# A Matching Based Decomposer for Double Patterning Lithography

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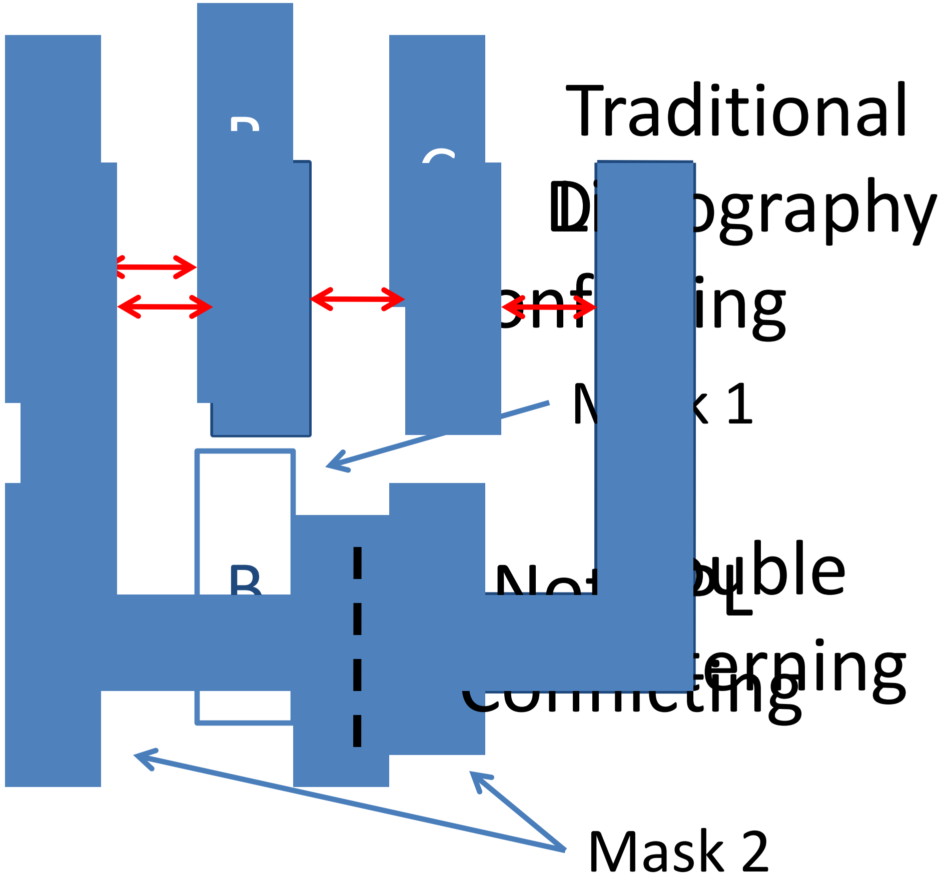
# Outline

- Problem Formulation
- Previous Work
- Algorithm Flow
- Planar Graph Proof
- Face Merging Based Formulation
- Decomposition Algorithm
- Experiment

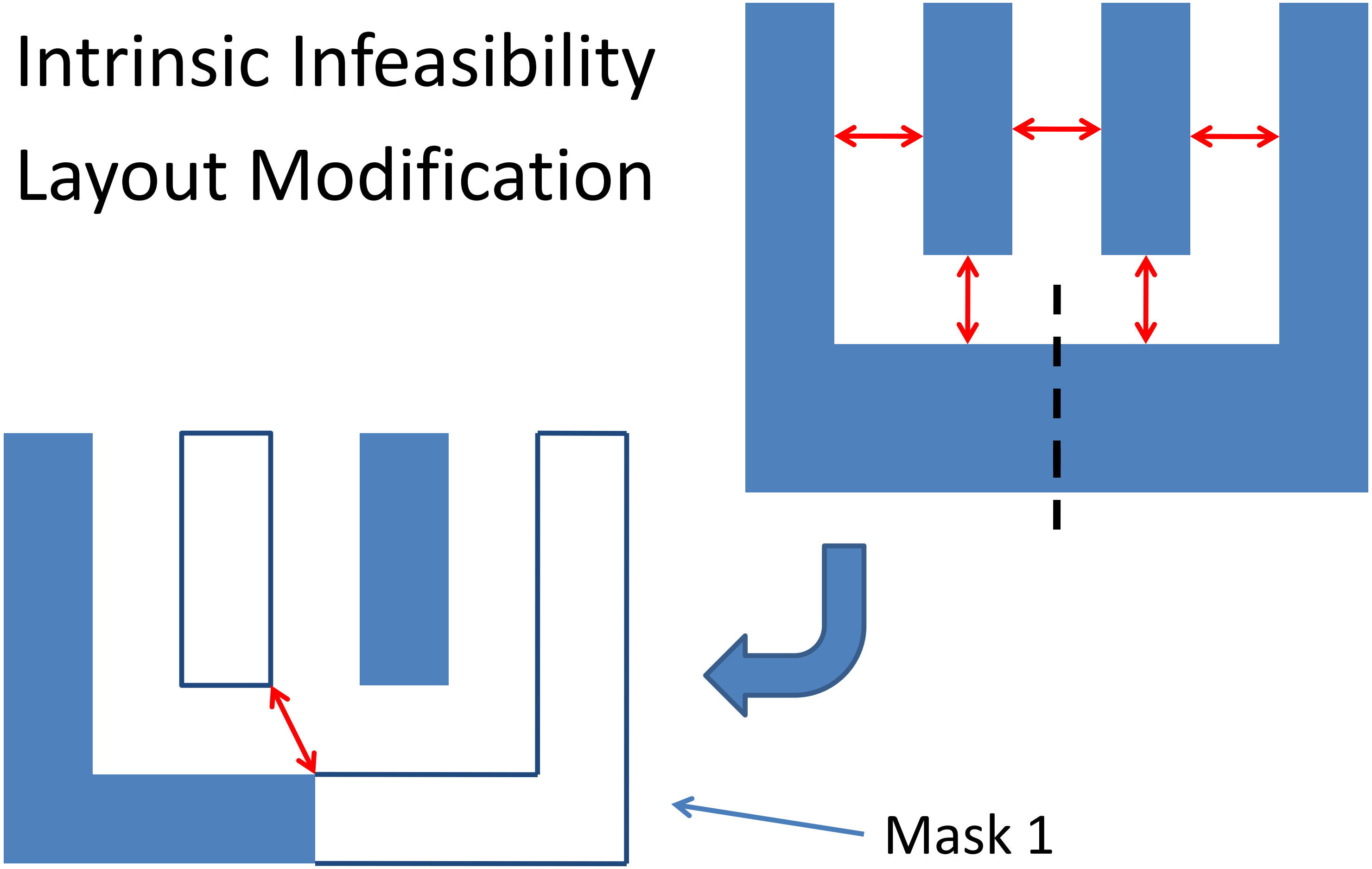
# Double Patterning Lithography

- Double Patterning: two masks
- DPL Conflict
- DPL Infeasibility:
- Stitches



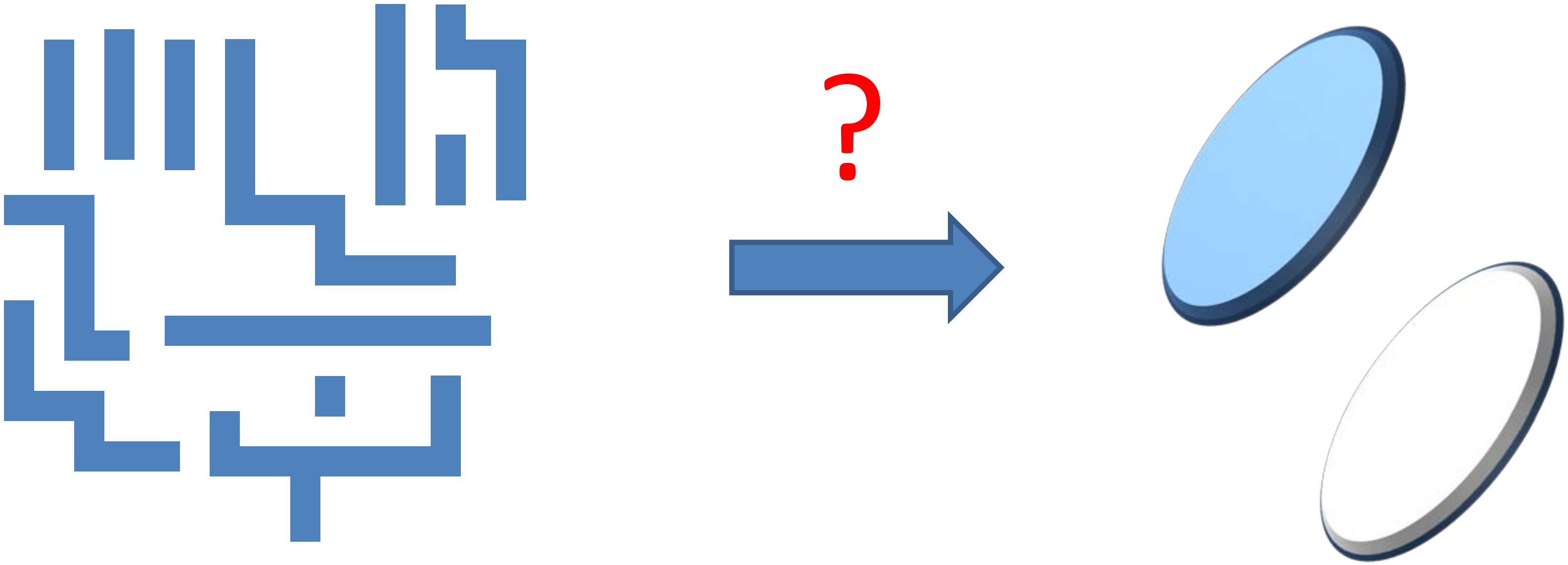
# Double Patterning Lithography

- Intrinsic Infeasibility
- Layout Modification



# DPL Decomposition Problem

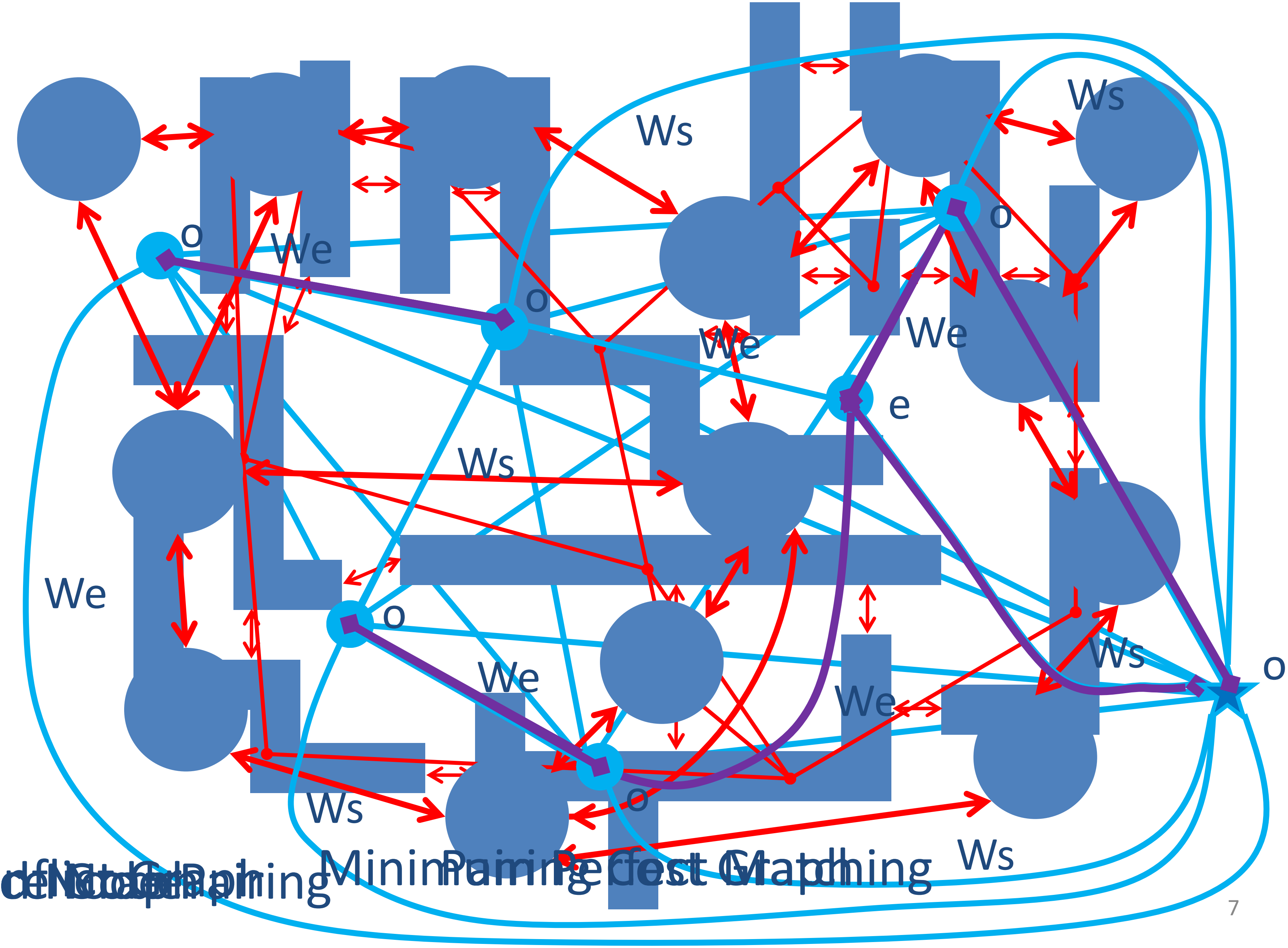
- Objective: To assign patterns on one layer to two masks and resolve every non-intrinsic infeasibility with minimum number of stitches



# Recent Decomposers

- Model Based Decomposer:
  - optical simulation
  - too slow for current complex and large-scale layout
- Rule Based Decomposer:
  - Heuristics that greedily slice and assign patterns
  - Pre-slice patterns and use ILP to select mask assignment for sliced patterns, Kahng ICCAD 2008, Yuan ISPD 2009

# Algorithm Flow



Odd Nodes
Cut Graph
Decomposition
Partitioning

Minimum Cost
Pairing
Perfect Matching
Cost Graph

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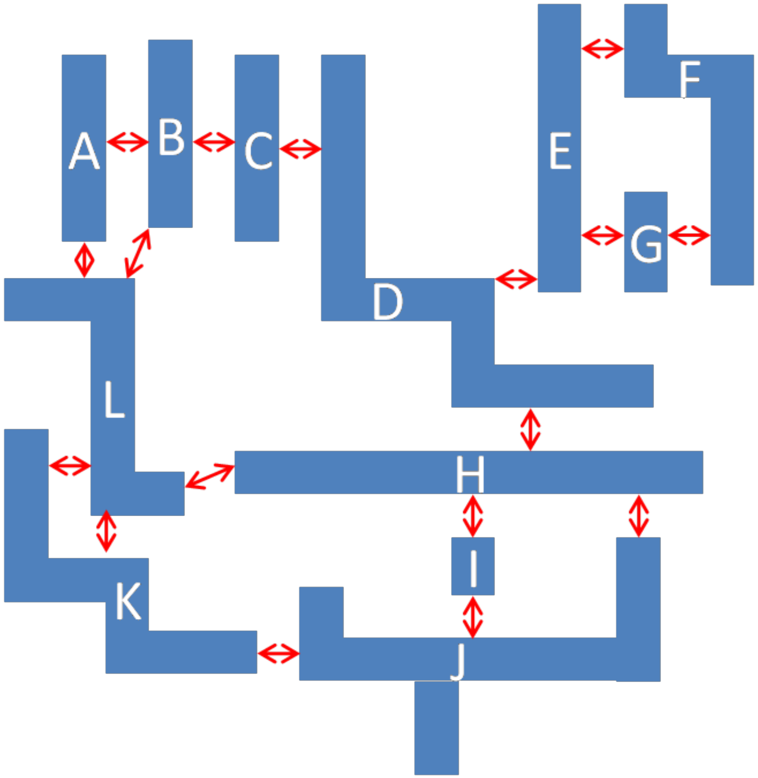
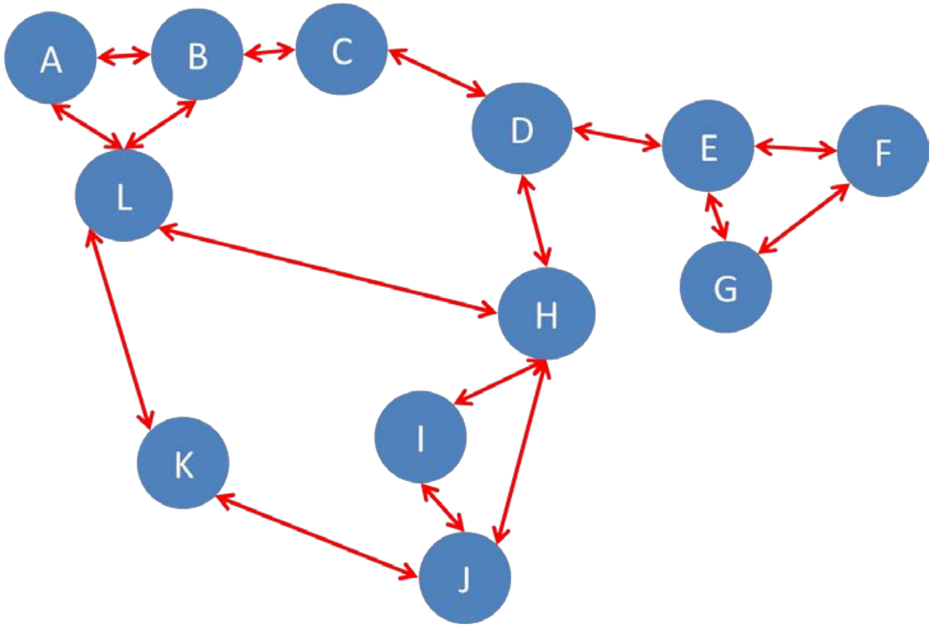
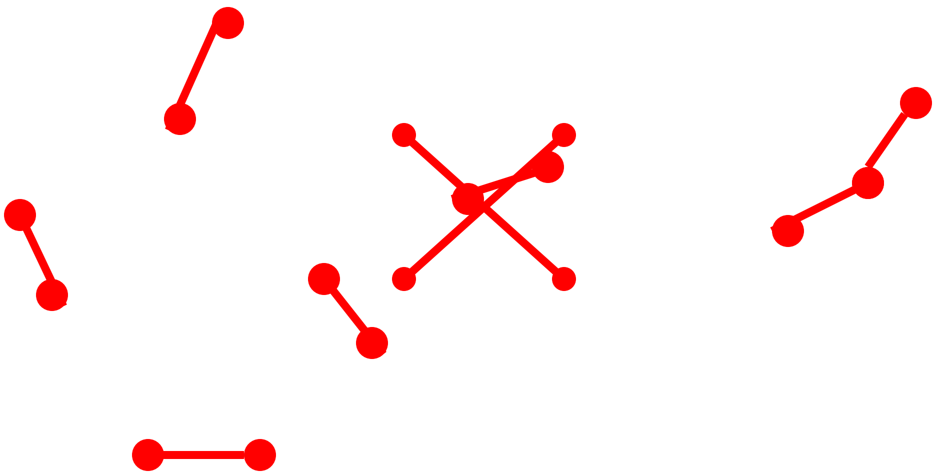
# Conflict Graph





# Planarity Of Conflict Graph

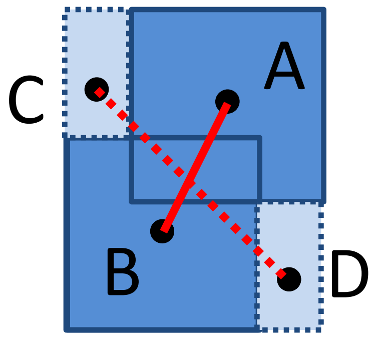
- Lemma 1: Crossing does not exist



Manhattan Distance: DPL Threshold $\leq$ 2× Min Spacing

Euclidian Distance: DPL Threshold $\leq \sqrt{2} \times$ Min Spacing

# Proof for Lemma 1



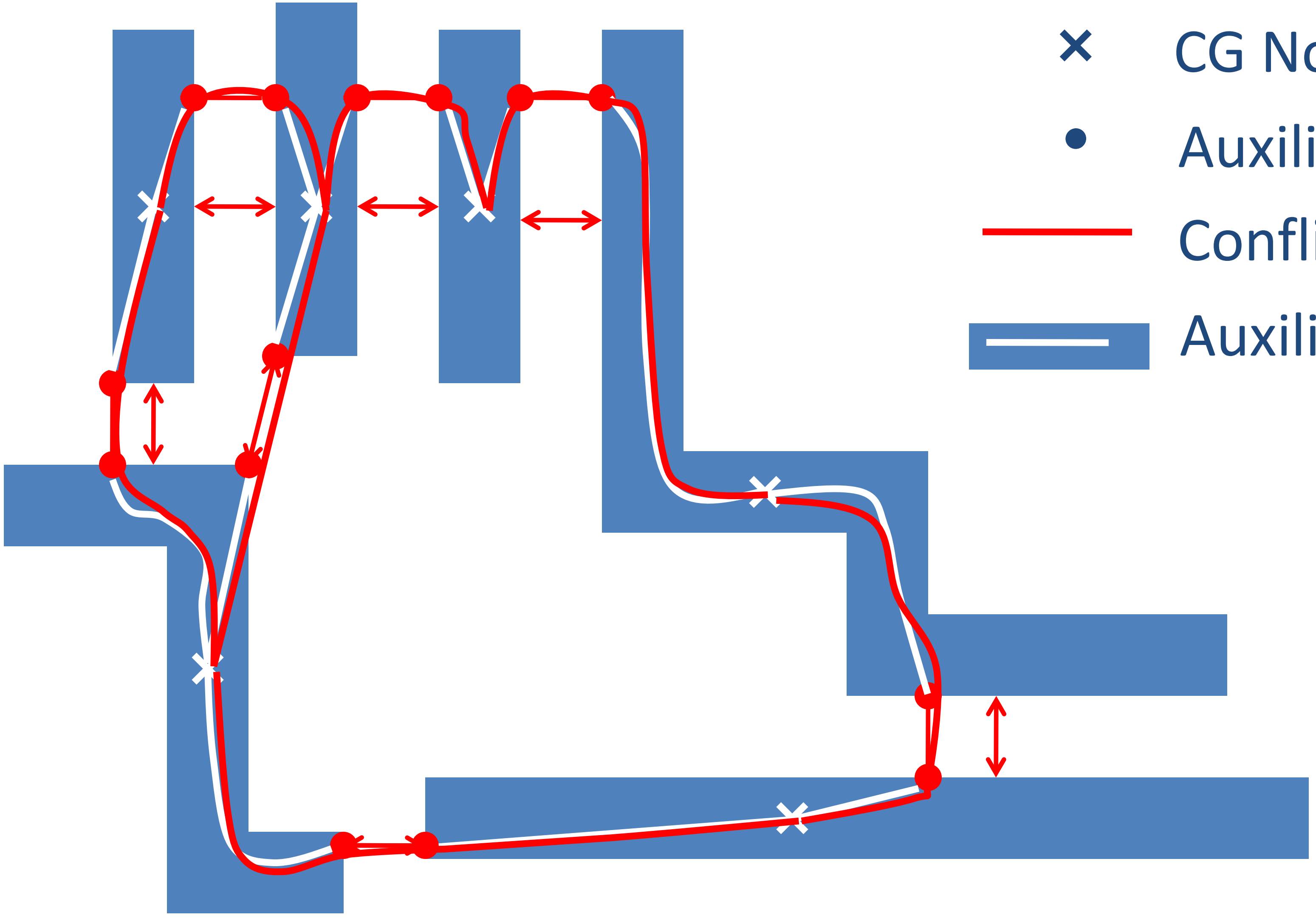
$$x_A - x_B + y_A - y_B < t$$

$$x_C \leq x_A - s$$
$$y_C \geq y_B + s$$
$$x_D \geq x_B + s$$
$$y_D \leq y_A - s$$

$$\begin{aligned} MD(C,D) &= x_D - x_C + y_C - y_D \\ &\geq x_B - x_A + 2s + y_B - y_A + 2s \\ &> 4s - t \end{aligned}$$

$$MD(C,D) < t \Rightarrow t \xcancel{>} 2s$$

# Planar Embedding



× CG Node

● Auxiliary Node

— Conflict Edge

▬ Auxiliary Edge

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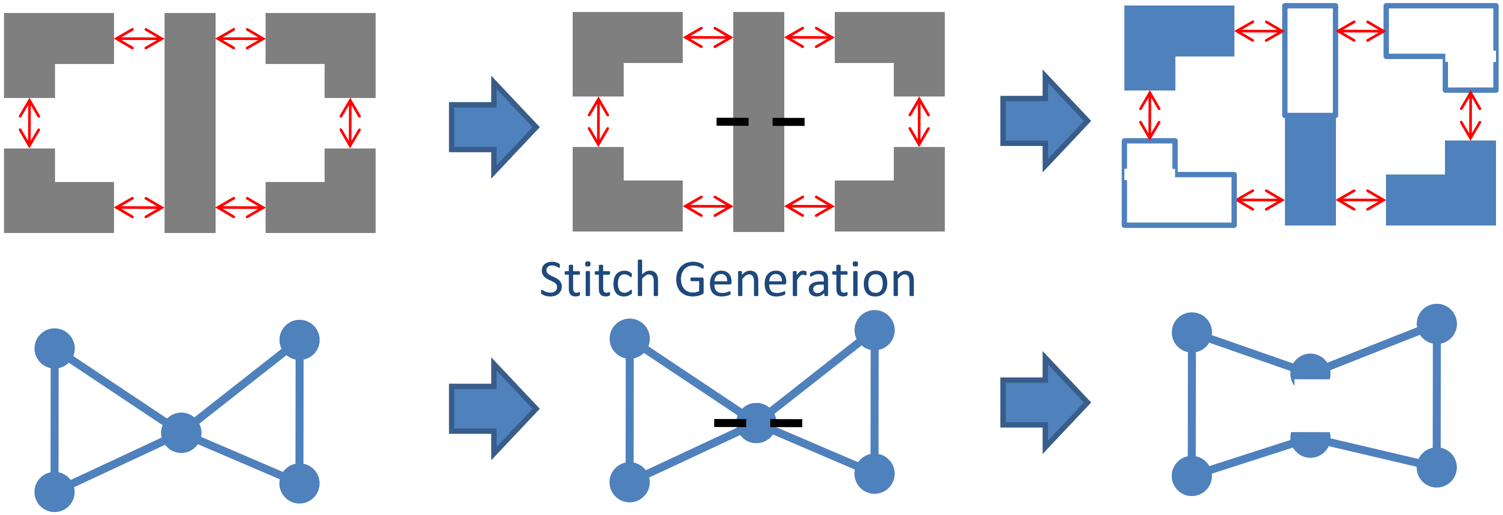
# Node Splitting

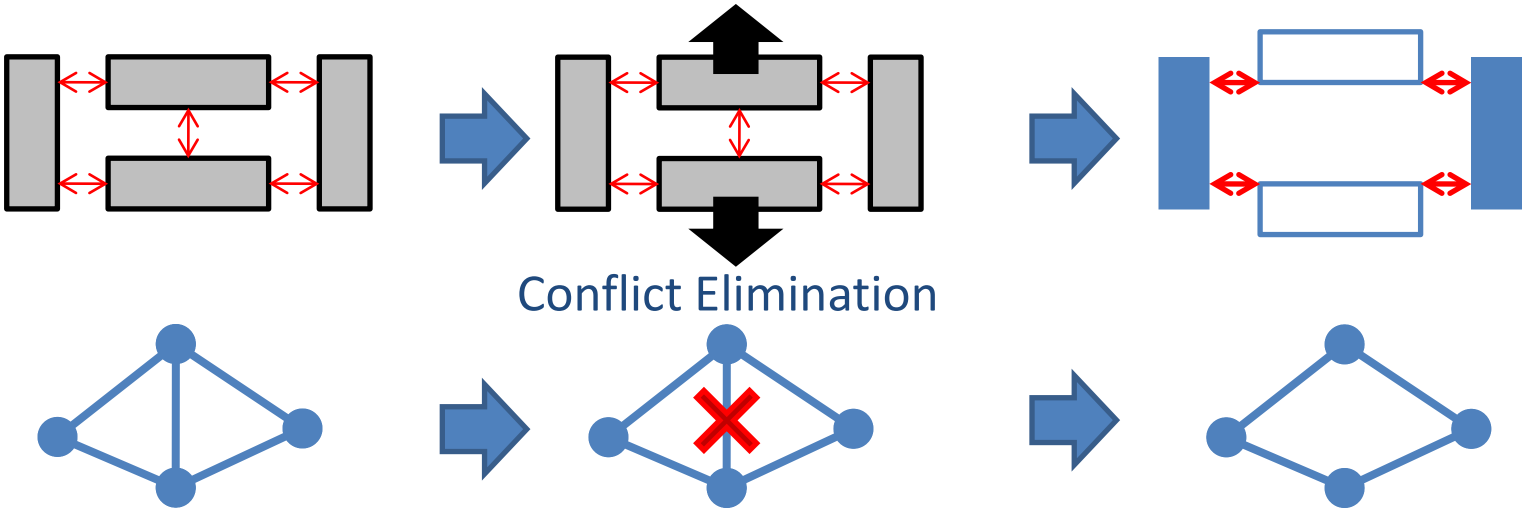


Layout

Stitch Generation

CG

# Edge Removal

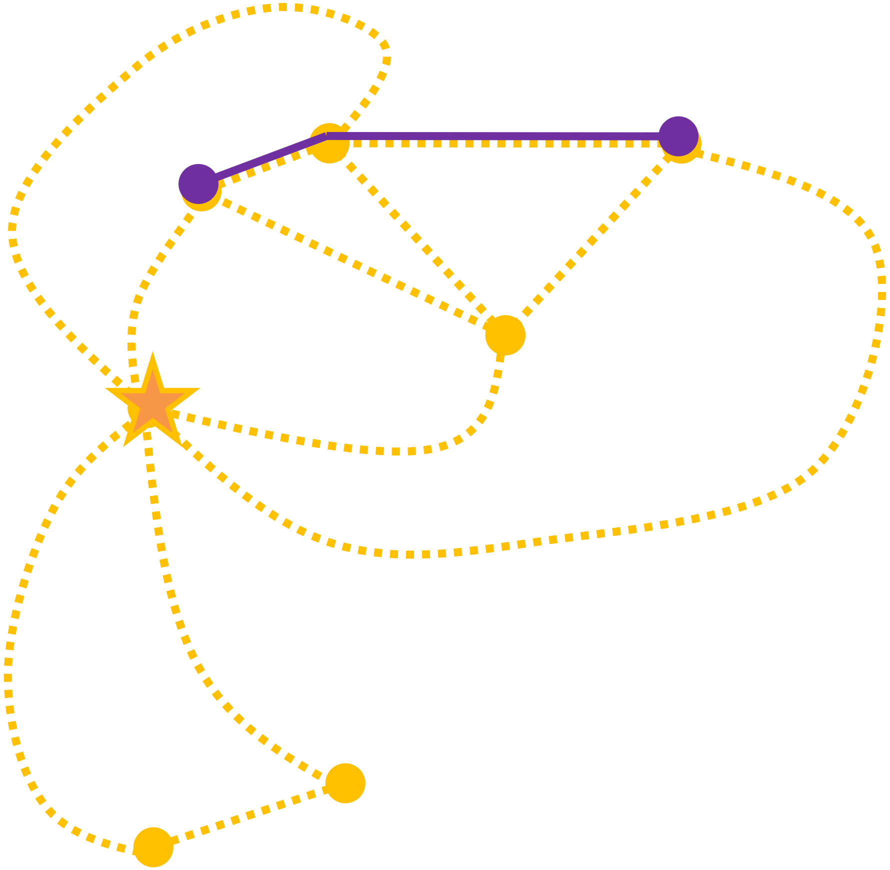


Layout

Conflict Elimination

CG

# Face Graph and Pairing



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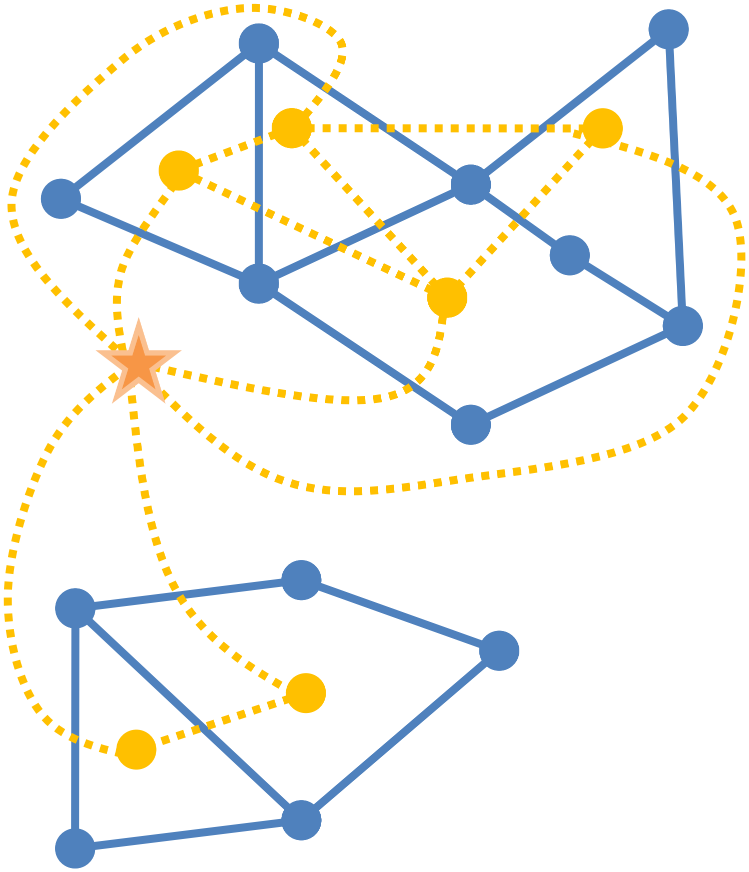
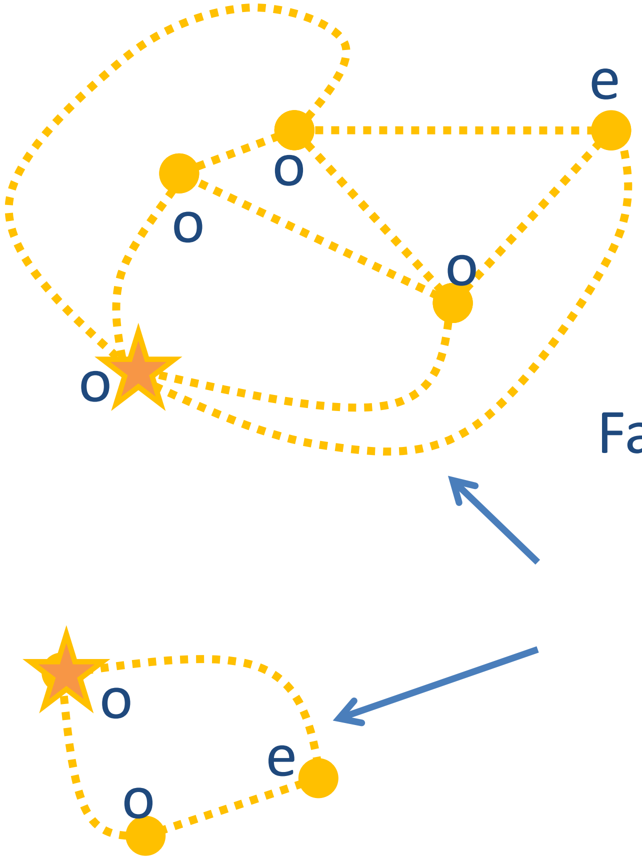
# Face Graph Partition

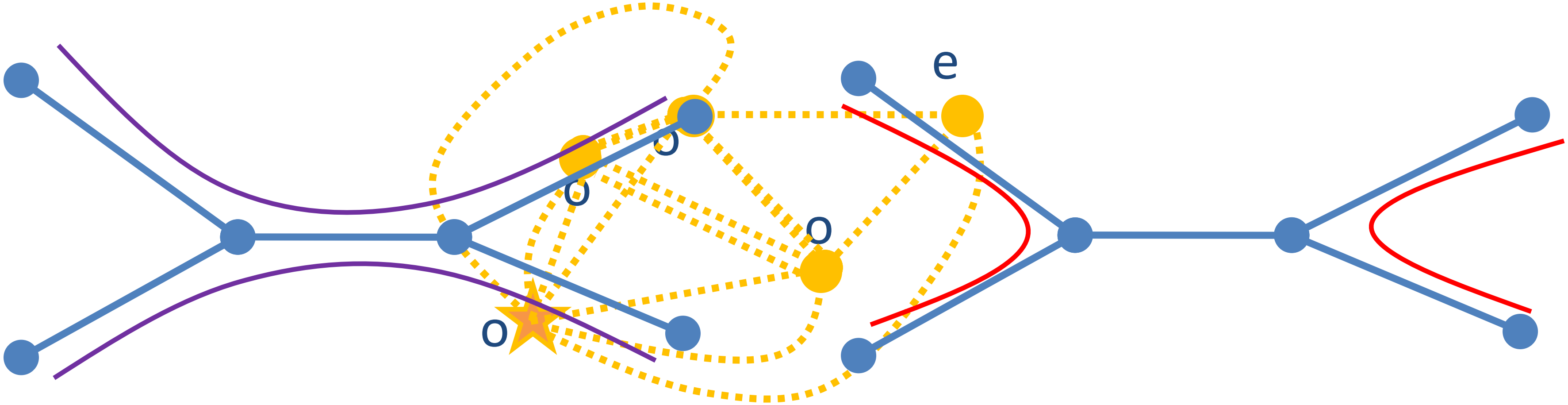




o/e:
Face Node
Polarity

# SubFG Simplification

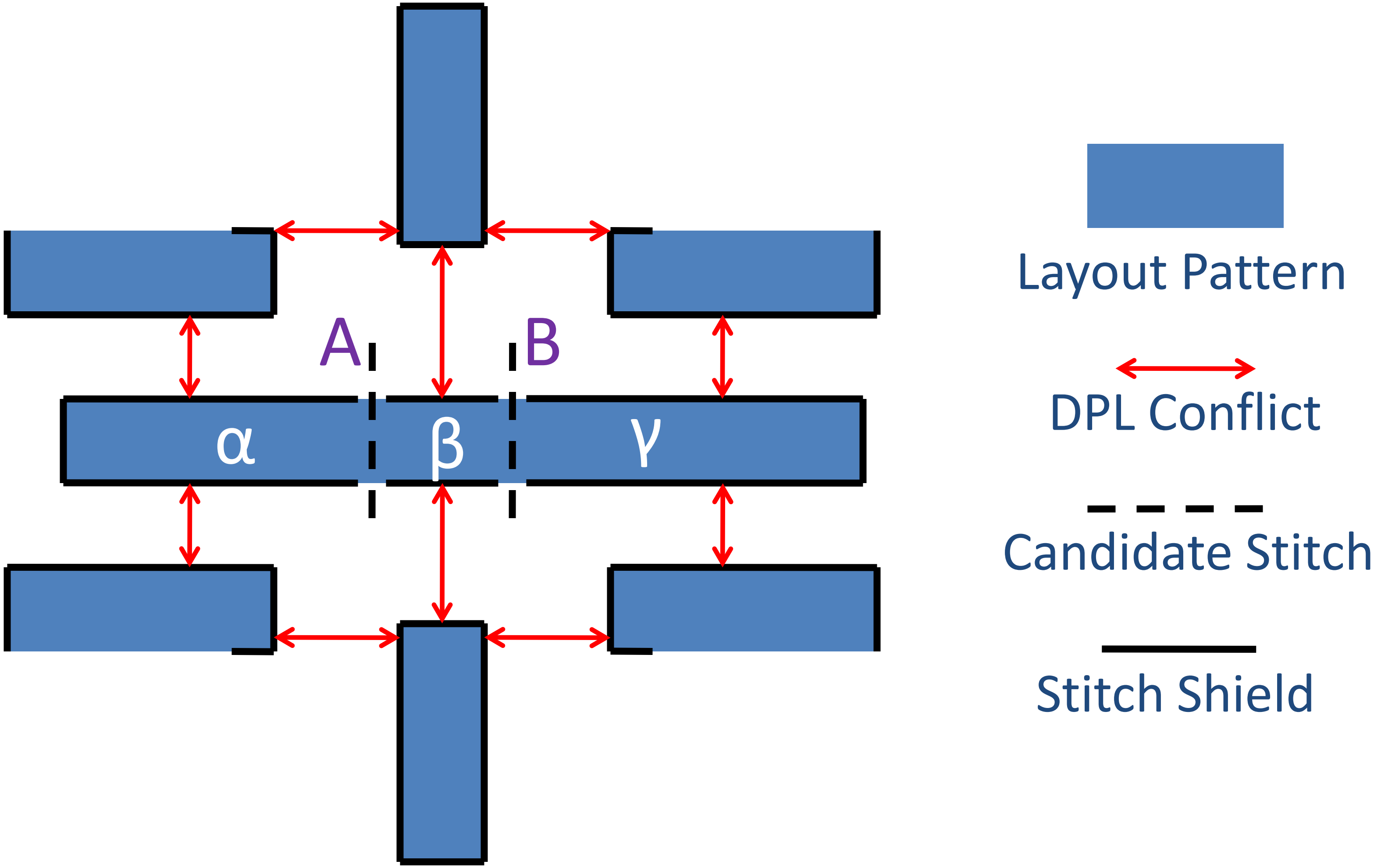
- Only odd face need to be paired
- Use Floyd-Washall algorithm to find the shortest path for each pair of odd nodes
- Create a complete graph called Pairing Cost Graph (PCG)



# Matching Based Solution

- The odd vertex pairing in the simplified SubFG is minimum weighted perfect matching problem
- Convert the minimum weighted perfect matching problem by changing edge weight into a maximum weighted matching problem

# Dependent Stitch



Layout Pattern

DPL Conflict

Candidate Stitch

Stitch Shield

# Contributions

- Prove that Conflict Graph is planar
- Create Face Graph to model two face merging operations
- Propose a new framework for optimal DPL decomposition
- Reduce odd-node pairing problem in the entire FG into a set of sub-problems
- Transform the pairing problem into minimum weighted matching problem
- Use an polynomial runtime maximum weighted matching to solve the minimum weighted matching

# Experiment Setup and Result

- Coded in C
- Simulation is run on a 2.8GHz Intel Linux machine with 32GB RAM

| | Matching Based Decomposer | | | Kahng’s | | |
|---|---|---|---|---|---|---|
| Design | # Stitch | # ER | CPU (s) | # Stitches | # ER | CPU (s) |
| AES | 31 | 0 | 4.9 | 33 | 0 | 17.2 |
| TOP-B | 11036 | 652 | 45.1 | 14072 | 800 | 448.1 |
| TOP-C | 68372 | 3711 | 214.3 | 69490 | 4000 | 6629 |
| TOP-D | 26917 | 1395 | 105.8 | 27908 | 1600 | 1228 |
| Comparison | 1 | 1 | 1 | 1.05 | 1.11 | 23.7 |

# Conclusion and Future Work

- Conflict Graph is Planar
- Matching Based Decomposer
- Optimal and Polynomial Complexity
- Extend the face merging formulation to simultaneously solve DPL decomposition and layout modification