EDA with ML, Rule-Based, or Both?

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Background

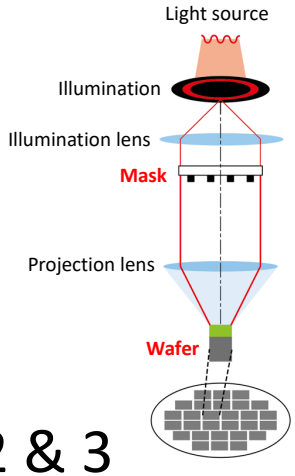
- ML vs Rule-based
  - ML is applicable for “large volume data”, which is often not the case in semiconductor industry
  - Rule-based is suited for smaller data volume

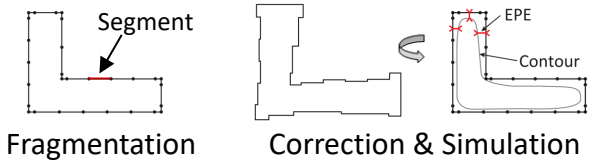
- Questions addressed in this talk
  - Compare ML and Rule-based in large- and small-volume data
  - Combine ML and Rule-based, so that Rule-based can be an efficient option in smaller data volume

J. Carew, “How to choose between a rules-based vs. machine learning system,” *TechTarget*, July 2020.

Example 1: Re-Fragmentation

- OPC process
  1. Fragmentation
  2. Correction of segments
  3. Lithography simulation to check EPE → Iterate 2 & 3



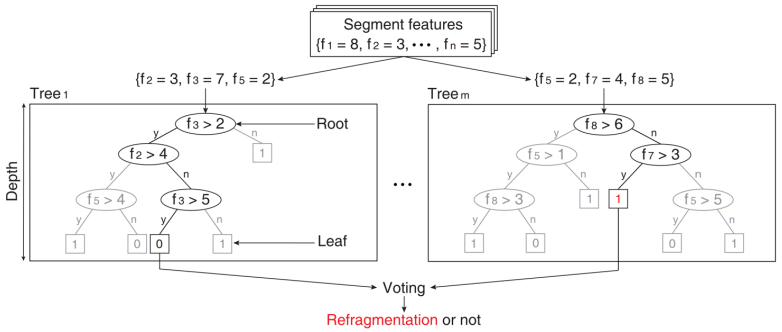


- Fragmentation
  - Based on simple rules (e.g. nominal segment length)
  - Segments which are not short enough are trouble
  - Re-Fragmentation: further divide a few segments (so that OPC can complete faster with smaller EPE)

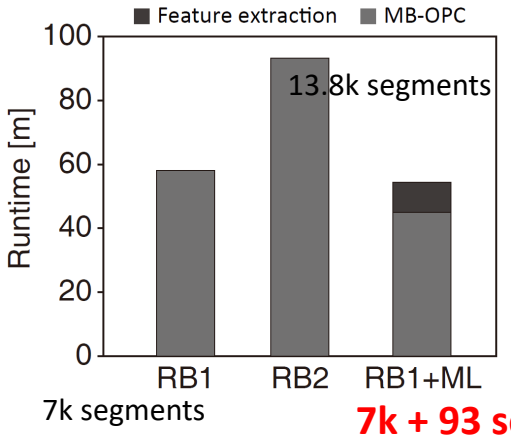
G. Cho, Y. Kwon, T. Kim, and Y. Shin, "Refragmentation through ML classifier for fast and accurate OPC," *Proc. SPIE Advanced Lithography*, 2022.

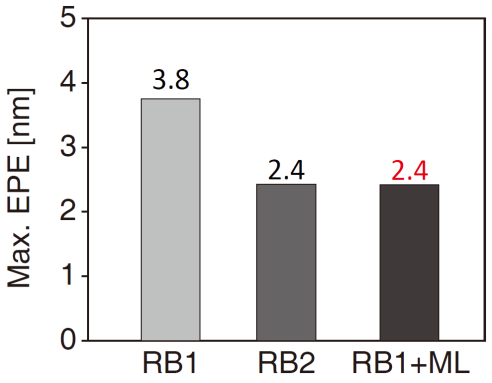
Re-Fragmentation with RFC

- RFC process
  - Each decision tree receives a random subset of segment features & predicts 1 (split) or 0 (no-split)
  - Voting is collected & segment is divided in half if #votes > threshold



- RFC has been "trained" with 28k segments



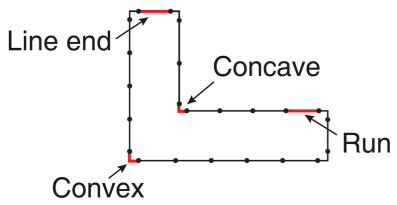


7k + 93 segments

Rule-Based Re-Fragmentation

- Same amount of data (28k segments) is used to set up a few rules
  - σ for length and 2σ for |initial EPE|

Segment type	Length	|Initial EPE|
Line-end	>25nm	>31.9nm
Convex	>42nm	>7.4nm
Concave	>40nm	>11.8nm
Run (adjacent to corner)	>38nm	>8.8nm
Run (not adjacent to corner)	>44nm	>5.6nm



- Rule-based is worse (in max EPE) than RFC, as expected, when data volume is enough

Refragmentation	Max. EPE [nm]	#Segments
No	3.83	7,000
RFC (big data)	2.42	7,096
Rules (big data)	3.07	7,163

RFC vs Rule-Based in Small Data Volume

- Sample data is reduced from 28k segments to 1.4k segments
- RFC model is re-trained; rules are also set up again
- Rule-based is better than RFC, this time
  - RFC is over fitted
  - Rules are less sensitive to the amount of data

Refragmentation	Max. EPE [nm]	#Segments
No	3.83	7,000
RFC (big data)	2.42	7,096
Rules (big data)	3.07	7,163
RFC (small data)	3.41	7,165
Rules (small data)	3.13	7,177

Revising Rules through RFC

- Intuitions from RFC (trained with small data volume!)
  - All the tree roots carry "$\phi_1 > 0.73$?" (top decision maker) if ϕ_1 is a feature
    - First optical signal (ϕ_1) is a main component in light intensity calculation
  - Such trees carry "|initial EPE| > x?" in leaves (final decision maker)
    - x values are collected and average is calculated

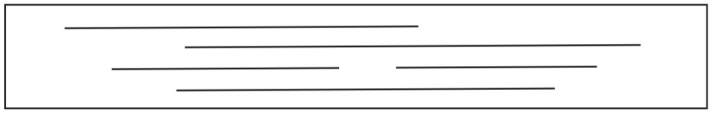
- Key observation
  - **Rule-based approach can be made very efficient, with intuitions extracted from ML model**

Segment type	Length	|Initial EPE| if $\phi_1 \leq 0.73$	|Initial EPE| if $\phi_1 > 0.73$
Line-end	>25nm	>29.4nm	>26.5nm
Convex	>42nm	>7.8nm	>7.0nm
Concave	>40nm	>10.2nm	>9.2nm
Run (adjacent to corner)	>37nm	>9.7nm	>8.7nm
Run (not adjacent to corner)	>44nm	>5.9nm	>5.3nm

Refragmentation	Max. EPE [nm]	#Segments
No	3.83	7,000
RFC (big data)	2.42	7,096
Rules (big data)	3.07	7,163
RFC (small data)	3.41	7,165
Rules (small data)	3.13	7,177
Revised rules (small data)	2.59	7,168

Example 2: Placement Utilization

- Very low aspect ratio design
  - Insufficient horizontal routing resources → very low placement utilization (with lots of whitespace)



- Different utilization for different sub-regions
  - Higher utilization towards left- and right-ends; Lower utilization in the center
  - CNN has been used to identify utilization distribution

S. Koh, Y. Jung, D. Hyun, and Y. Shin, "Routability optimization for extreme aspect ratio design using convolutional neural network," *Proc. ISCAS*, 2021.

Placement Utilization

- Rule-based approach
  - Utilization distribution is assumed to be linear from center to left- or right-end
    - #sub-regions: proportional to % of GRCs with overflow
    - Rules are set up to identify “center utilization” and “linear slope”
- CNN vs Rule-based
  - Large data volume
    - CNN: ~0% overflows ↔ Rule-based: 3% overflows
  - Small data volume
    - CNN: 5.5% overflows ↔ Rule-based: 3.3% overflows

Summary

- ML is not a silver bullet
  - Lack of training samples with high coverage, in semiconductor industry
- ML model may be a foundation for highly efficient rule-based method
  - Even when training samples are not enough!