Deep Learning-Driven Simultaneous Layout Decomposition and Mask Optimization

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Biography

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Outline

Introduction

Algorithm

Experimental Results

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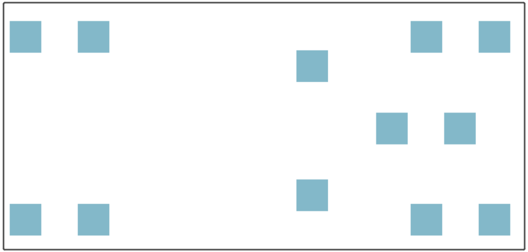
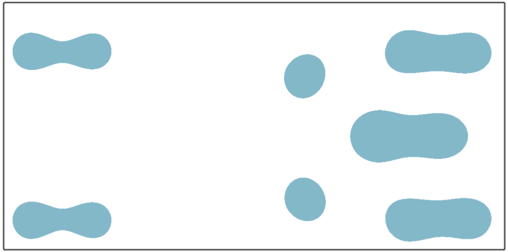
Optical Proximity Effect



Target

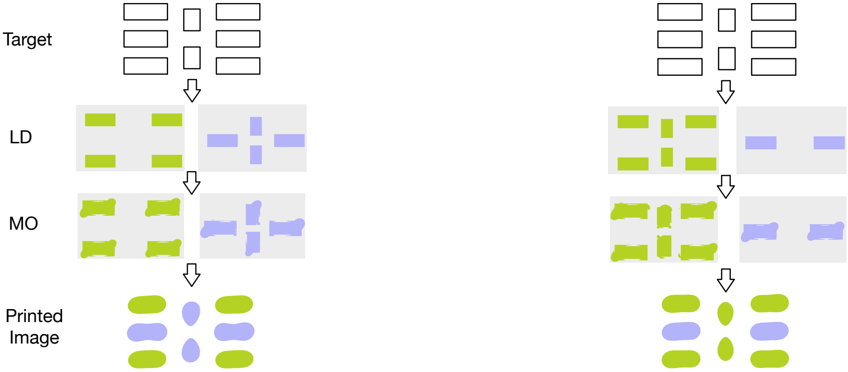


Result

- Resolution enhancement Technologies (RETs):
  - OPC
  - MPL

Layout Decomposition for Mask Optimization

- Different decomposition results converge to divergent printability

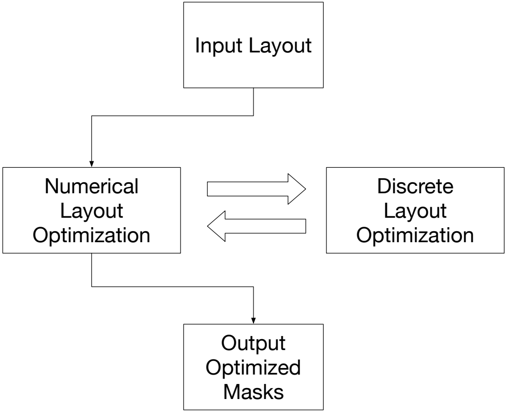


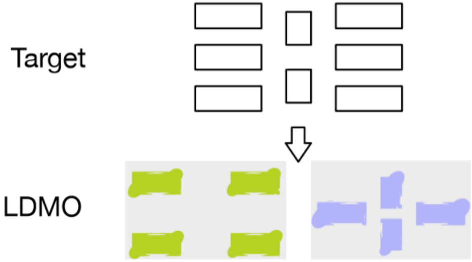
#EPE Violation = 3

#EPE Violation = 1

Option for Decomposition Selection

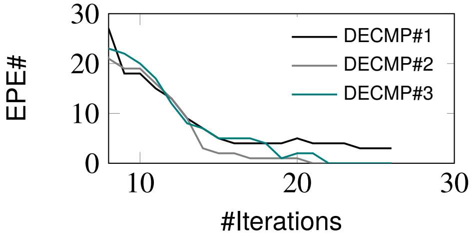
- Solution: Collaboration of LD and MO in a unified framework [Ma+,ICCAD'17].



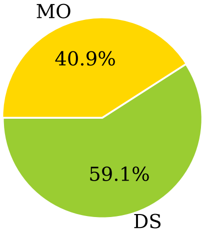


Issues

- Not Accurate: Greedy pruning.
- Not Efficient: OPC suffers from large computational complexity.



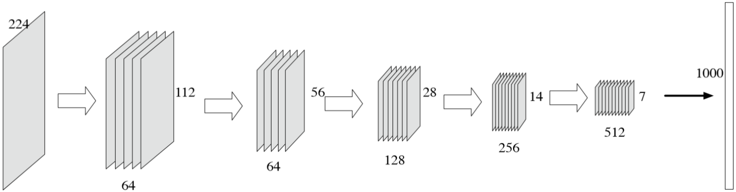
Decomposition convergence of EPE



Runtime break down

Motivation

- Powerful convolutional neural network (CNN)
  - Build mapping relationship automatically.
  - Large amount of data required.



- CNN application in EDA field:
  - Routing predicting [Xie+,ICCAD'18]
  - Hotspot detection [Yang+,TCAD'18]
  - Resist modeling [Lin+,TCAD'18]
- How about integrating CNN for decomposition selection?

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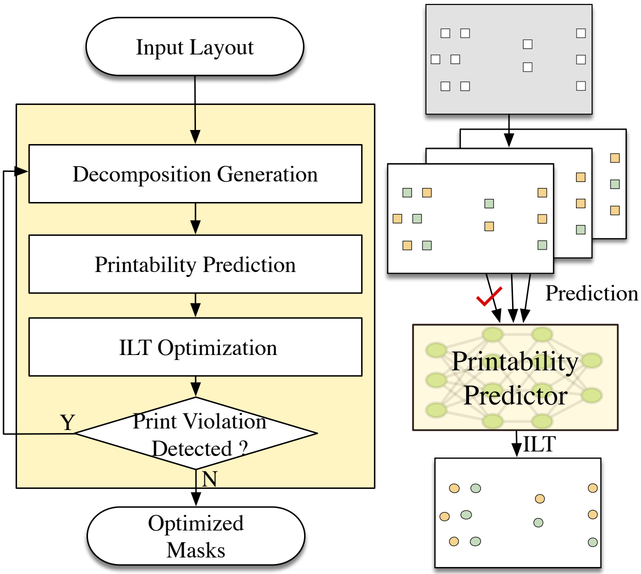
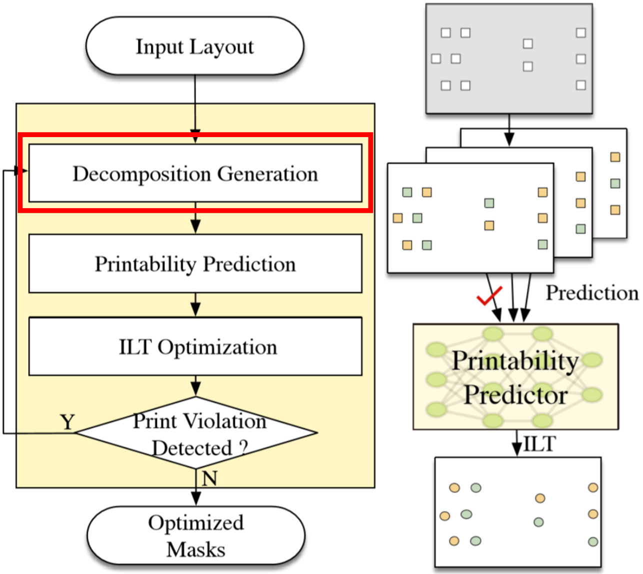
Forward Optimization Flow



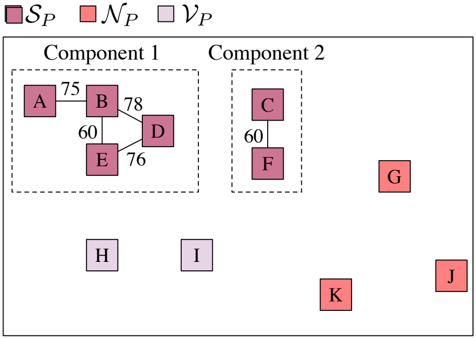
Decomposition Generation

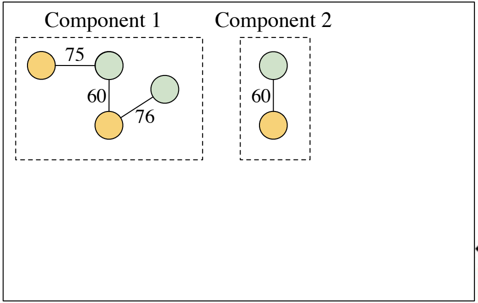


Decomposition Generation

- Classify patterns & build minimal spanning tree

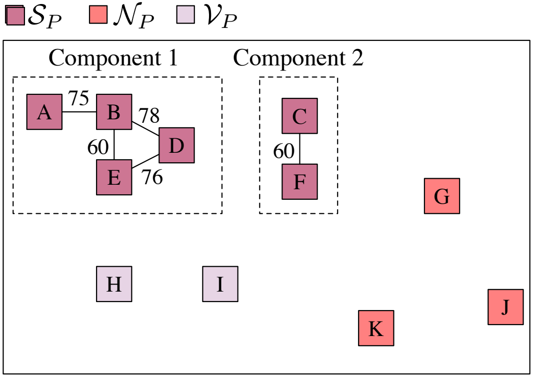
$$\mathcal{E} \in \begin{cases} \mathcal{S}_P, & \text{if } d \leq n_{min}, \\ \mathcal{V}_P, & \text{if } n_{min} < d \leq n_{max}, \\ \mathcal{N}_P, & \text{if } n_{max} < d. \end{cases}$$





Decomposition Generation

- n-wise arrays
  - $\mathcal{S}_P$ and $\mathcal{V}_P$ with three-wise
  - $\mathcal{N}_P$ with two-wise



$Arrs1$	$\mathcal{S}_P$		$\mathcal{V}_P$	
	B	F	H	I
#1	1	0	0	1
#2	1	1	1	1
#3	0	0	1	1
#4	0	0	0	0
#5	0	1	1	0
#6	1	1	0	0
#7	1	0	1	0
#8	0	1	0	1

$Arrs2$	$\mathcal{N}_P$		
	G	J	K
#1	0	1	0
#2	0	0	1
#3	1	1	1
#4	1	0	0

Decomposition Generation

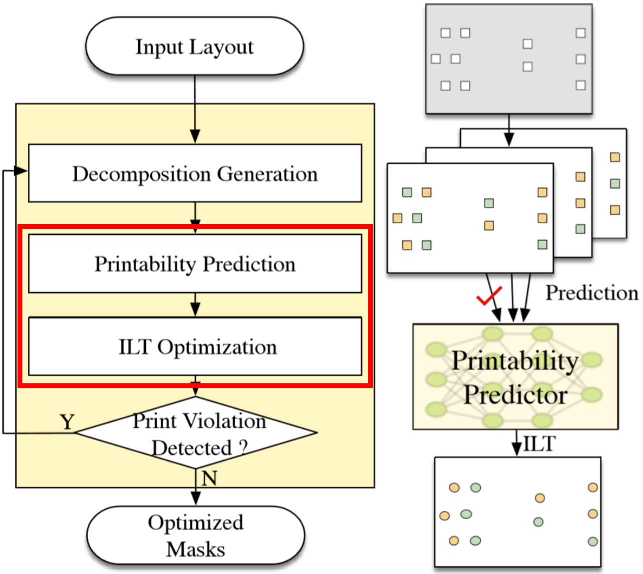
- n-wise arrays
  - Relax combination strength
  - Complete combination of n factors

Any three columns contain complete combination from 000 to 111

	factor1	factor2	factor3	factor4
#1	1	0	0	1
#2	1	1	1	1
#3	0	0	1	1
#4	0	0	0	0
#5	0	1	1	0
#6	1	1	0	0
#7	1	0	1	0
#8	0	1	0	1

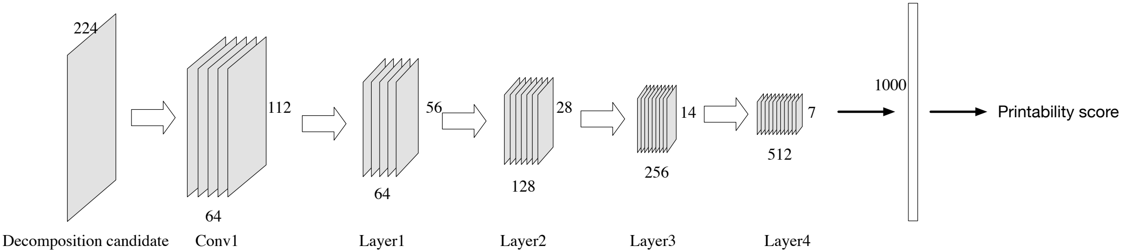
Three-wise arrays

Printability Prediction & Mask Optimization



Printability Prediction & Mask Optimization

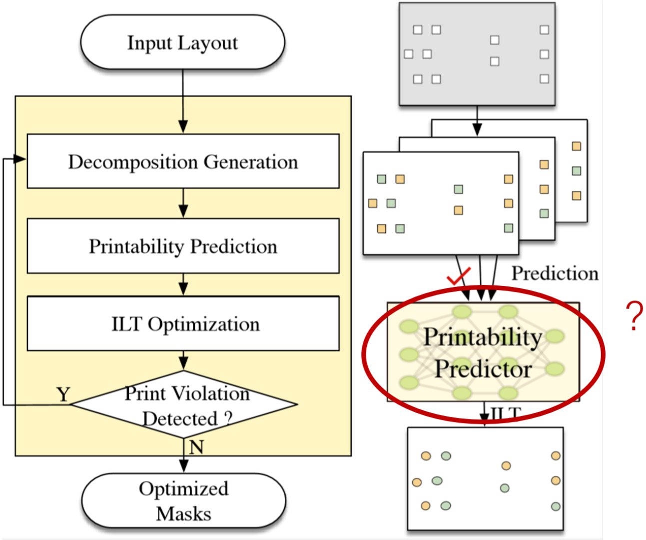
- Select the best decomposition candidate for OPC engine



$$\text{Printability score} = \alpha \times \#\text{EPE} + \beta \times \text{L2 Error} + \gamma \times \#\text{Print Violation}$$

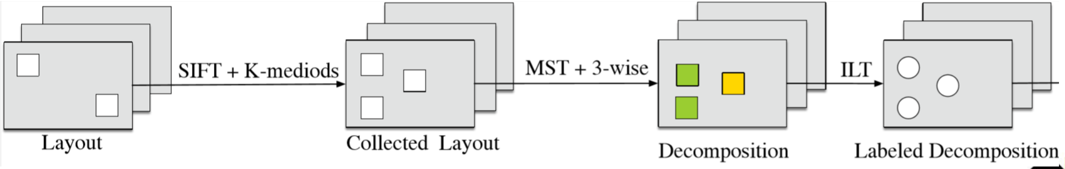
How to Sample Data?

- Sample typical data for train



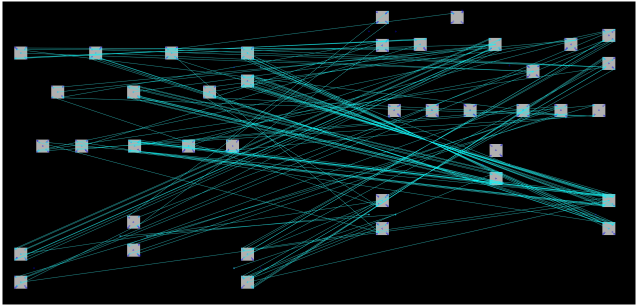
How to Sample Data?

- Layout sampling
- Decomposition sampling
  - Similar to decomposition generation stage
- Get printability score



Layout Sampling

- Calaulate point distance
  - Match points
  - Euclidean distance as matched points distance
- Calculate layout distance
  - Sum up matched poinnts as layout distance
- Cluster layouts



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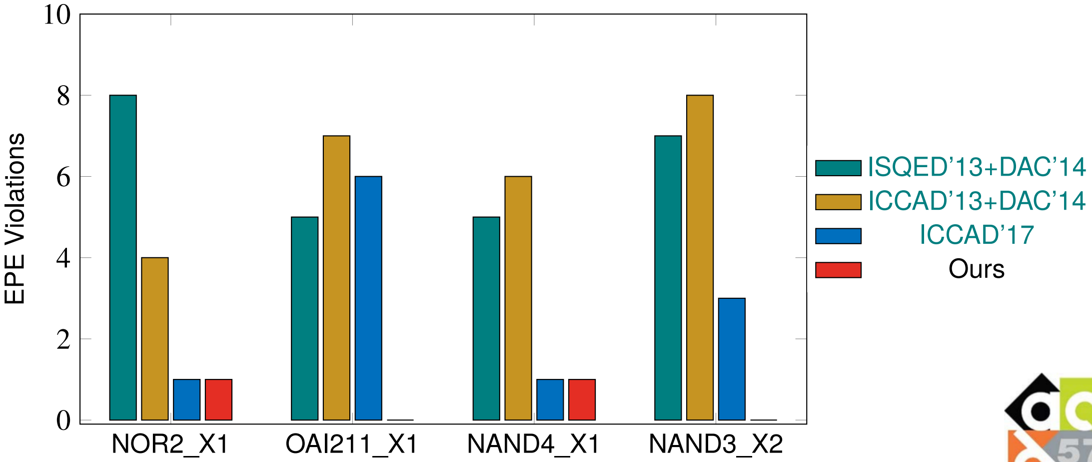
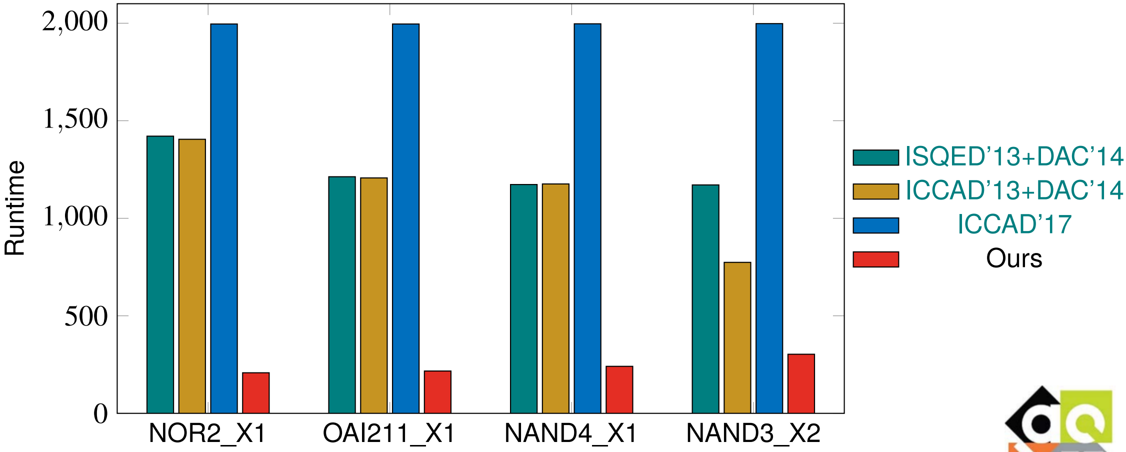
Comparision on EPE violations

- Outperform state-of-the-art.
- Reduce 68.0% EPE violations on average.



Comparision on Runtime

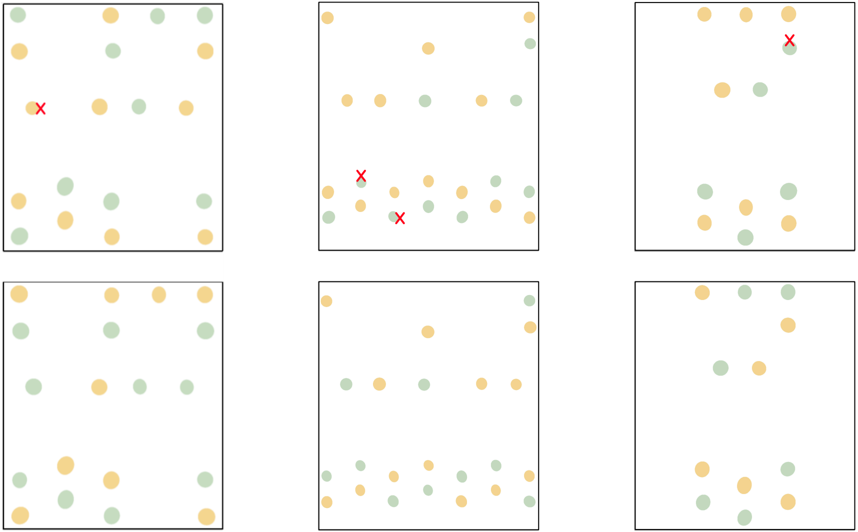
- About 4X speed up.



Optimization results

ICCAD'17

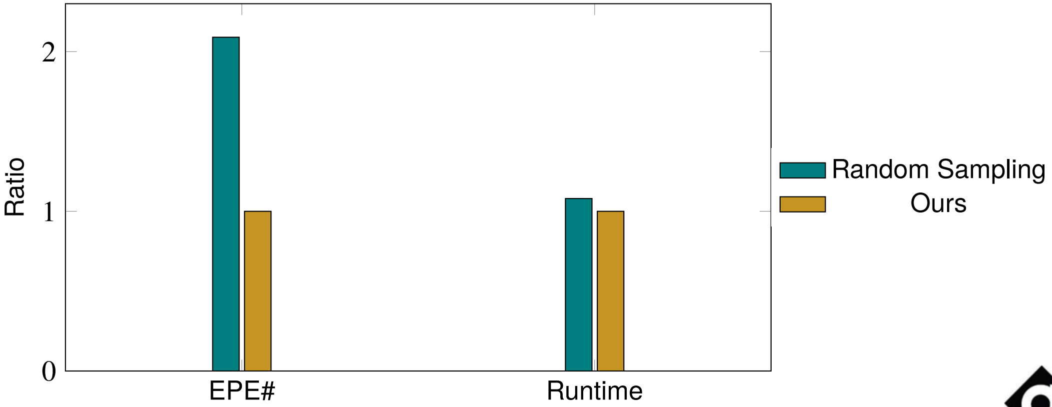
Ours



AOI211_X1 NAND3_X2 BUF_X1

Comparision with Random Sampling

- Reduce half of EPE violations.



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- Deep learning based layout decomposition and mask optimization framework.
  - Decomposition generation approach.
  - Decomposition printability estimation.
- A set of sampling strategies.
- Experimental results demonstrate the effectiveness and efficiency.

Thank You

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