An MILP-Based Wire Spreading Algorithm for PSM-Aware Layout Modification

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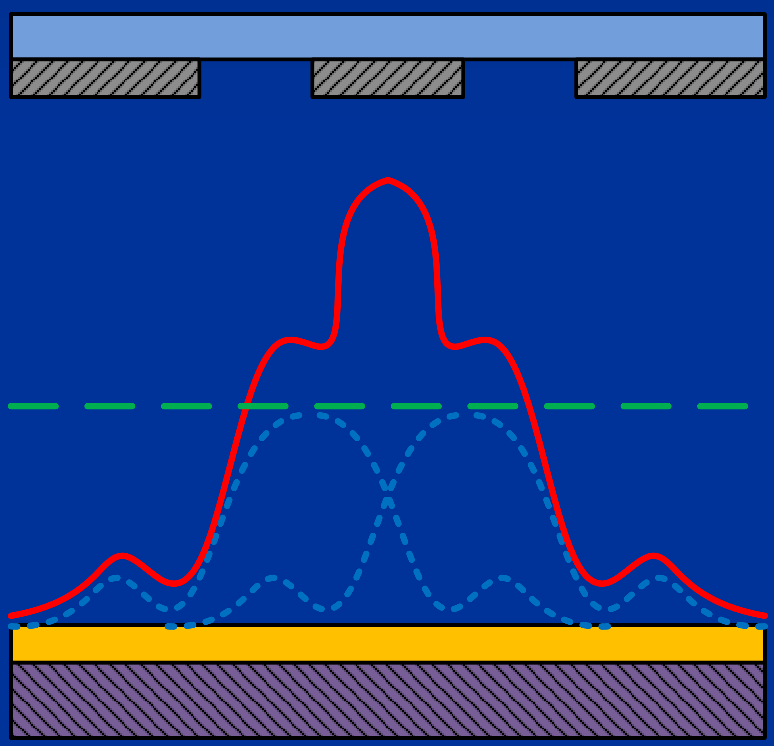
Outline

- Introduction
- Motivation
- Algorithm
- Experimental results
- Conclusion

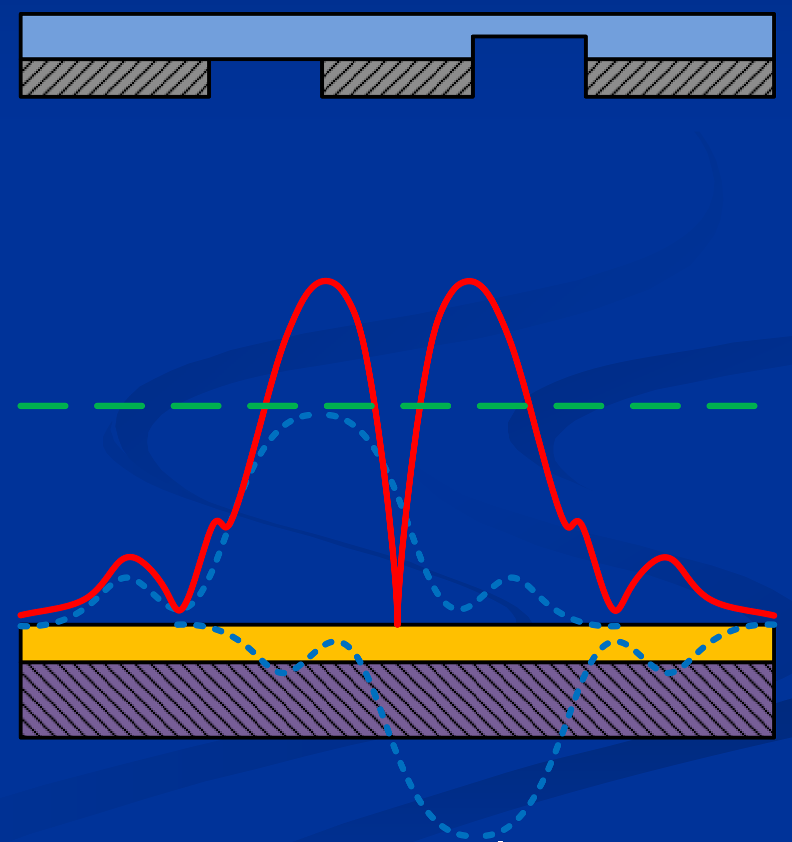
Introduction

- Deep sub-micron lithograph has almost reached physical limit of optics.
- To achieve better image quality, various resolution enhancement techniques are used by VLSI industries, such as OPC, PSM and immersion lithography.
- Although PSM shows great potential in resolution enhancement, a layout must compliant to the phase assignment constraint.

Introduction

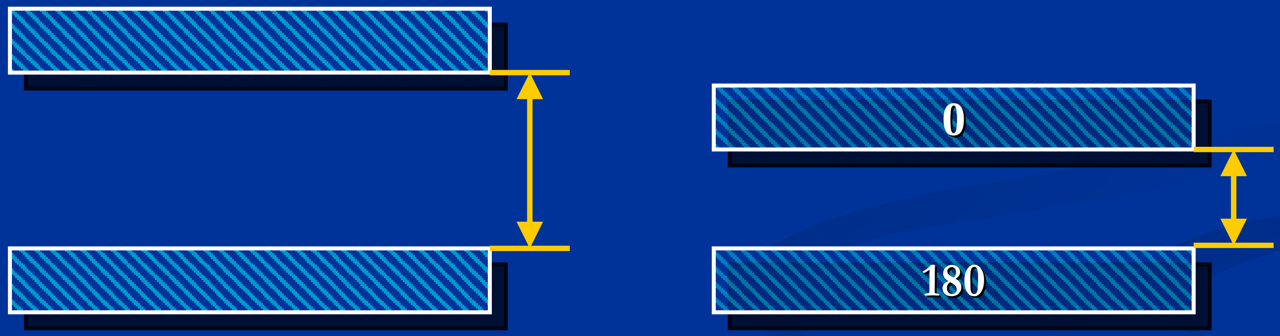


Conventional mask



PSM mask

Introduction



Conventional tech.
In-phase

altPSM tech.
opposite phases

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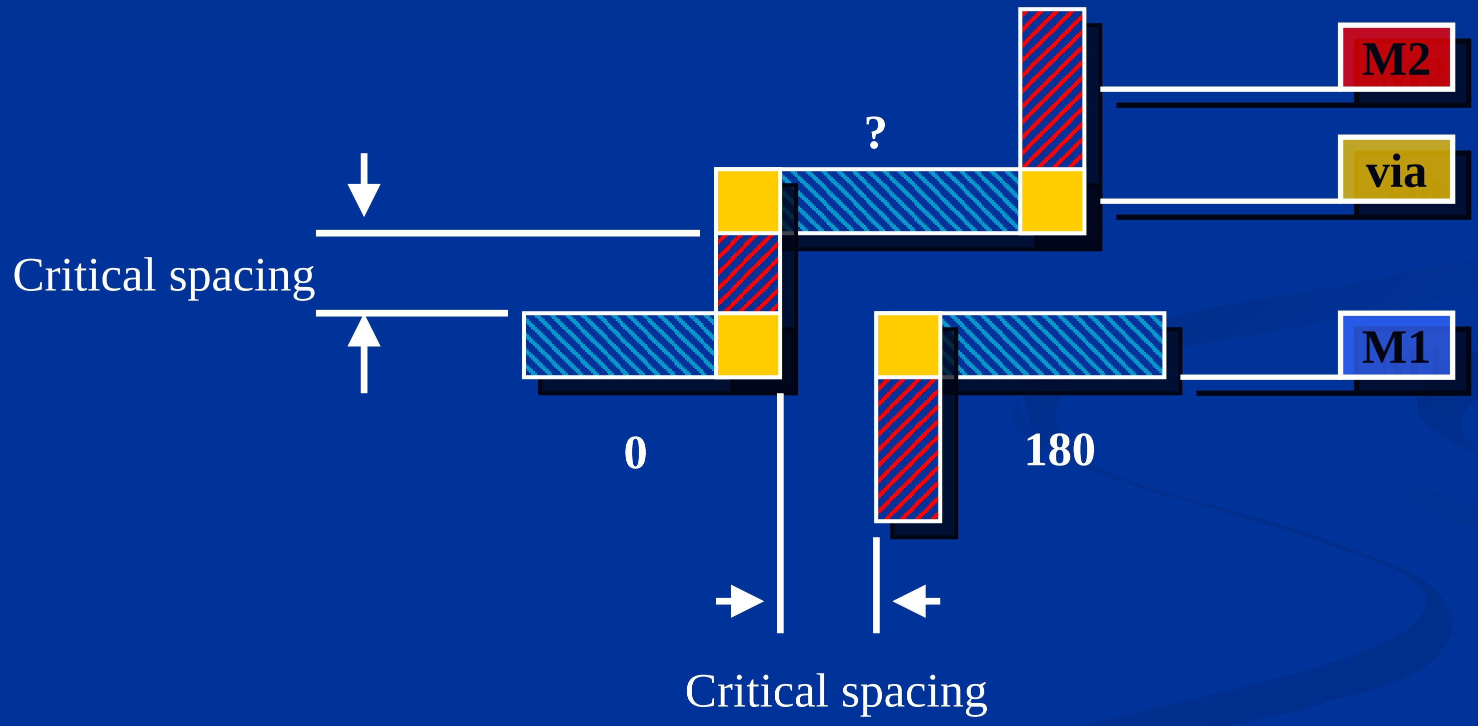
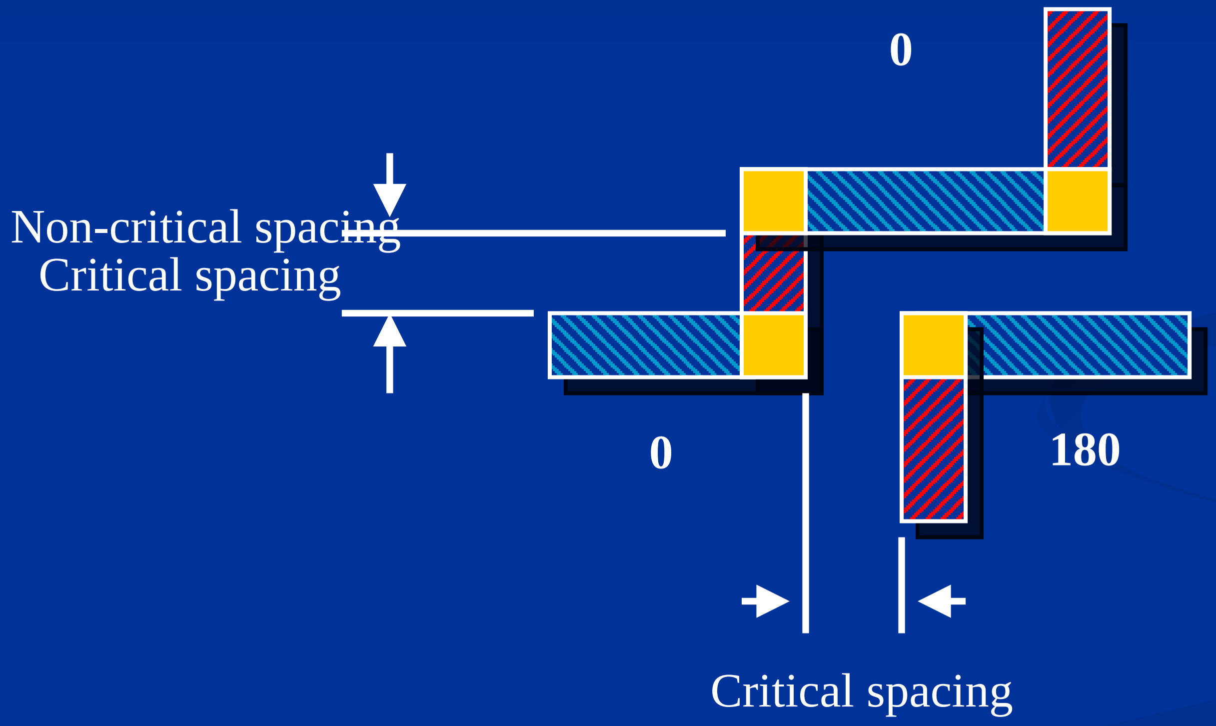
Motivation



Motivation


0
Non-critical spacing
Critical spacing
0
180
Critical spacing

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  - Preliminaries
  - Problem formulation
  - MILP approach
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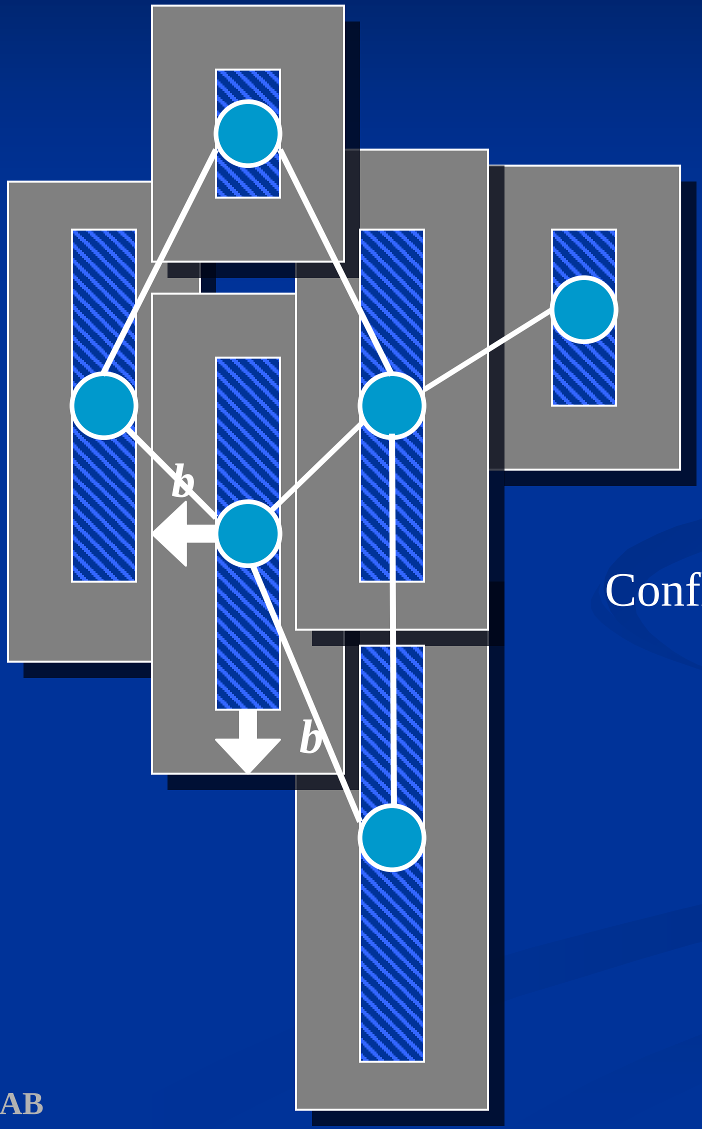
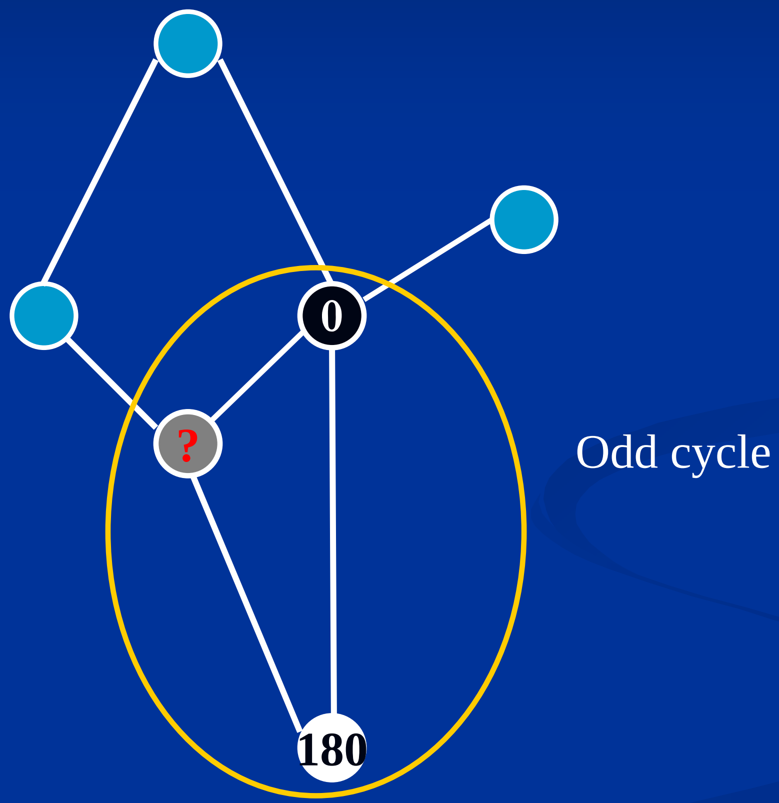
Preliminaries

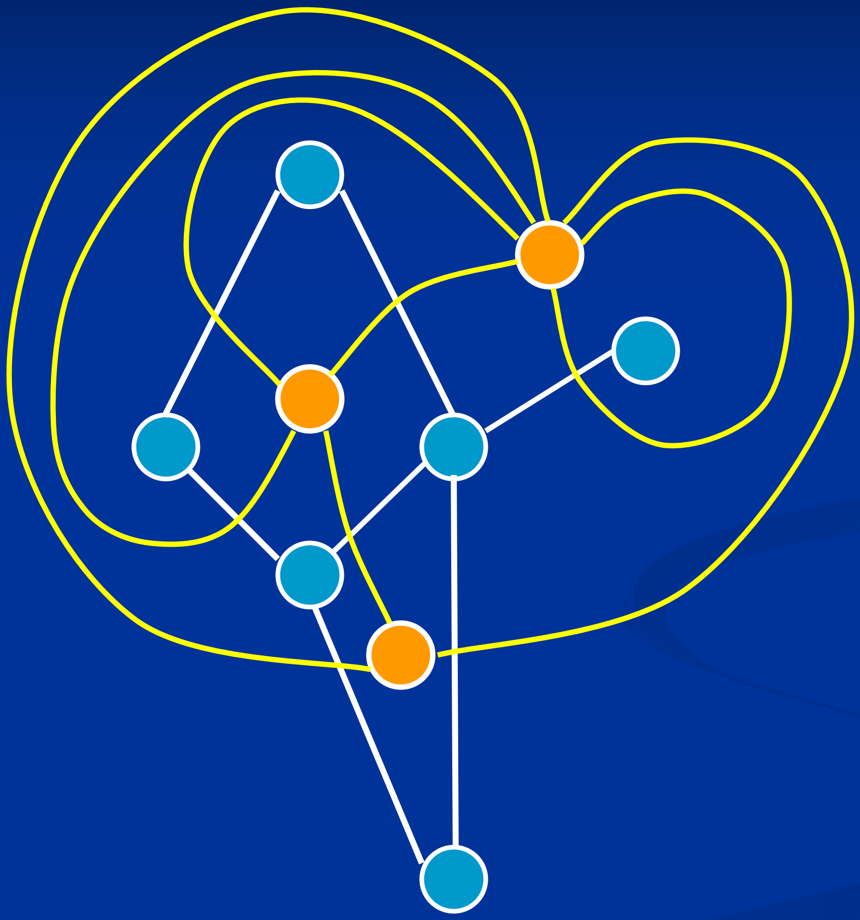


Conflict graph

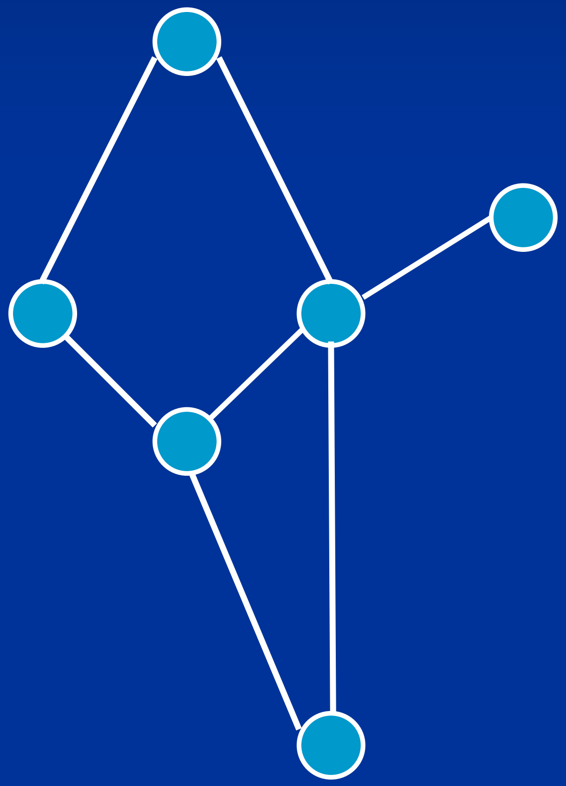
Prelimiaries

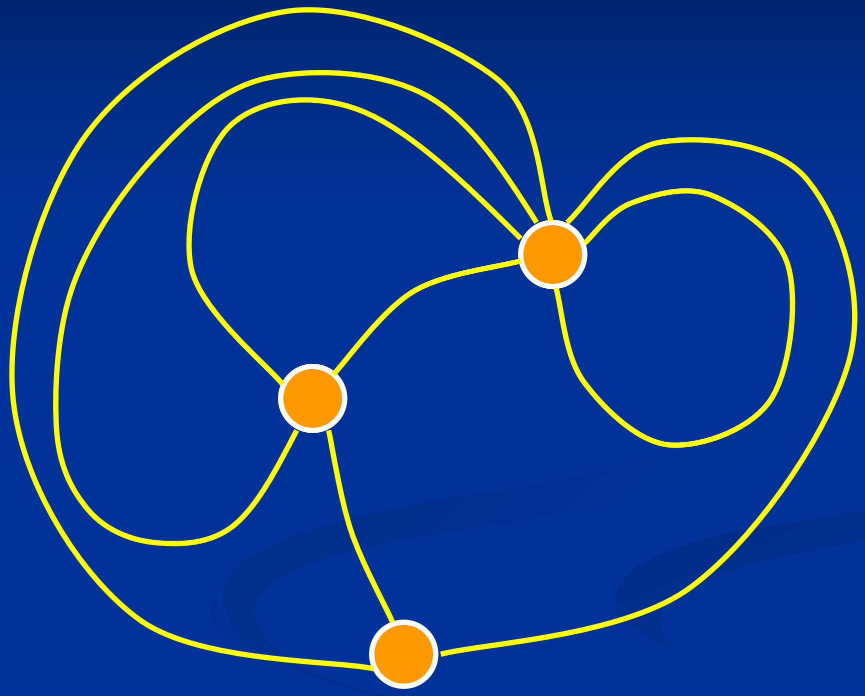


Preliminaries

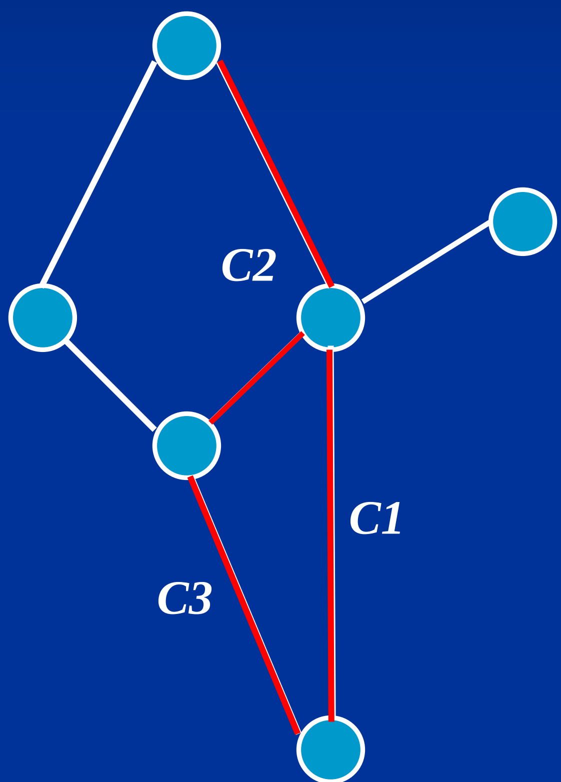


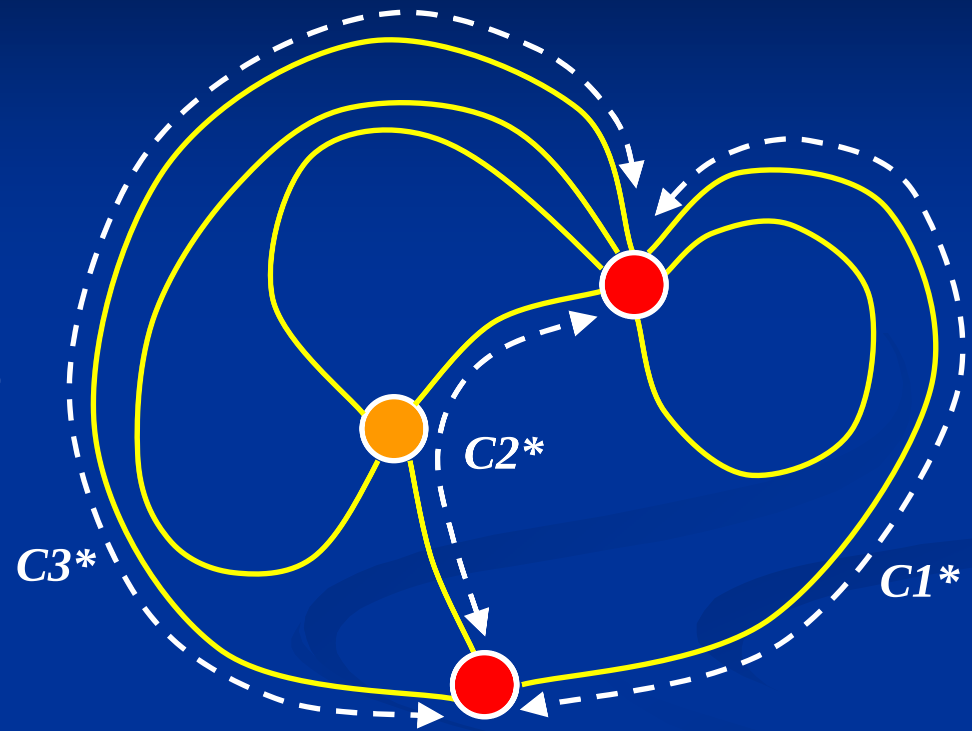
Preliminaries



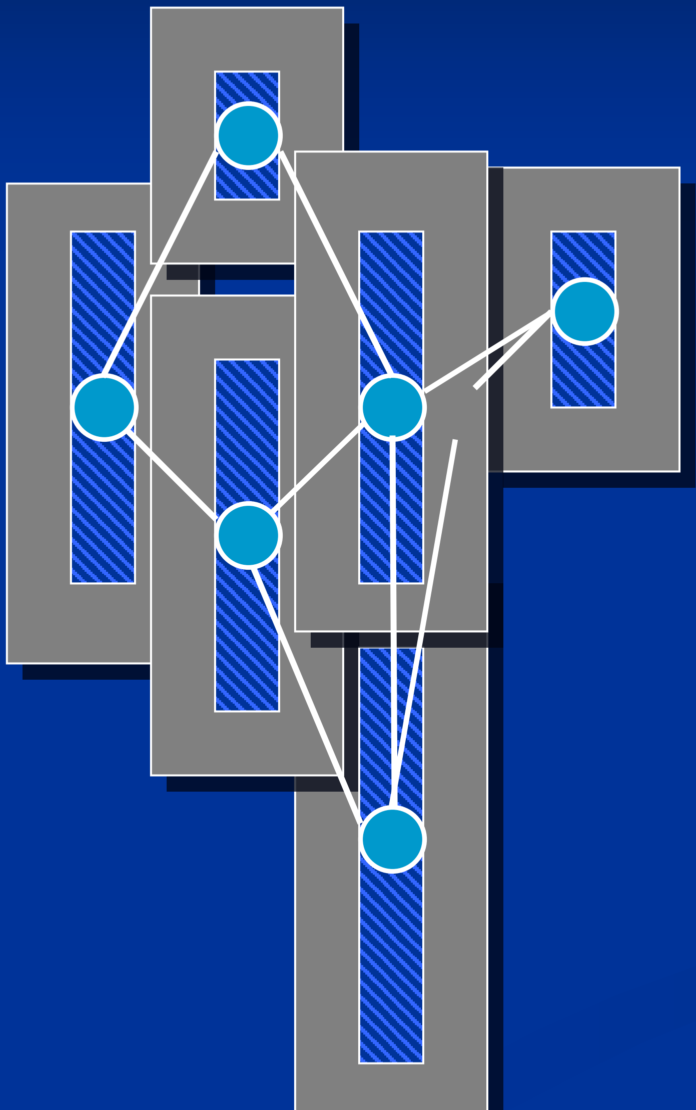


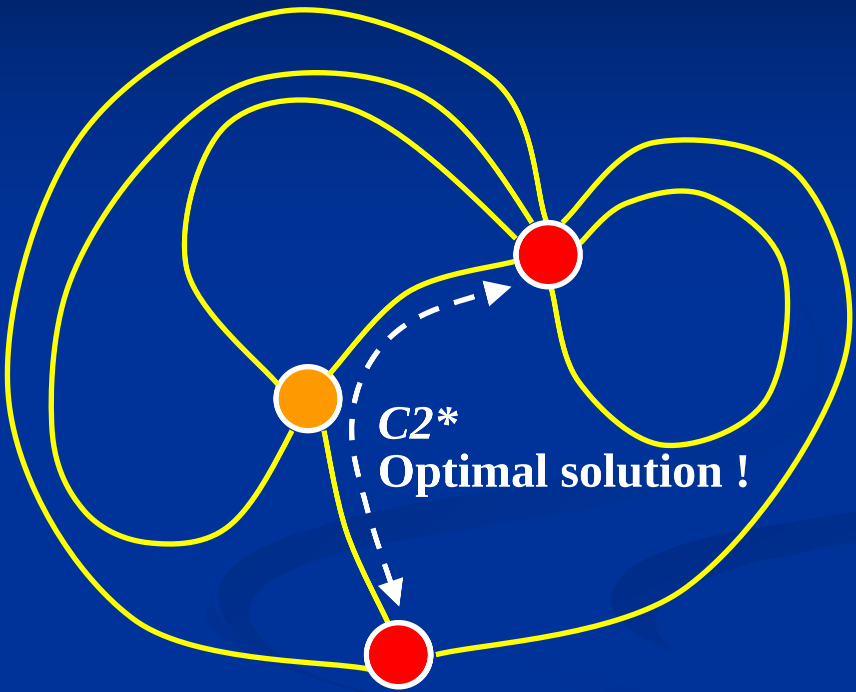
Preliminaries





Prelimiaries





Problem formulation

- Candidate removal set problem:

  Given an *n*-layer layout, this problem asks for finding a candidate removal set and a corresponding feasible wire spreading solution such that the guaranteed reduce in number of odd faces is maximized and the induced deviation is minimized.

MILP approach

- Objective:
  Maximize:
  β *reduced num. of odd face – induced deviation
- Subject to:
  1. Die region constraint
  2. Fixed pin constraint
  3. Connection constraint
  4. Vertical order constraint
  5. Minimum spacing constraint
  6. Maximum movement constraint
  7. Graph simplicity constraint

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Experimental results

- Our algorithm was implemented in C++ and run on an Intel 1.6GHz Linux machine. We use CPLEX to solve the MILP problems. The following table shows the number of nodes, edges and odd face of the four benchmarks which are used to test our algorithm.

	#node	#edge	#odd_face	#net
C1	1009	436	14	254
C2	4984	2088	58	1702
C3	10974	6668	330	3514
C4	19642	12578	668	6175
C5	57182	36373	1908	17787

Experimental results

	Our algorithm				Adjacent pairing algorithm				Aggressive algorithm			
	#rof	deviation	%comp	runtime	#rof	deviation	%comp	runtime	#rof	deviation	%comp	runtime
C1	0	629	100%	0.2	0	629	100%	0.2	0	677424	100%	0.2
C2	0	3667	100%	1.8	0	3503	100%	2.9	0	3504300	100%	1.3
C3	2	18691	99.39%	9.1	48	13599	85.45%	8.2	0	13756230	100%	8.6
C4	8	33967	98.88%	24.0	102	23339	84.73%	9.9	0	23933200	100%	22.1
C5	30	96535	98.43%	297.7	324	70711	83.02%	131.4	0	69980000	100%	140.8
	normalized				normalized				normalized			
	#rof	deviation	%comp	runtime	#rof	deviation	%comp	runtime	#rof	deviation	%comp	runtime
	1	1	1	1	11.85	0.73	0.85	0.46	0	728.7	1.01	0.52

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Conclusion

1. We present an MILP-based wire spreading algorithm to solve the phase conflict problem with minimum perturbation on layout.
2. Instead of predefined edge weight our algorithm use the exact deviation as cost, which is different from the previous work.
3. The experiment results show that less than 2% of odd face are left in the modified layout without increasing the die size.
4. The flexible MILP model allows integrating with a variety of practical issues, such as the length of critical path.