# An Automatic Optical-Simulation-Based Lithography Hotspot Fix Flow for Post-Route Optimization

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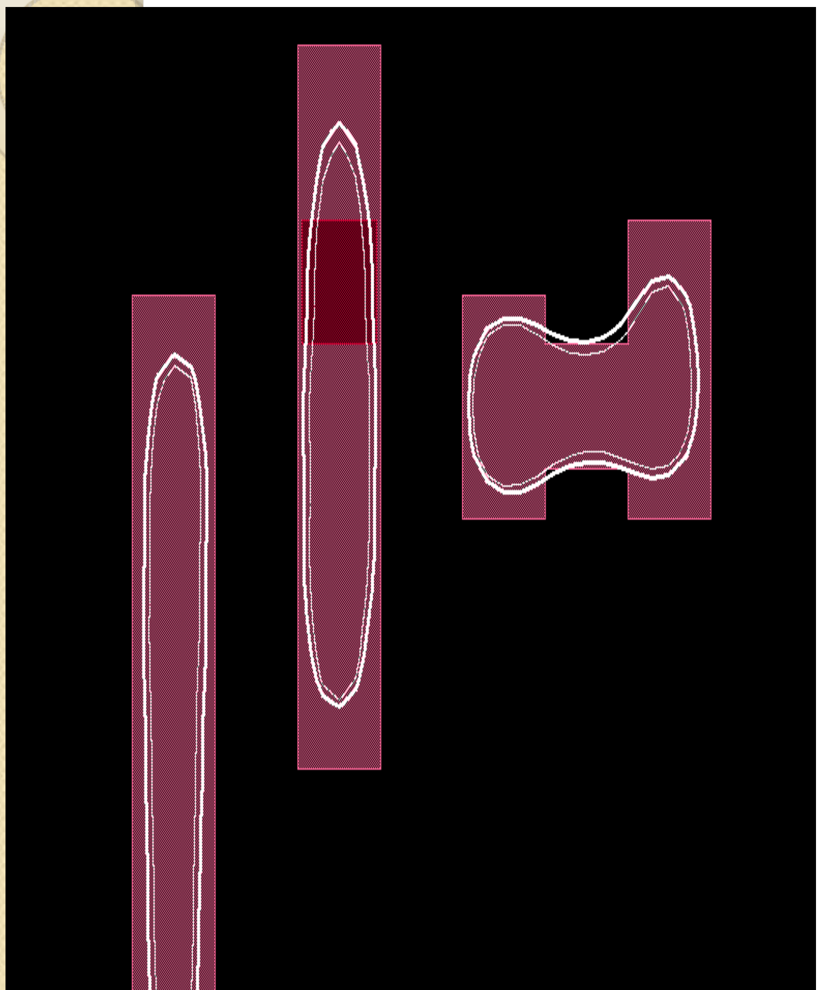
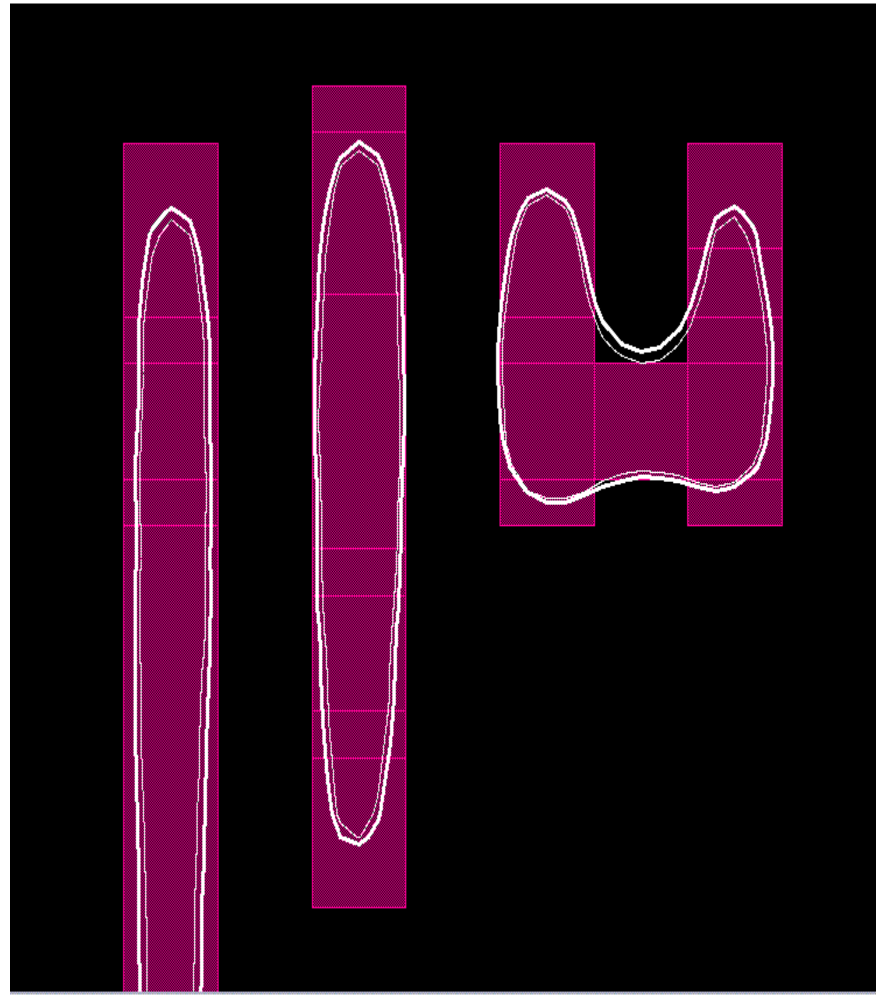
# This work summarized in one picture





Before Fix After Fix

# Motivation

- Lithography hotspots impacts IC manufacturing
- Reroute makes too much change, OPC makes too little change
- Local Fix in post-route stage is most suitable for fixing litho hotspots
- Issues in local fix:

  - Generation of local fix

  - How many local fix is enough to fix?

# Outline

- Lithography & OPC Introduction
- Previous Work
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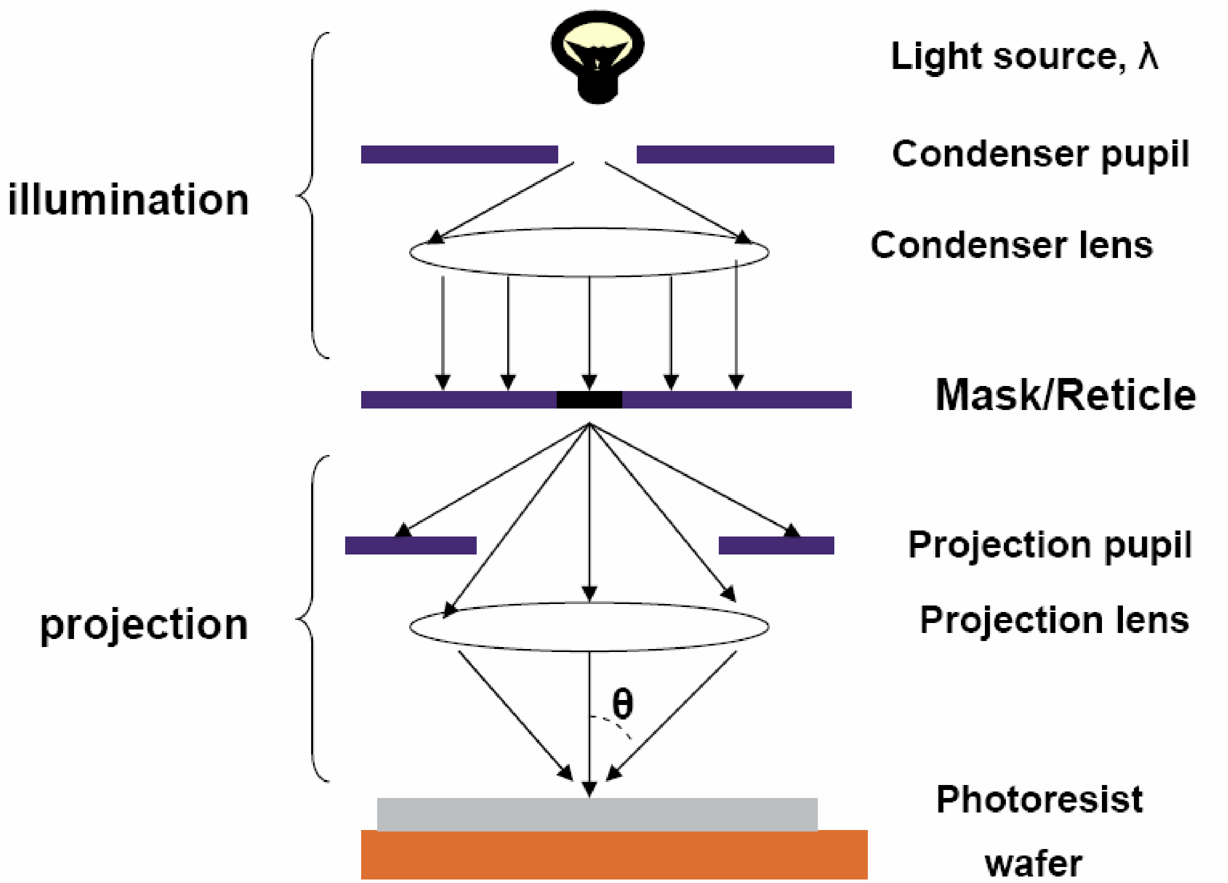
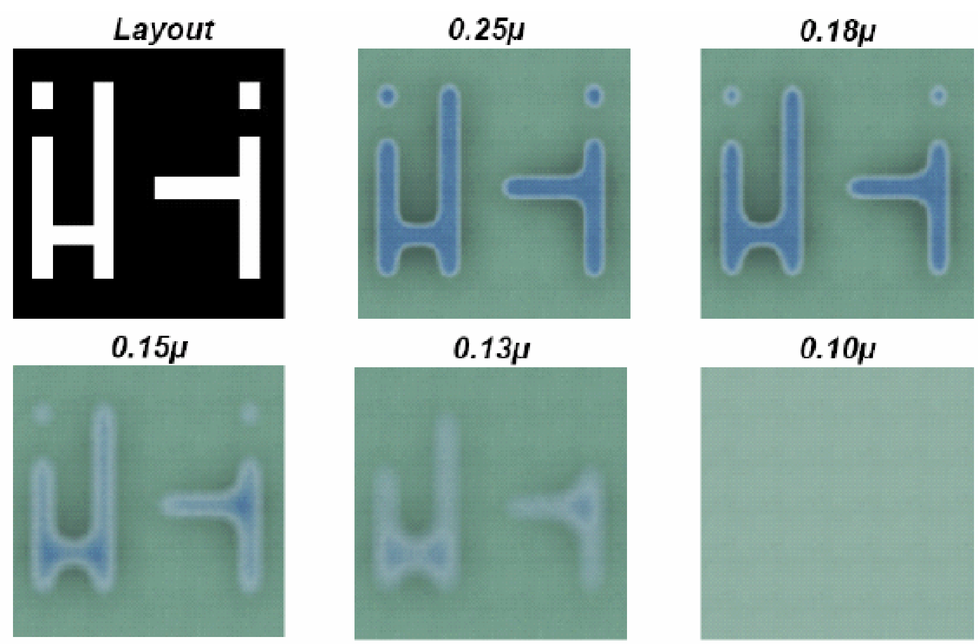
# Lithography Introduction (1)



# Lithography Introduction (2)

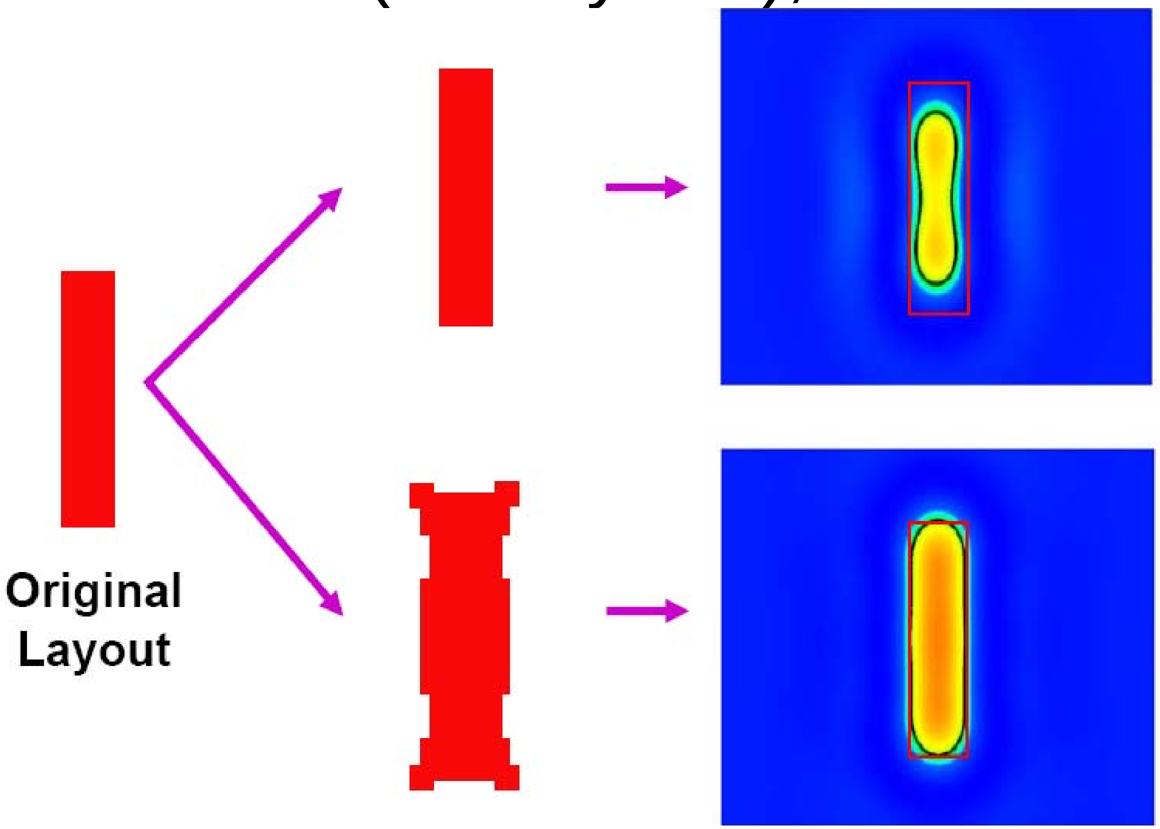
- Impact of process node shrinking down
  - Gets serious as wavelength is comparable with feature. (Diffraction)
  - 193 nm to expose 90 nm → 65 nm → 45 nm …



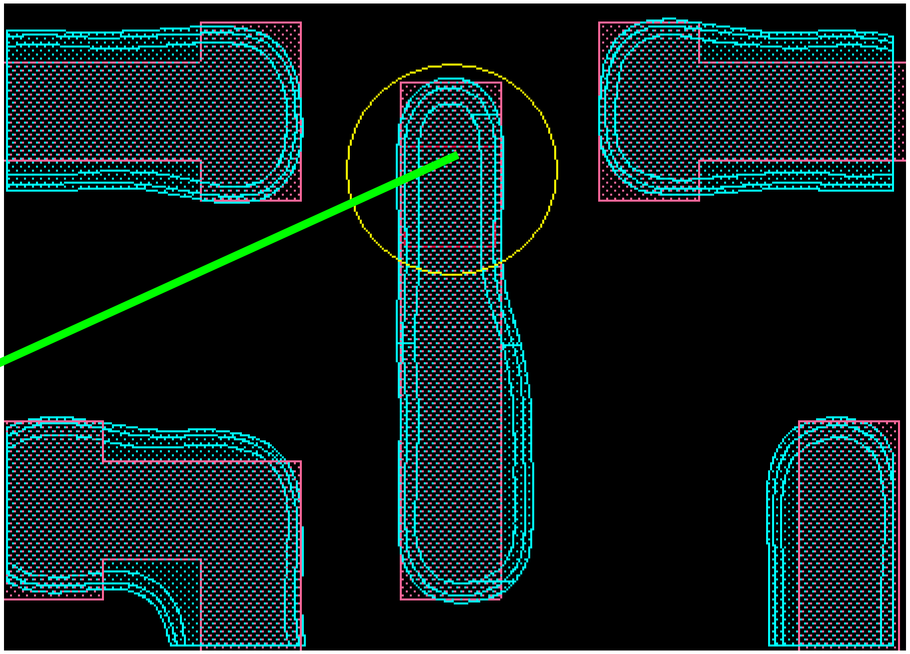

Courtesy of Numerical Technologies

# OPC

- OPC – Optical Proximity Correction
  - Add features to original shapes
  - Hammer Head (Mickey Ear), Line Biasing, Seri



# Lithography Hotspot



Litho Hotspot

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# Previous Work

- M.-C. Tsai, D. Zhang and Z. Tang. “Modeling Litho-Constrained Design Layout.” In *Proc. DAC, pages. 354-357, San Diego, CA, June* 2007
- J. Mitra, P. Yu and D.-Z. Pan. “RADAR: RET-Aware Detailed Routing Using Fast Lithography Simulations.” In *Proc. DAC, pages 369-372,* Anaheim, CA, June 2005
- T.-C. Chen and Y.-W. Chang. Multilevel full-chip gridless routing with applications to optical-proximity correction. *IEEE Trans.CAD* June 2007

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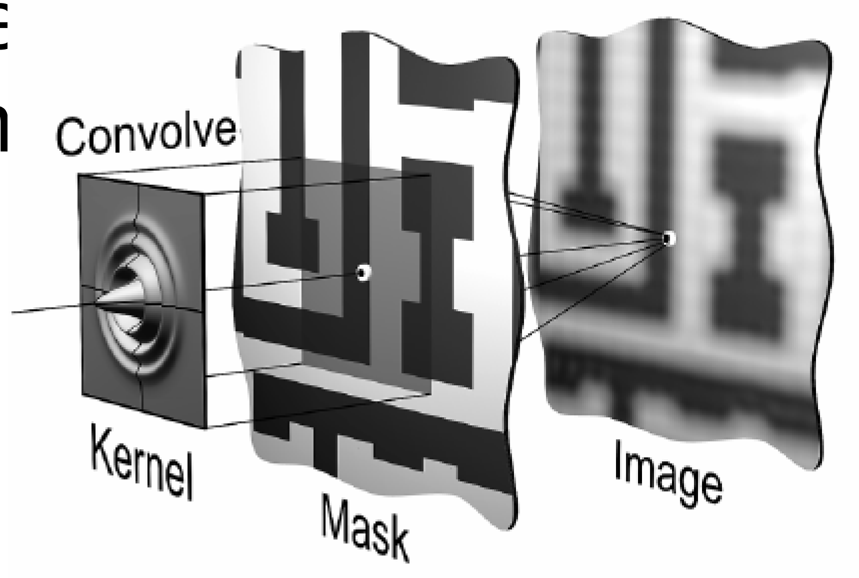
# Our Optical Simulation Engine

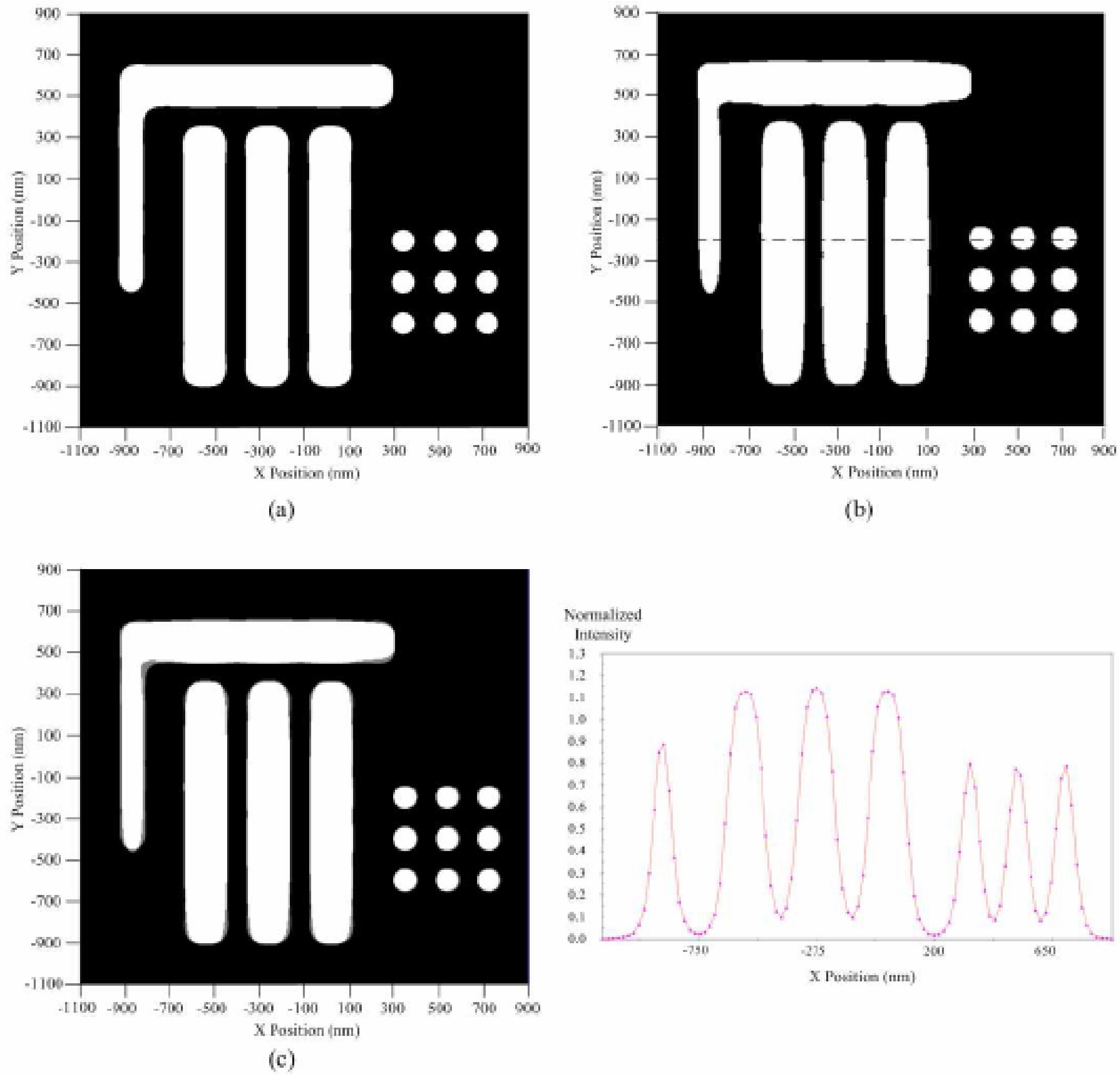
- Derived from Hopkin's equation, the intensity function can be approximated as

$$I(x_i, y_i) \approx \sum_{k=1}^{n} \alpha_k \left|(f \otimes \phi_k)(x_i, y_i)\right|^2,$$

- We ernel fun



# Our Optical Simulation Engine v.s. Prolith Simulation



# Our Optical Simulation Engine v.s. Prolith Simulation

- Skipped detailed manufacturing parameters
- Fast

  \- Our engine: 4 seconds

  \- Prolith: 232 seconds
- Acceptable precision to be used in router.

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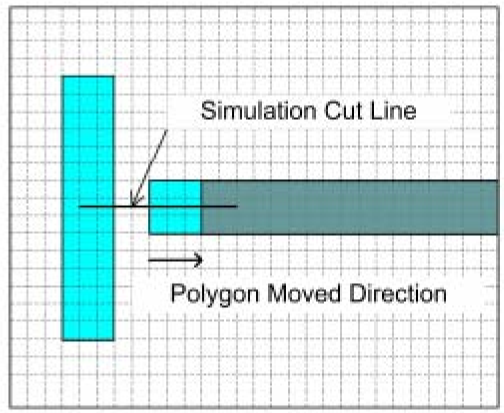
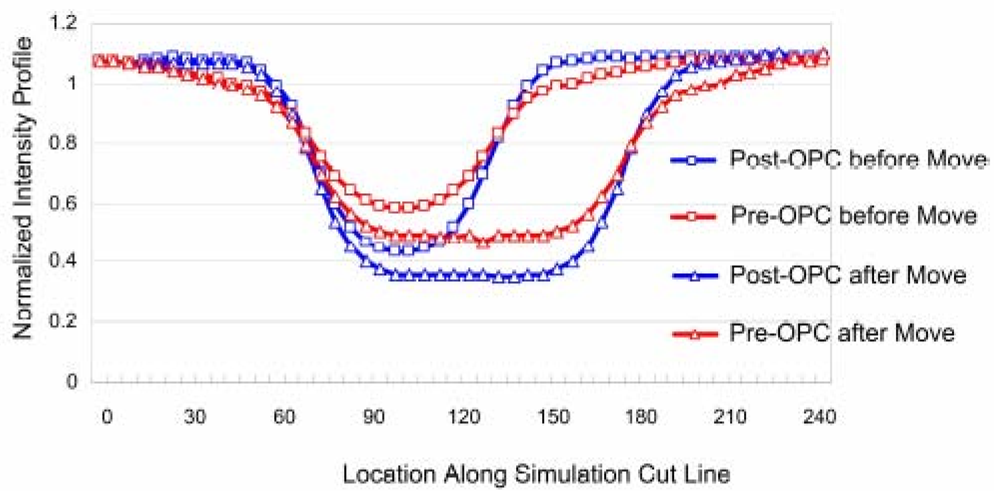
# Pre- v.s. Post-OPC intensity map




(a)




(b)

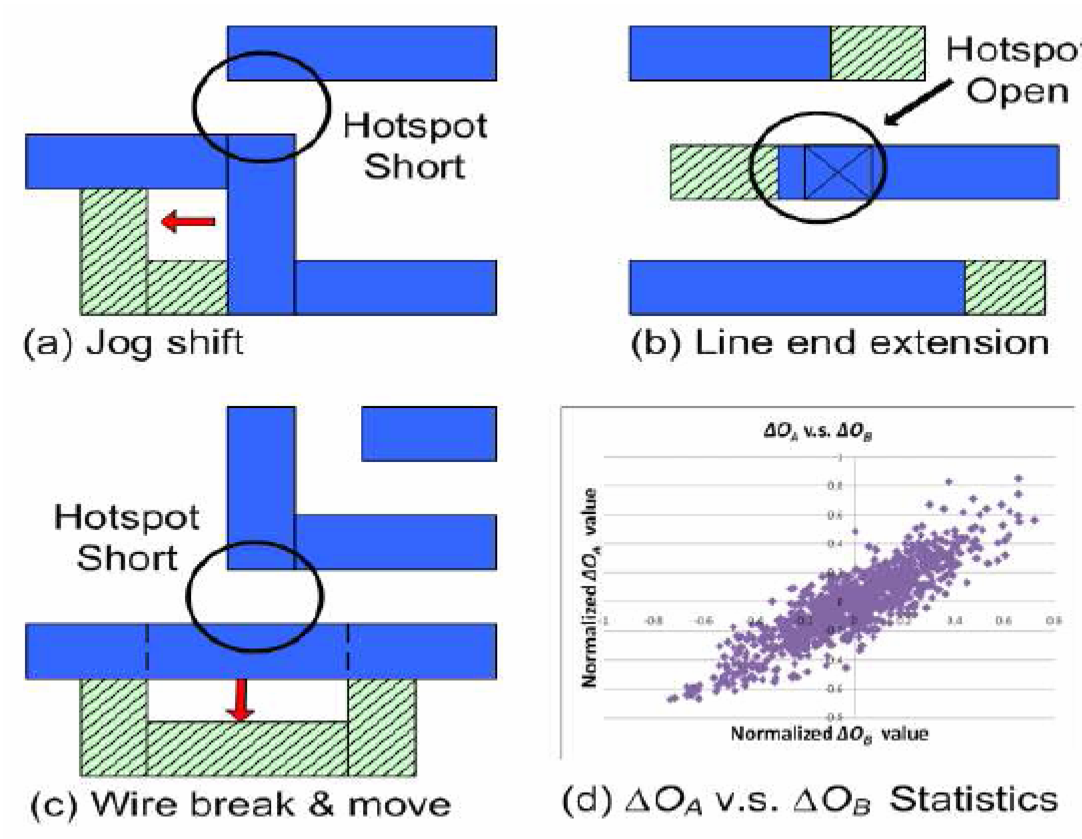
# Pre-OPC v.s. Post-OPC schemes

- Much difference in the simulated contours
- Similarity observed in terms of shape move
- The fix percentage of a HS → Area integration of light intensity

$$\Delta O_A = \int I_A^{posc}(x,y)dxdy - \int I'^{prsc}_A(x,y)dxdy \qquad (6)$$

$$\Delta O_B = \int I_B^{posc}(x,y)dxdy - \int I'^{prsc}_B(x,y)dxdy, \qquad (7)$$

# Correlation Coefficient = 0.88




(a) Jog shift (b) Line end extension

(c) Wire break & move (d) $\Delta O_A$ v.s. $\Delta O_B$ Statistics

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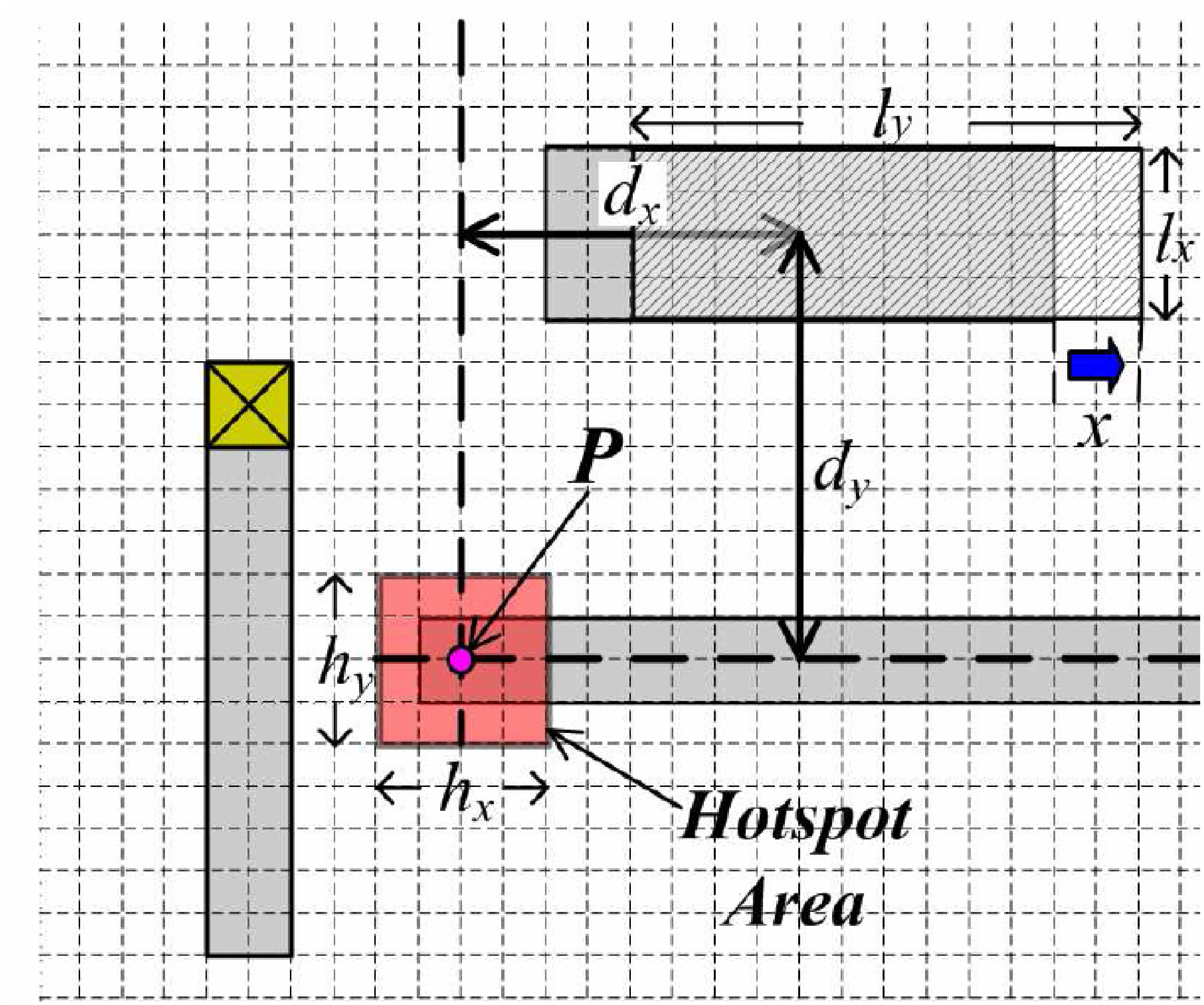
# Optimal Shape Change Amount



# Optimal Shape Change in Taylor Expansion

- Expand $I(x_i, y_i) \approx \sum_{k=1}^{n} \alpha_k \left|(f \otimes \phi_k)(x_i, y_i)\right|^2$, with Taylor Expansion.
- Try every "Manufacturing grid" in the following equation

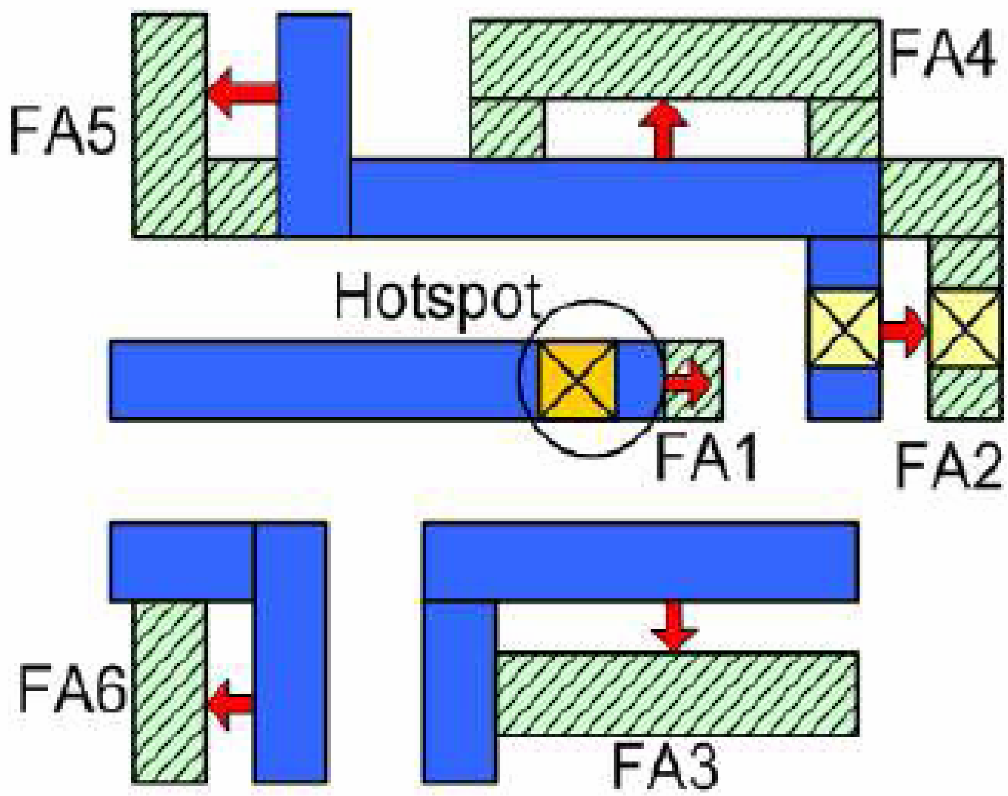
$$I(d_x, d_y) \cong I(a,b) + \frac{1}{1!}[\frac{\partial I(a,b)}{\partial d_x}(d_x - a) + \frac{\partial I(a,b)}{\partial d_y}(d_y - b)] \tag{8}$$

$$+ \ldots + \frac{1}{n!}[\frac{\partial^n I(a,b)}{\partial d_x^{\ n}}(d_x - a)^n + \ldots + \frac{\partial^n I(a,b)}{\partial d_y^{\ n}}(d_y - b)^n]$$

$$R(d_x, d_y) = \frac{1}{(n+1)!}[\frac{\partial^{n+1} I(c_x, c_y)}{\partial d_x^{\ n+1}}(d_x - a)^{n+1} + \ldots + \frac{\partial^{n+1} I(c_x, c_y)}{\partial d_y^{\ n+1}}(d_y - b)^{n+1}], \tag{9}$$

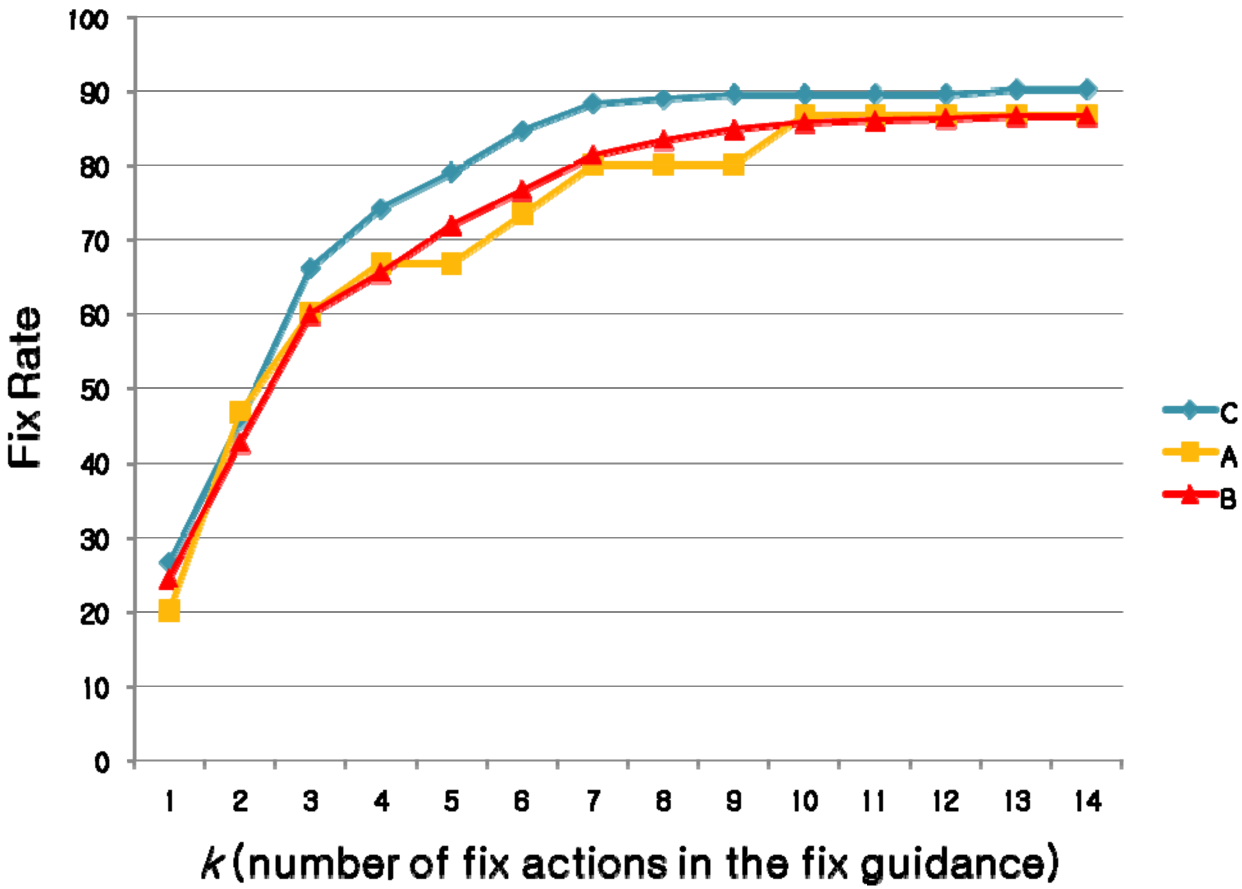
$$(c_x, c_y) \in [(a,b),(d_x, d_y)],\ (d_x, d_y) \in [(a - \frac{h_x}{2}, b - \frac{h_y}{2}),(a + \frac{h_x}{2}, b + \frac{h_y}{2})]$$

# Fix Action v.s. Fix Guidance




FA is "Fix Action",
Fix Guidance is composed by one or several FAs.
For Ex:
FG1 = {FA1}
FG2 = {FA1, FA2}
FG3 = {FA1, FA3, FA4}

# Fix Rate v.s. FA # (K) in FG



# Generate Fix Guidances

- The more FA, the better fix rate
- FG generation Algorithm  (Kmax = 14, ρ= 0.2, from experiments.)

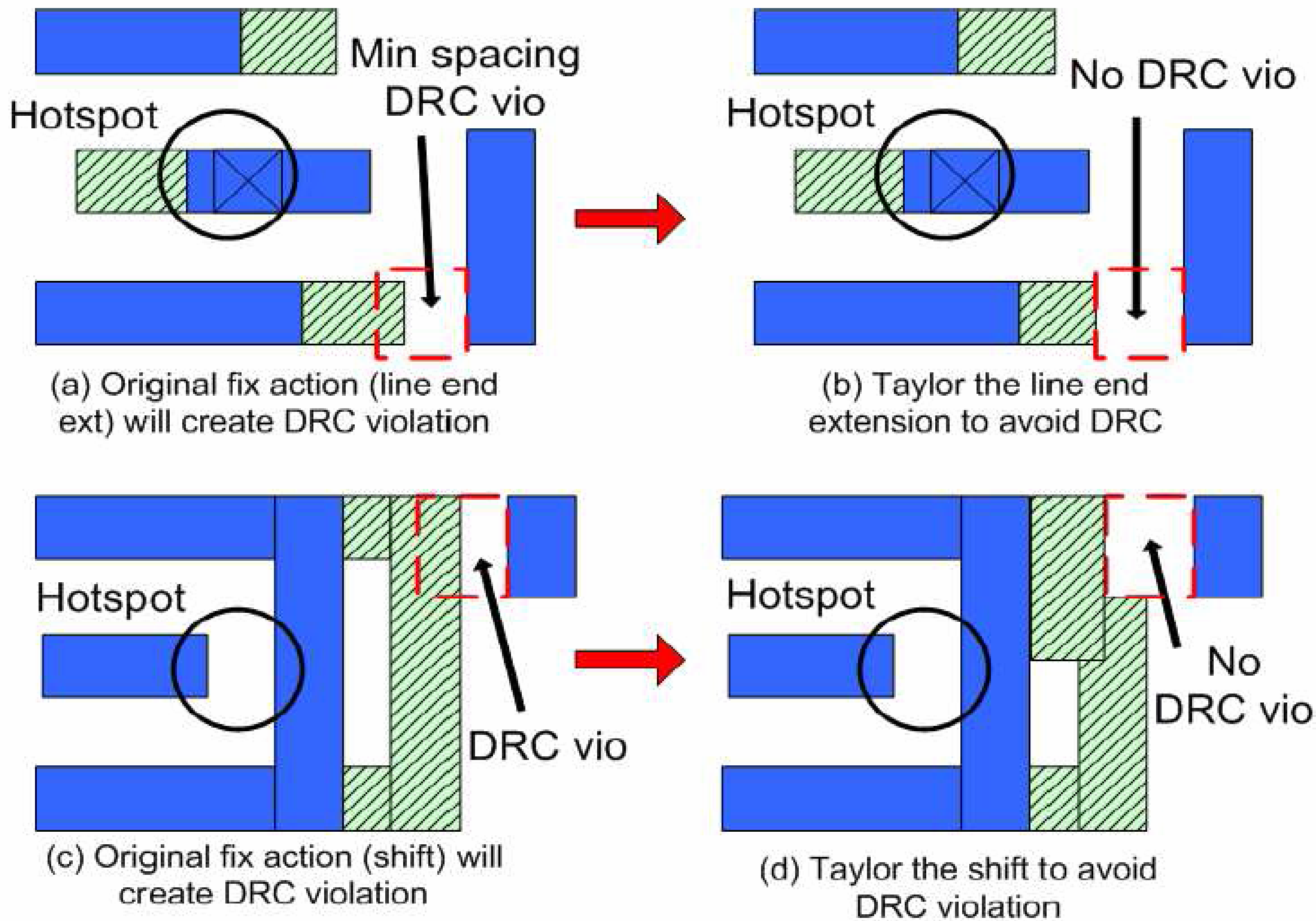
  (1) Get All fix action sets, *Sfa* = { *fa1, fa2*, …}.

  Let *K* = Kmax. *Th* = Intensity_org * ρ.

  (2) Choose *K, K-1, K-2* exclusive FAs from *Sfa* that yields gain > *Th*. Name the set of FG as FGs.

  (3)  Sort FGs according to gain

# DRC Avoidance



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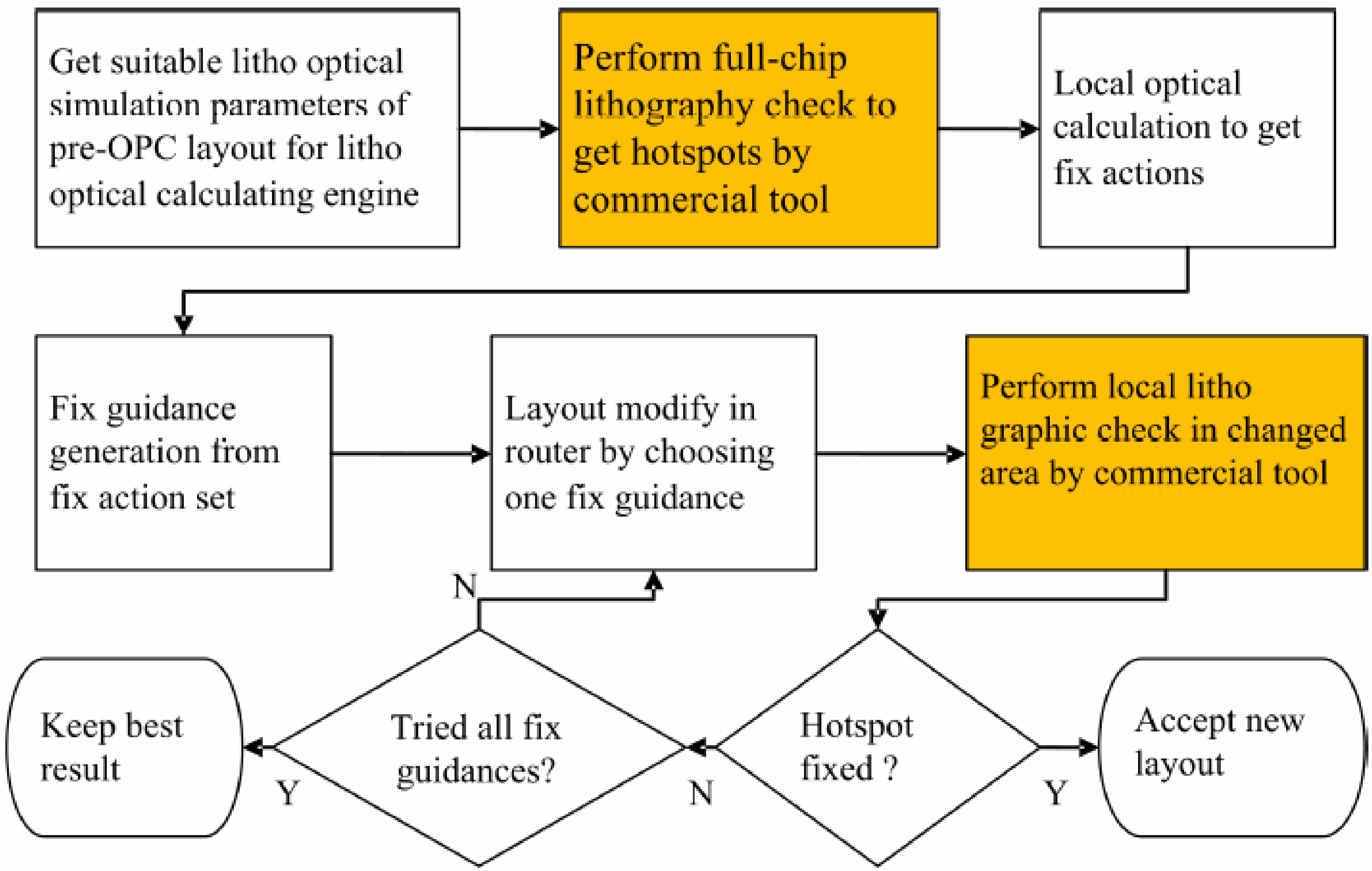
# OSELF Algorithm

```
Algorithm OSELF (design D, hotspot set hss)
Begin
    fix_count = 0
    foreach (hotspot hs in hss) do
        fas = Fix_Action_Set_Generation_By_Aerial_Image_Simulation(D, hs);
        fgs = Fix_Guidance_Set_Generation(fas);
        Sort_Fix_Guidance_By_Gain(fas);
        is_hotspot_clean = False;
        foreach (fix guidance fg in fgs) do
            DRC_number = Try_Fix (D, fg);
            if (DRC_number > 0) then
                Try_Tailor_Fix_Actions (D, fg);
            is_hotspot_clean = Local_Lithographical_Compliance_Check(D, hs);
            if (is_hotspot_clean = True) then do
                Accept_Fix (D, fg);
                break;
        if (is_hotspot_clean = True) then fix_count = fix_count + 1;
end
```

# OSELF Fix Flow



# Time Complexity of Our Alg-Linear

- # of manufacturing grids in one pitch is fixed.
- Constant run time in substituting the positions into Taylor expansion eq.
- Limited # of shape changes to14 in one FG.
- For every changeable shape, the max shape change is 8 (Ext in 4 directions, move in 4 directions)
- Max Fix guidance is limited due to only K, K-1, K-2 fix actions will be selected, max K is 14.

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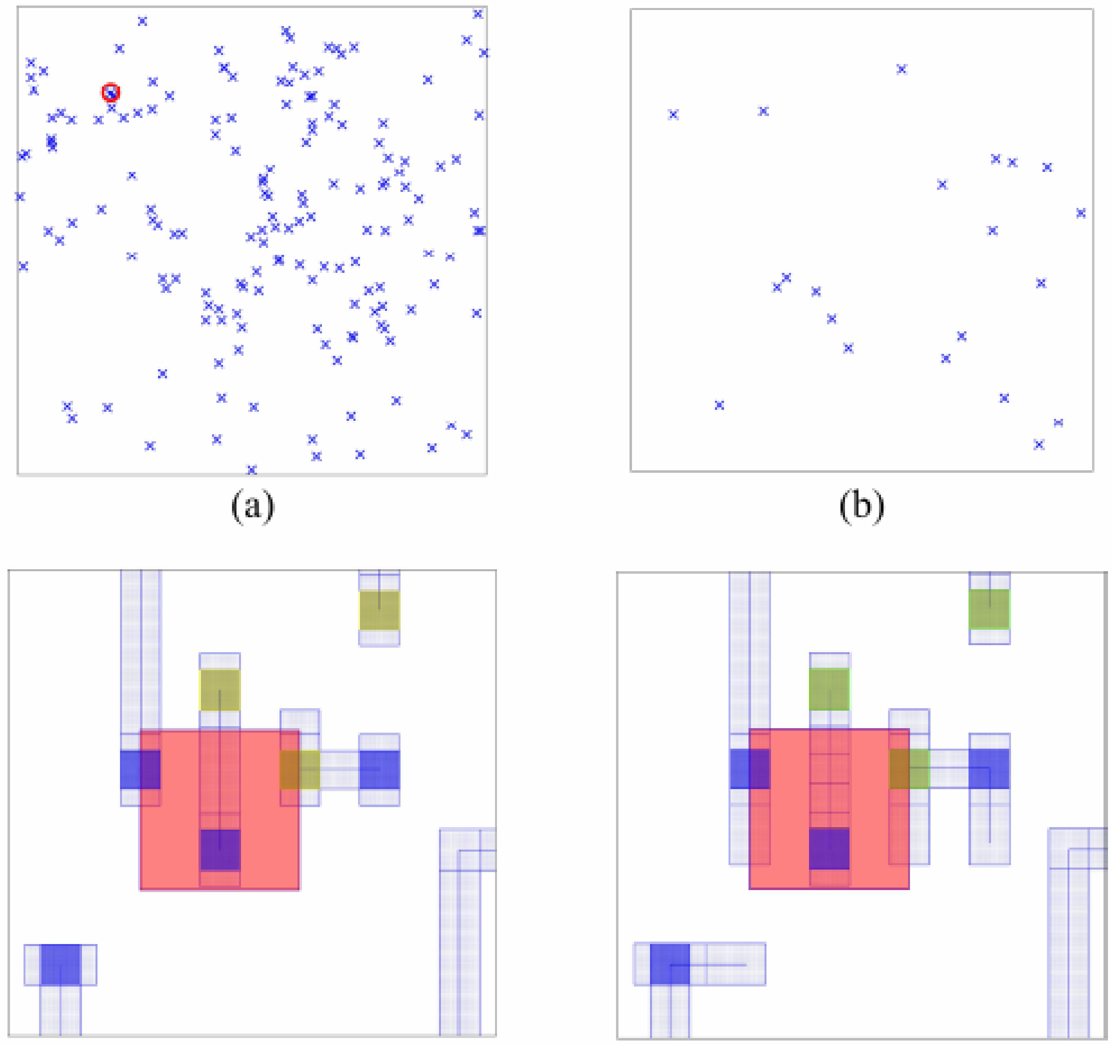
# Testcases

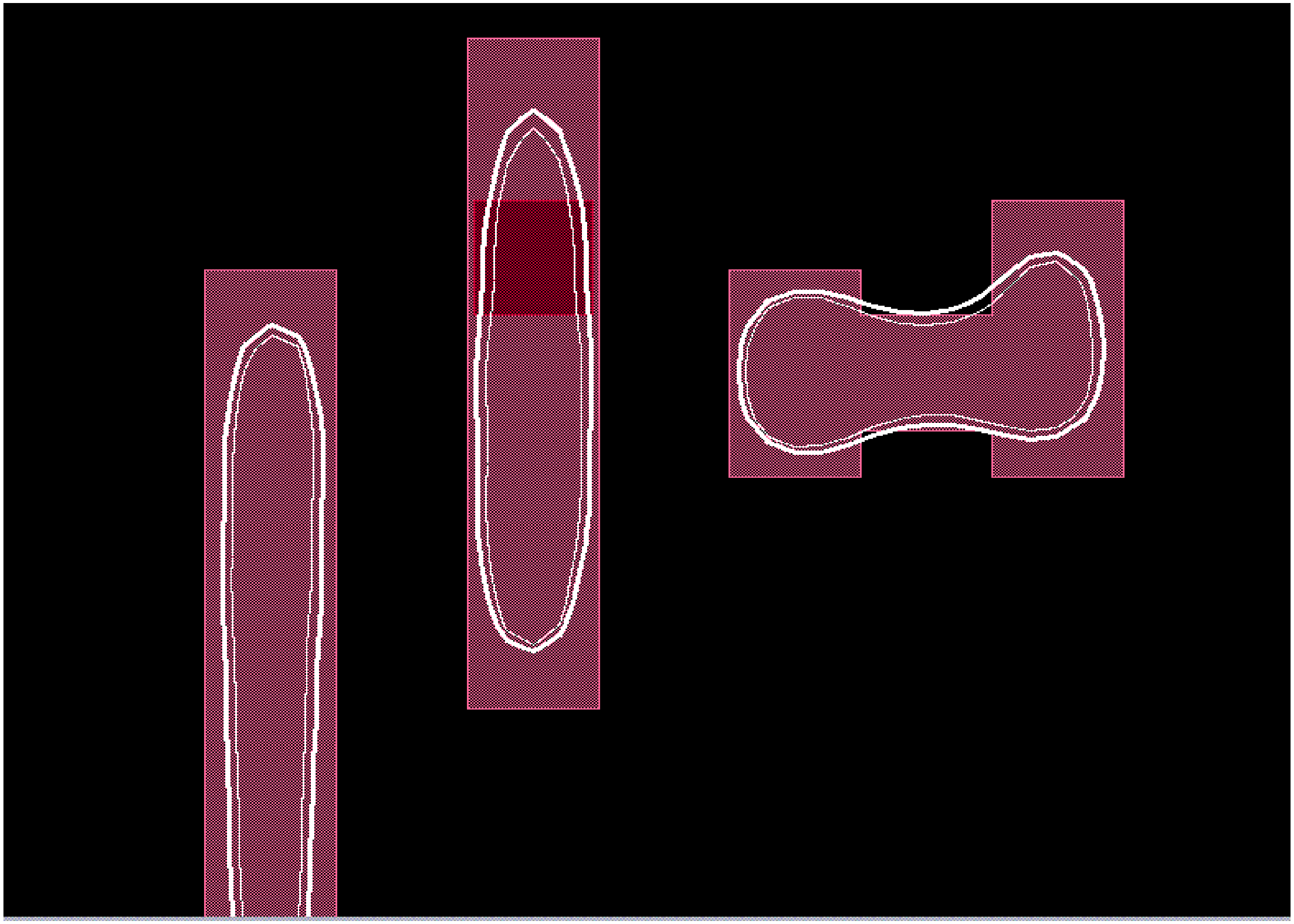
- Testcase info: Three 65-nm industry designs. Pitch: 200 nm (low layers), 400 nm (high layers)
- DVR : Double-Via rate

| Design | Size($mm^2$) | #Layers | #Nets | #Pins | DVR* |
|---|---|---|---|---|---|
| A | 1.5 × 1.5 | 6 | 30981 | 199856 | 3.26% |
| B | 0.9 × 4.0 | 7 | 7915 | 41552 | 59.7% |
| C | 0.6 × 0.6 | 9 | 31290 | 129823 | 45.6% |

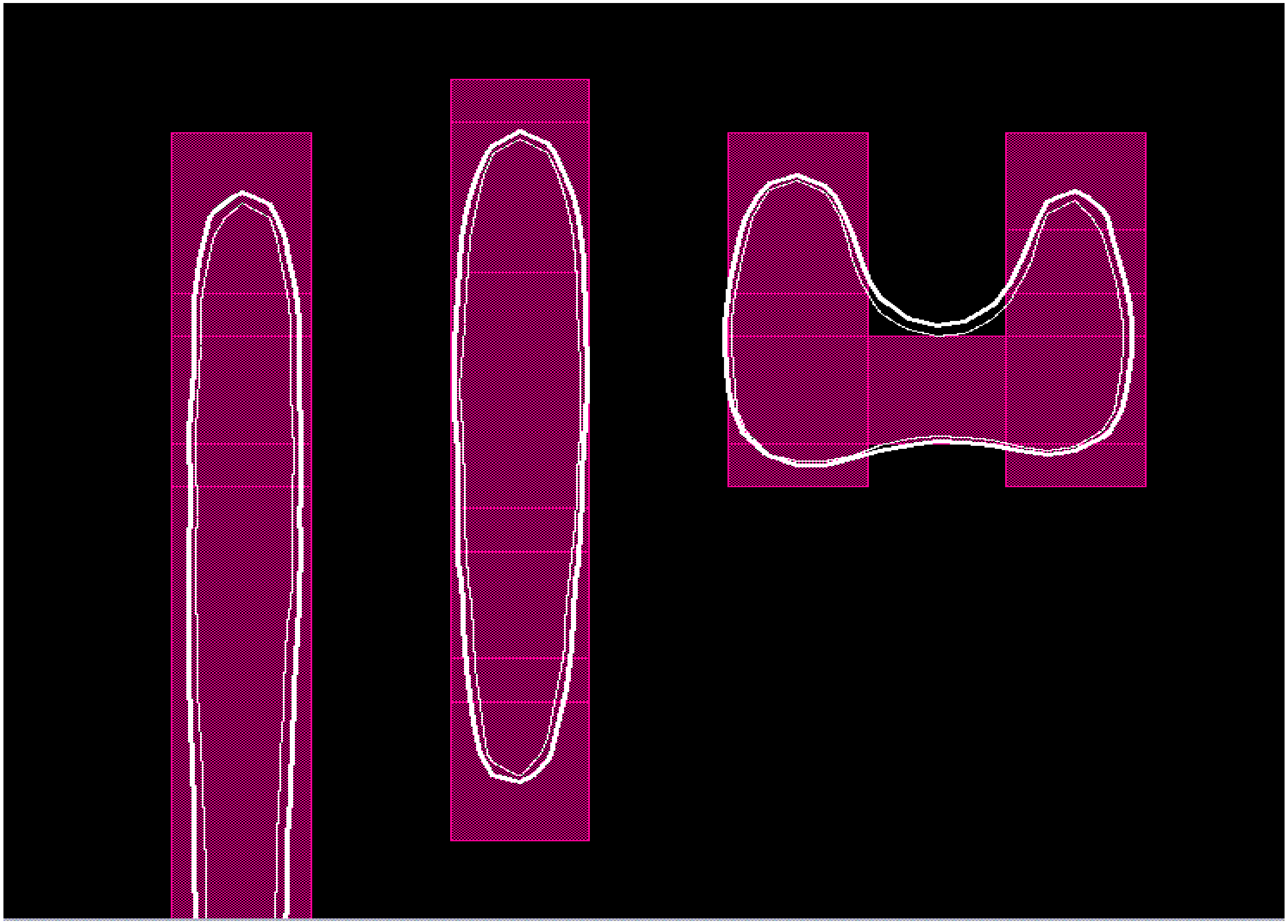
# Experiment Result (1) - OSELF


(a)
(b)
(c)
(d)

# Experiment Result (2) – unfixed HS



# Experiment Result (2) – fixed HS



# Experiment Result (3) - OSELF

- Fix Rate > 86% for three 65-nm real designs
- 1.4X ~ 1.9X fix rate compared with Industry tool.
- No circuit timing impact

| General Info | | Our Flow | | | | Industry Flow | | | |
|---|---|---|---|---|---|---|---|---|---|
| Design | Detected Hotspot Number | Fiexed Hotspot Number | Fix Rate | Run Time (sec) | TNS Impact | Fixed Hotspot Number | Fix Rate | Run Time (sec) | TNS Impact |
| A | 15 | 13 | 86.6% | 26 | 0.00079% | 7 | 46.6% | 31 | 0.00064% |
| B | 341 | 295 | 86.5% | 565 | 0.0046% | 194 | 56.9% | 587 | 0.0039% |
| C | 162 | 146 | 90.1% | 287 | 0.0039% | 95 | 58.6% | 313 | 0.0034% |

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# Conclusions

- Fast optical simulation engine
- 0.88 correlation coefficient between pre-OPC and post-OPC schemes
- Automatic Fix Action generation
- An effective & efficient heuristic to generate Fix Guidance.
- High Fix Rate in OSELF (1.4~1.9X)

Acknowledgements

- Thank for Synopsys RDs to provide suggestions and help.
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# Thank you for your attention!

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