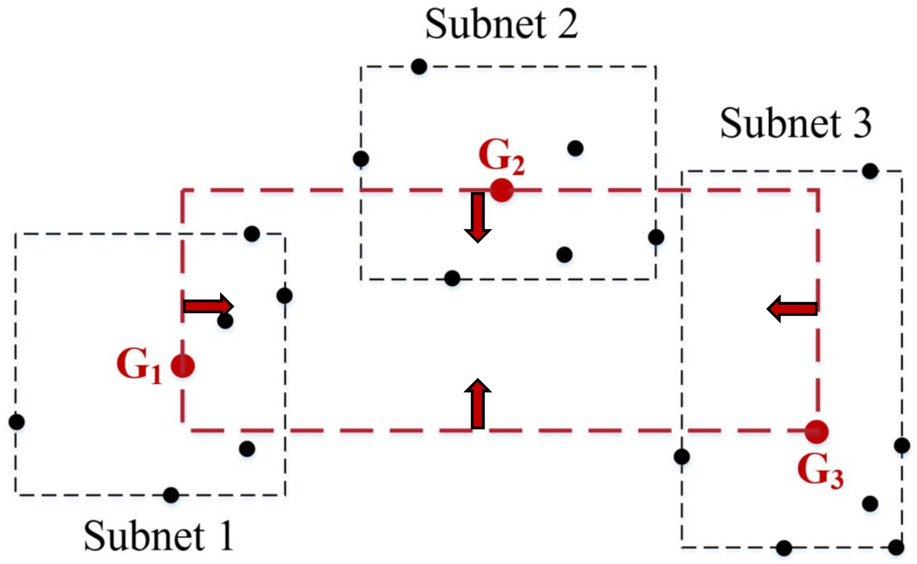
$$\mathbf{WL}_n = HPWL_{\mathrm{n}} \quad \Rightarrow \quad \mathbf{WL}_n = \sum_{S_i \in n} HPWL_{S_i} + HPWL_{G}$$



- $\sum_{S_i \in n} \boldsymbol{HPWL_{S_i}}$ promotes the shrinking of each subnet

Centroid-based Wirelength Prediction

$$\mathbf{WL}_n = HPWL_{\mathrm{n}} \quad \Rightarrow \quad \mathbf{WL}_n = \sum_{\boldsymbol{S_i \in n}} HPWL_{\boldsymbol{S_i}} + HPWL_{\boldsymbol{G}}$$



- $\sum_{\boldsymbol{S_i \in n}} \boldsymbol{HPWL_{S_i}}$ promotes the shrinking of each subnet
- $\boldsymbol{HPWL_G}$ encourages subnets to approach each other

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Experimental Settings

- **Baseline:** CRP2.0
- **Benchmark:** ISPD 2018 and ISPD 2019
- **Benchmark Information**
  - Maximum Degree (MD)
  - Average Degree (AD)
  - Ratio of high-degree nets (R-h)
  - Placement Density (PD)
- **Use Gurobi as the MIP solver and Placement Metrics are from CUGR**

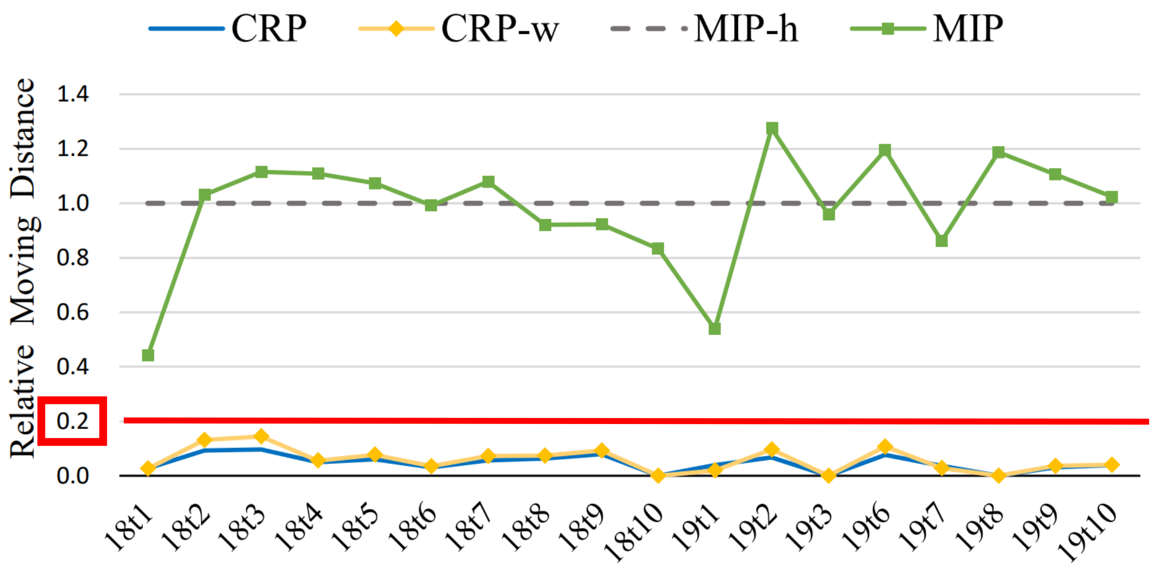
Comparison between Objective Functions

- **MIP** is our algorithm
- **MIP-h** sets HPWL as the objective function

		ISPD18										ISPD19								Avg.
		test1	test2	test3	test4	test5	test6	test7	test8	test9	test10	test1	test2	test3	test6	test7	test8	test9	test10	
Info	#Cell	9k	36k	36k	72k	72k	108k	180k	192k	192k	290k	9k	72k	8k	180k	360k	540k	899k	899k	231k
	#Net	3k	37k	37k	72k	72k	108k	180k	180k	179k	182k	3k	72k	9k	180k	359k	538k	895k	895k	222k
	#Macro	0	0	4	0	0	0	16	16	0	0	0	4	4	16	16	16	16	16	7
	Time (s)	0.9k	3.6k	3.6k	6.4k	6.4k	10k	16.9k	19.6k	19.6k	28.9k	0.9k	6.4k	0.9k	16.9k	36.1k	52.9k	90k	90k	22.8k
	MD	66	181	277	458	554	459	1108	1108	724	724	66	458	130	1108	1832	2556	2556	2556	940
	AD	**5.46**	4.29	4.32	4.38	4.38	4.40	4.40	4.40	4.42	4.45	**5.46**	4.38	3.37	4.40	4.41	4.41	4.42	4.42	4.45
	R-h (%)	**9.29**	5.01	5.02	5.10	5.10	5.14	5.17	5.17	5.20	5.14	**9.29**	5.10	4.76	5.17	5.19	5.19	5.20	5.20	5.58
	PD (%)	85	57	65	89	92	99	90	90	91	100	83	72	84	75	96	79	84	88	84
#Via (%)	MIP-h	-0.67	1.50	2.50	1.41	0.54	-0.05	1.04	1.19	0.80	0.12	-1.19	0.49	1.23	1.69	0.21	0.82	0.77	0.63	0.72
	MIP	-0.16	1.38	2.16	1.09	0.36	-0.14	0.69	0.88	0.59	0.05	-0.62	0.14	1.09	1.36	0.12	0.49	0.52	0.41	0.58
HPWL (%)	MIP-h	0.83	3.91	3.60	1.42	0.97	0.30	1.43	1.37	1.52	0.22	0.88	2.47	2.43	3.40	0.80	2.49	2.29	1.64	1.78
	MIP	0.42	3.32	3.25	1.22	0.83	0.21	1.24	1.07	1.20	0.13	0.63	2.34	2.23	3.20	0.57	2.28	2.01	1.37	1.53
WL (%)	MIP-h	0.01	1.71	1.59	0.89	0.45	0.16	0.83	0.82	0.93	0.08	-0.38	1.31	2.16	2.25	0.29	1.47	1.39	0.95	0.94
	MIP	0.15	1.75	1.67	0.84	0.44	0.11	0.84	0.75	0.85	0.09	0.24	1.54	1.93	2.48	0.27	1.64	1.49	1.04	1.02

Comparison with Previous Work

- **CRP** is comprehensive mode
- **CRP-w** is the wirelength-only mode of **CRP**



Comparison with Previous Work

		ISPD18										ISPD19								Avg.
		test1	test2	test3	test4	test5	test6	test7	test8	test9	test10	test1	test2	test3	test6	test7	test8	test9	test10	
Info	#Cell	9k	36k	36k	72k	72k	108k	180k	192k	192k	290k	9k	72k	8k	180k	360k	540k	899k	899k	231k
	#Net	3k	37k	37k	72k	72k	108k	180k	180k	179k	182k	3k	72k	9k	180k	359k	538k	895k	895k	222k
	#Macro	0	0	4	0	0	0	16	16	0	0	0	4	4	16	16	16	16	16	7
	Time (s)	0.9k	3.6k	3.6k	6.4k	6.4k	10k	16.9k	19.6k	19.6k	28.9k	0.9k	6.4k	0.9k	16.9k	36.1k	52.9k	90k	90k	22.8k
	MD	66	181	277	458	554	459	1108	1108	724	724	66	458	130	1108	1832	2556	2556	2556	940
	AD	5.46	4.29	4.32	4.38	4.38	4.40	4.40	4.40	4.42	4.45	5.46	4.38	3.37	4.40	4.41	4.41	4.42	4.42	4.45
	R-h (%)	9.29	5.01	5.02	5.10	5.10	5.14	5.17	5.17	5.20	5.14	9.29	5.10	4.76	5.17	5.19	5.19	5.20	5.20	5.58
	PD (%)	85	57	65	89	92	99	90	90	91	100	83	72	84	75	96	79	84	88	84
#Via (%)	CRP	0.31	-0.01	1.28	0.40	0.31	-0.01	0.42	0.32	0.36	0.00	17.61	-0.02	-15.80	14.43	-1.83	13.31	13.66	-0.17	2.48
	CRP-w	0.12	-0.38	0.50	0.21	0.17	-0.06	0.24	0.19	0.21	0.00	17.48	-0.35	-15.80	14.18	-1.88	13.31	13.59	-0.27	2.30
	MIP	-0.16	1.38	2.16	1.09	0.36	-0.14	0.69	0.88	0.59	0.05	-0.62	0.14	1.09	1.36	0.12	0.49	0.52	0.41	0.58
HPWL (%)	CRP	0.02	0.04	0.10	-0.02	0.00	0.00	0.02	0.02	0.03	0.00	0.00	-0.01	0.00	0.15	0.00	0.00	0.03	0.02	0.02
	CRP-w	0.04	-0.04	0.06	0.01	-0.01	-0.01	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.18	0.01	0.00	0.04	0.04	0.02
	MIP	0.42	3.32	3.25	1.22	0.83	0.21	1.24	1.07	1.20	0.13	0.63	2.34	2.23	3.20	0.57	2.28	2.01	1.37	1.53
WL (%)	CRP	0.08	-0.10	0.23	0.09	0.14	0.00	0.21	0.17	0.21	0.00	1.19	0.81	-0.45	1.48	0.19	0.67	0.90	0.74	0.36
	CRP-w	0.22	-0.05	0.06	0.12	0.15	0.02	0.16	0.13	0.14	0.00	1.30	0.86	-0.45	1.52	0.22	0.67	0.89	0.80	**0.37**
	MIP	0.15	1.75	1.67	0.84	0.44	0.11	0.84	0.75	0.85	0.09	0.24	1.54	1.93	2.48	0.27	1.64	1.49	1.04	**1.02**

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Conclusion

- A force-directed algorithm is developed to prune the problem, presenting a new perspective to assign potential regions
- A new fast wirelength prediction method is proposed to measure high-degree nets more accurately
- The proposed algorithm is able to reduce wirelength by 1.02% on average and outperforms the state-of-the-art related work in wirelength optimization under both its comprehensive mode and wirelength-only mode

Thanks for Listening!

If You Have any Question, Please Contact Us at

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