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Accurate Pseudo-Constructive Wirelength and Congestion Estimation

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Outline

- ➔ Wirelength and Congestion Estimation
- Previous Work and Our Contribution
- New Wire Density Model
- Estimation of Detoured Nets
- Experimental Confirmation
- Conclusions and Future Work

Wirelength and Congestion Estimation

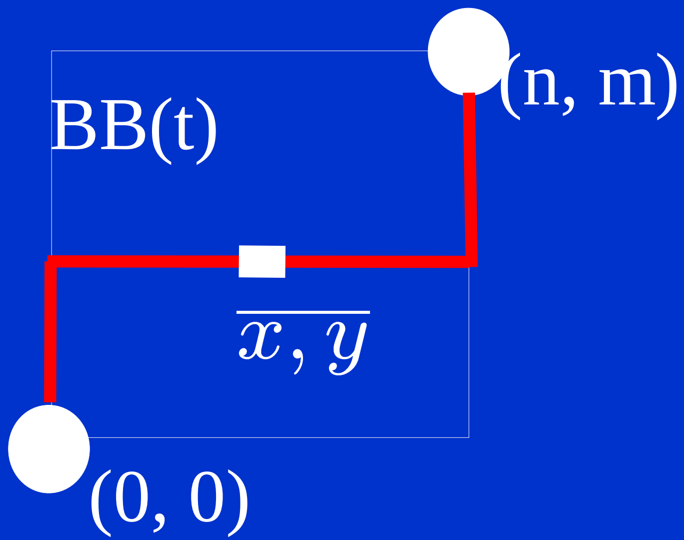
Wirelength and Congestion Estimation Problem

Given: A placed VLSI standard-cell design

Estimate: Total wirelength and congestion

Wire density $D^t(x,y)$

= probability that line segment $\overline{x,y} \in$ BB(t) will be used in the routed path for this connection



BB(t) = Bounding box of net t

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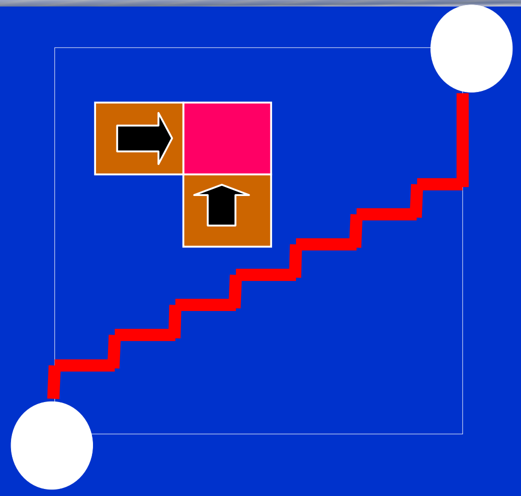
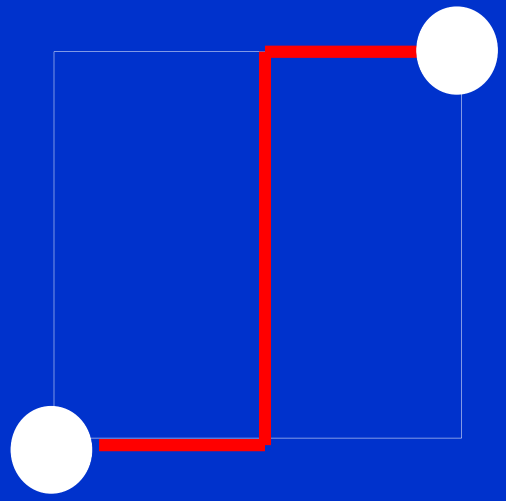
Previous Works and Our Contribution

- Lou et al. (ISPD-2001) assume that every path has the same probability of occurrence



Typical Path

➔ We assume that paths with smaller number of bends have larger probability of occurrence

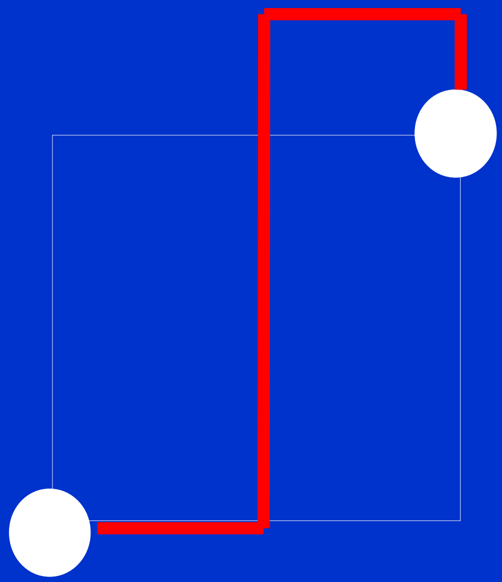


Typical Path

Previous Works and Our Contribution

- Previous probabilistic methods ignore detouring
- WL Estimation = Estimation of RSMT WL

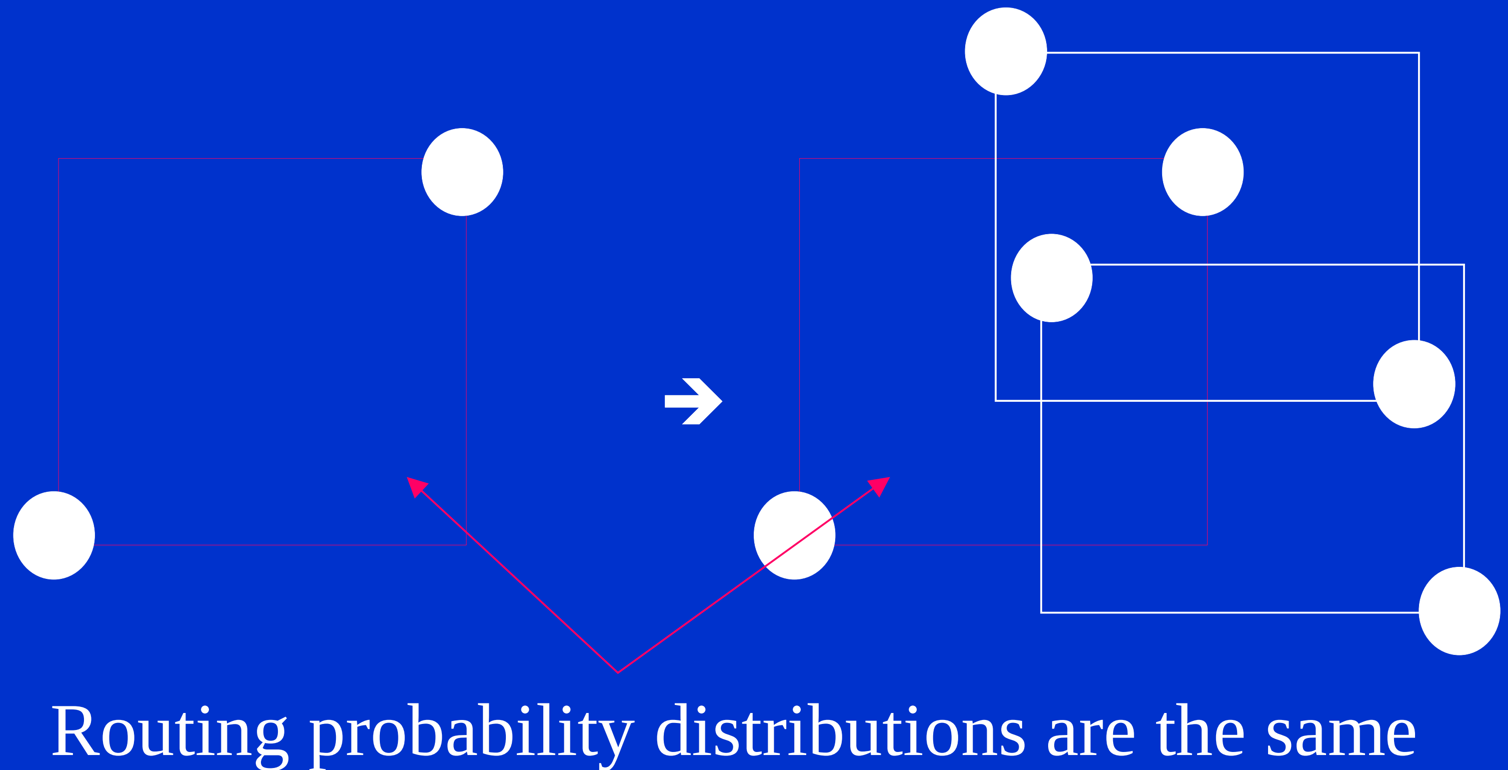
➔ We take detouring into account so that the predicted congestion map can better fit actual routing results



Detoured Path

Previous Works and Our Contribution

- Previous congestion map constructions are “one-shot”



➔ We give an ***iterative*** congestion map construction by considering the interaction between nets

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Bend Distribution

Goal: More practical model for congestion estimation

- Not all paths have same probability of occurrence

  ➔Our model assumes that only paths with the same number of bends have the same probability of occurrence
- Empirical data: Bend distribution is **log-normal**

$$p_b = -0.05 + \frac{1.33}{\sqrt{2\pi}\eta b} e^{-\frac{\ln^2\left(\frac{b}{2.2}\right)}{2\eta^2}}$$

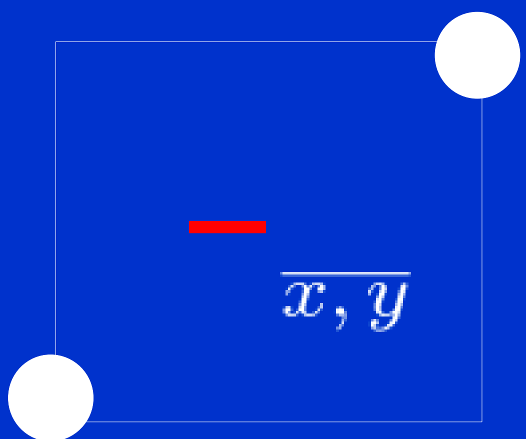
p_b = Probability of b-bend paths

- = 0.6

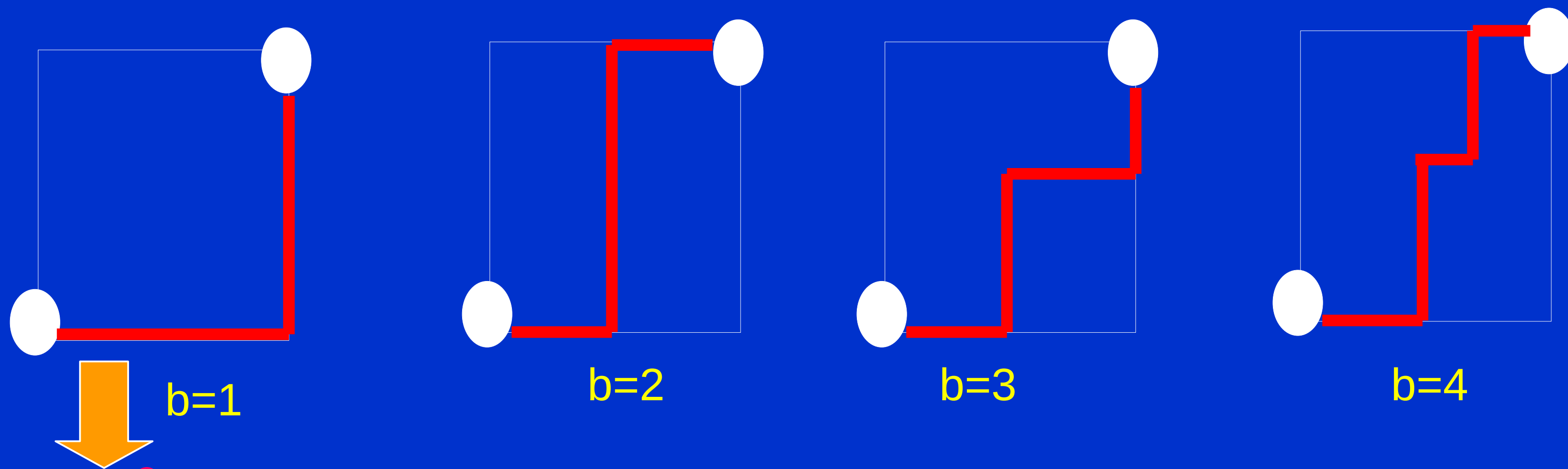
New Wire Density Model

- Fit to observed statistics of routing paths in real layouts
- $\overline{x,y}$ = unit-length segment with left endpoint at (x,y) in the bounding box of net t

$$D_b^t(x,y) = \frac{\#\ b-bend\ paths\ passing\ \overline{x,y}}{Total\ \#\ b-bend\ paths} p_b$$



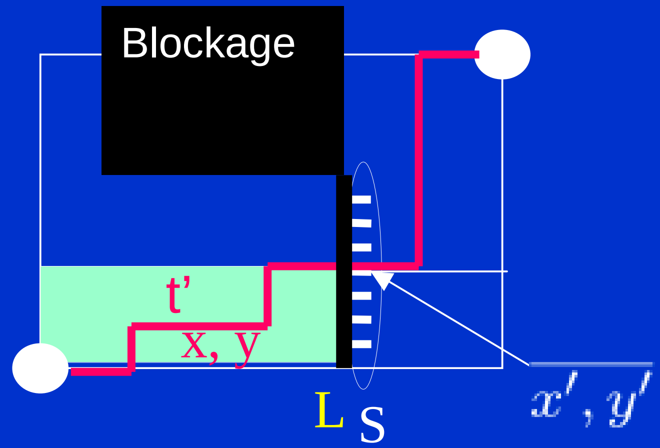
New Wire Density Model



$$D^t(x,y) = \begin{cases} \frac{p_1}{2} + p_2\frac{n-x-1}{n+m-2} + \frac{p_3(n-x-1)}{2(n-1)} + p_4'\frac{n-x-1}{n-1}\frac{n-x-2}{n+m-4} & y=0 \\ \frac{p_1}{2} + p_2\frac{x-1}{n+m-2} + \frac{p_3(x-1)}{2(n-1)} + p_4'\frac{x-1}{n-1}\frac{x-2}{n+m-4} & y=m \\ \frac{p_2}{n+m-2} + \frac{p_3}{2(m-1)} + 2p_4'\frac{(n-x-1)(m+x-y-2)+(x-1)(y-1)+w(x(n-x)-y(n-y))}{(n+m-4)(n-1)(m-1)} & 0<y<m \end{cases}$$

w = Multi-bend factor

Blockage Effect Model



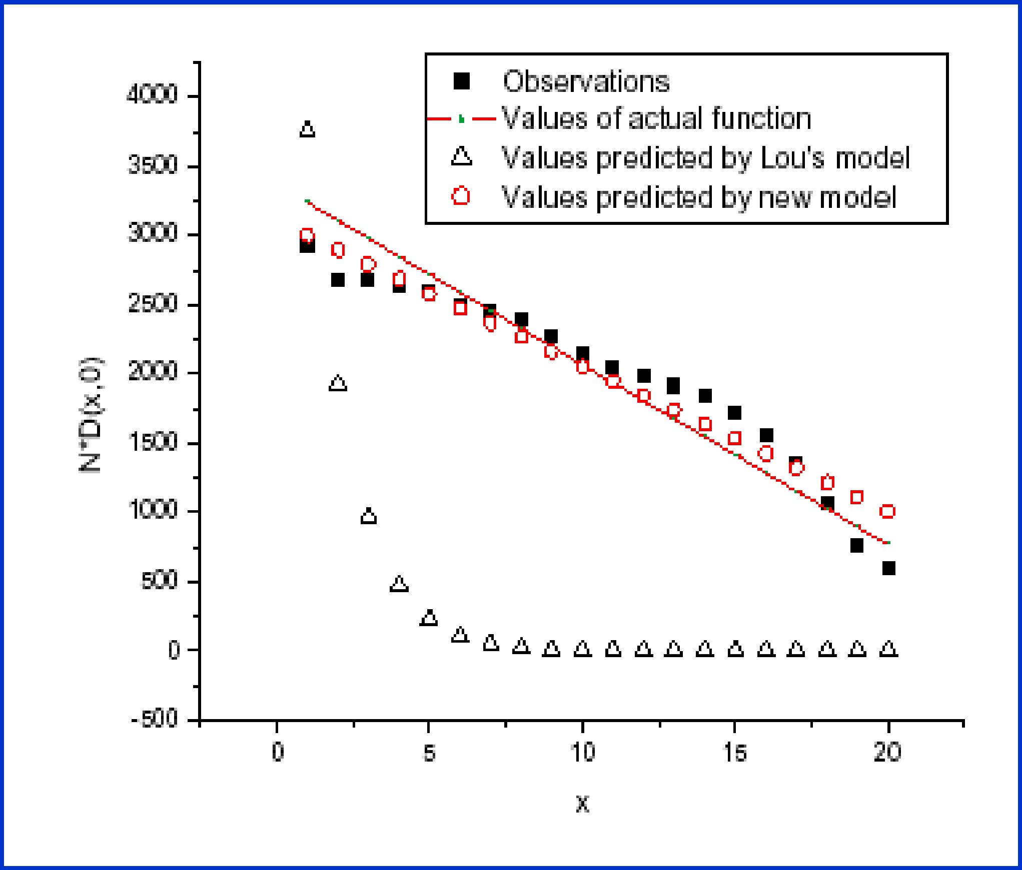
Every path must pass exactly one of line segments in S.

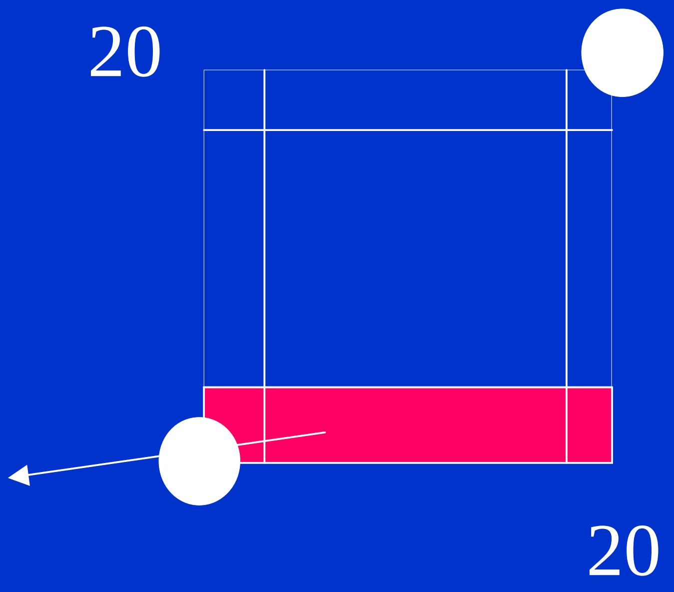
$$D^t(x,y) = \sum_{\overline{x',y'} \in S} P(\overline{x,y}\ routed | \overline{x',y'}\ routed) \bullet P(\overline{x',y'}\ routed)$$

$$P(\overline{x,y}\ routed | \overline{x',y'}\ routed) = D^{t'}(x,y)$$

$$P(\overline{x',y'}\ routed) = \frac{D^o(x',y')}{\sum_{\overline{x',y'} \in S} D^o(x',y')}$$

Testing the New Model





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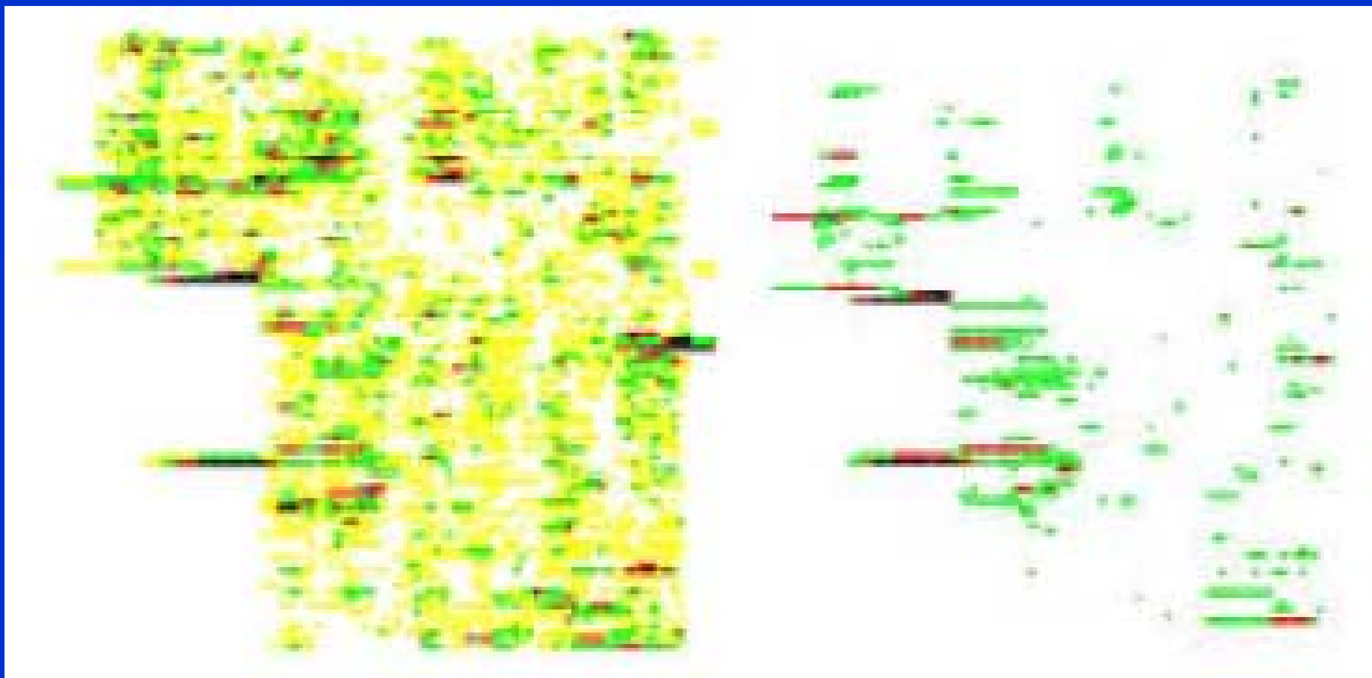
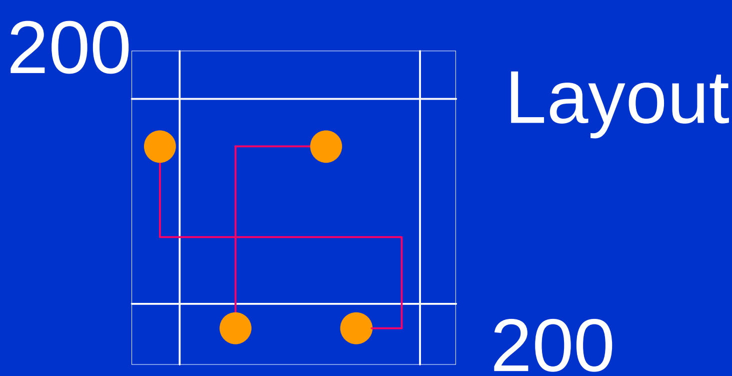
Two Questions to Answer

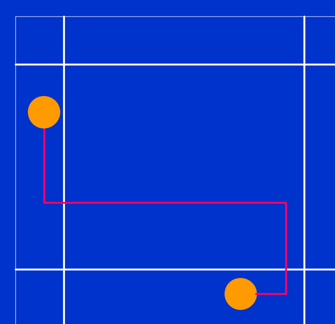
- Which nets will detour?
- How to predict detoured wirelength?

Relationship Between Congestion and Detouring



Detoured nets are around congested regions





Only detoured nets are counted

Congestion_Factor

$$Congestion\_Factor(t) = \frac{1}{F(t)} \sum_{(x,y) \in BB(t)} \{(C(x,y) - D^t(x,y)) \bullet D^t(x,y)\}$$

$F(t)$ = Half-perimeter of $BB(t)$

$C(x, y)$ = Congestion of $\overline{x, y}$

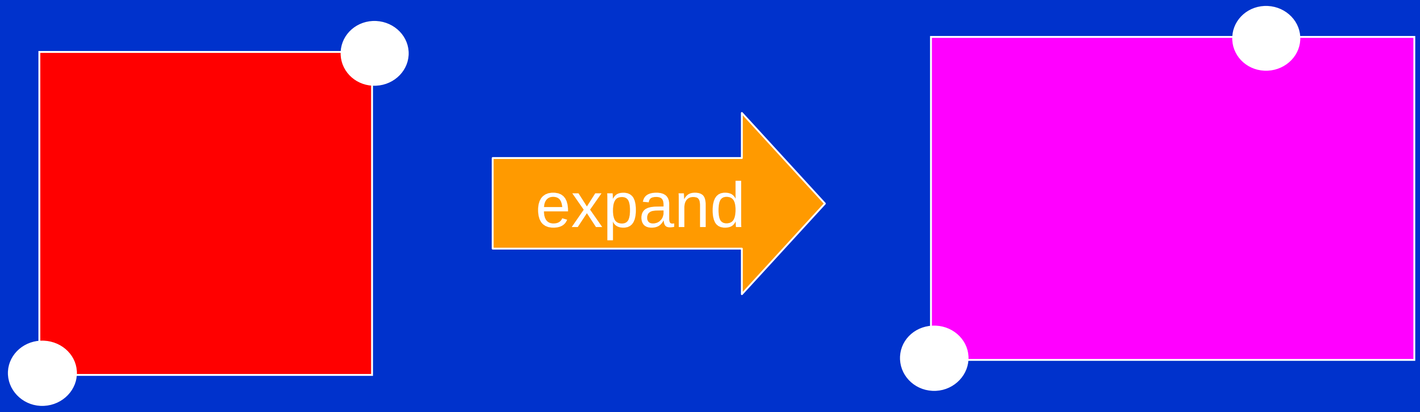
- Well correlated with whether a net will detour
- Hard to estimate the detoured WL, since it also depends on (nets in) the region outside BB(t)

Detour length	# of nets	Avg. Congestion Factor
0	27627	0.36195
[0, 10]	2575	0.930869
[10, 20]	52	1.95588
[20, 30]	22	1.29852
[30, 40]	11	0.780612
[40, 50]	14	1.13645
[50, 60]	4	1.17296
[60, 300]	19	1.65263

Iterative Estimation Method

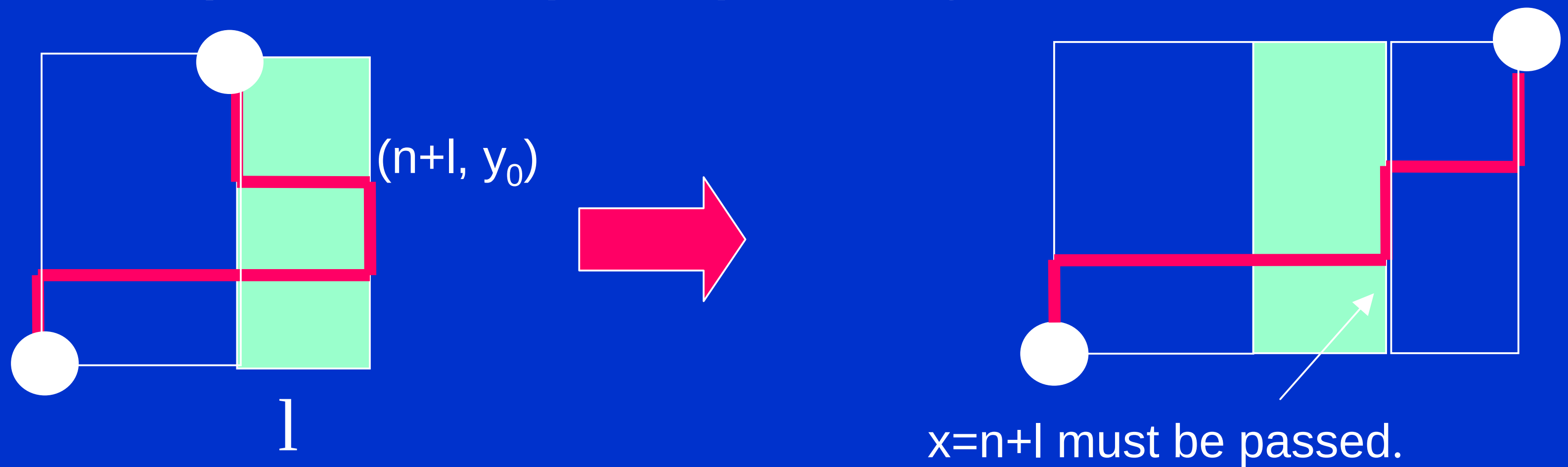
- If Congestion_Factor(t) > a
  ➔Expand the net bounding box in the least congested direction in order to reduce Congestion_Factor(t)
  ➔Recalculate wire density function and Congestion_Factor(t) for detoured nets
  Keep expanding until Congestion_Factor(t) < a for all nets

- Need a model for detoured nets



Detoured Nets Model

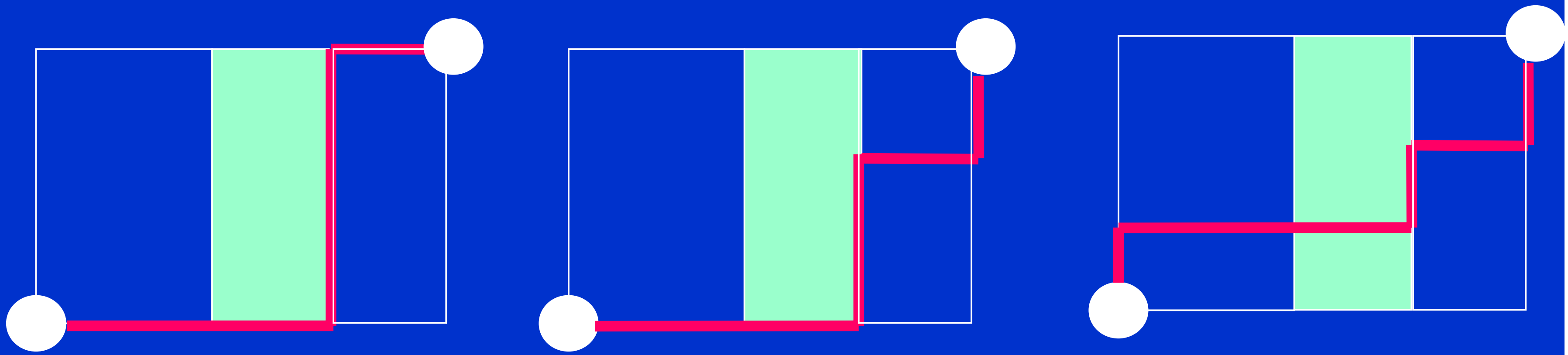
- Main idea: mapping the detoured paths in an n x m grid to paths without detouring in an expanded (n+2l) x m grid.



$$
(x, y) \rightarrow \begin{cases} (x, y) & \text{if } y < y_0 \\ (n+2l-x, y) & \text{otherwise} \end{cases}
$$

l = Detoured wirelength

Detoured Nets Model



b=2 b=3 b=4

$$D^t(x,y) = \begin{cases} p_{d,2} + \frac{p_{d,3}}{2} + \frac{2n+4l-2x-2}{2n+4l+m-6} p'_{d,4} & y = 0 \quad x \in [0, n+l] \\ p_{d,2} + \frac{p_{d,3}}{2} + \frac{2x-2}{2n+4l+m-6} p'_{d,4} & y = m \quad x \in [n+l, n+2l] \\ \frac{p_{d,3}}{2(m-1)} + \frac{2n+4l-2x+2y-4}{(m-1)(2n+4l+m-6)} p'_{d,4} & 0 < y < m \quad x \in [0, n+l] \\ \frac{p_{d,3}}{(m-1)} + \frac{2x+2m-2y-4}{(m-1)(2n+4l+m-6)} p'_{d,4} & 0 < y < m \quad x \in [n+l, n+2l] \end{cases}$$

$p_{d,b}$= Probability of b-bend detoured paths

Congestion_Factor Based Algorithm

Input : Placed netlist with fixed pin location
Output : Total wirelength and congestion map

For each net in the layout
  For each line segment
    calculate wire density and update its congestion
For each net t in the layout
    calculate Congestion_Factor(t)
While (the maximum of Congestion_Factor > a)
    expand BB(t) by 1 unit in the least congested direction
    and recalculate the Congestion_Factor(t)

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Experimental Setup

- Five industry designs obtained as LEF/DEF files
- Divide the layout into 40000 equal regions
- Output includes total wirelength and congestion
- Output results are compared with actual routing results of a commercial detailed router, Cadence WarpRoute

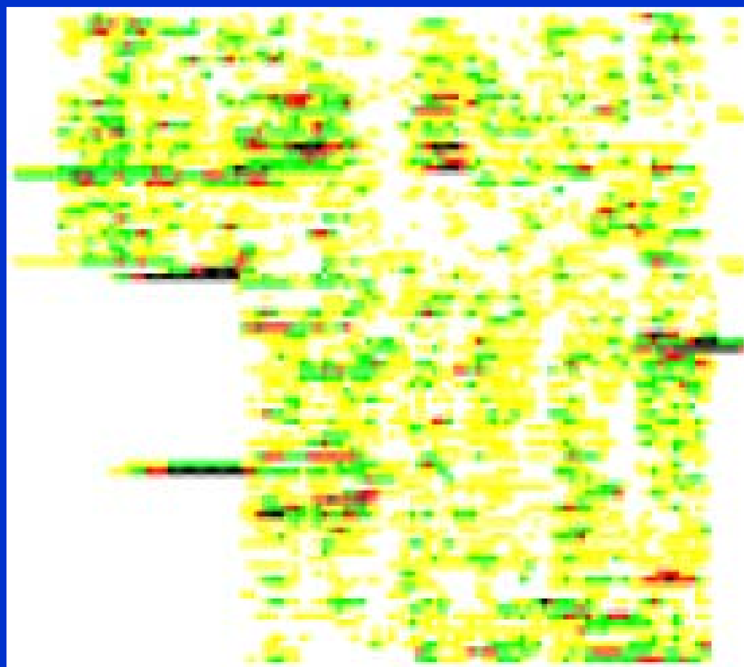
Comparison of Total Wirelength

Test case	RSMT_WL	Actual_WL	Congestion_Factor Based		
			Est. WL	improve	CPU
A	4.249	4.389	4.381	94%	15.69
B	3.214	3.317	3.307	78%	7.64
C	5.345	5.507	5.517	97%	3.37
D	2.190	2.372	2.368	93%	23.51
E	6.673	6.821	6.808	89%	7.91

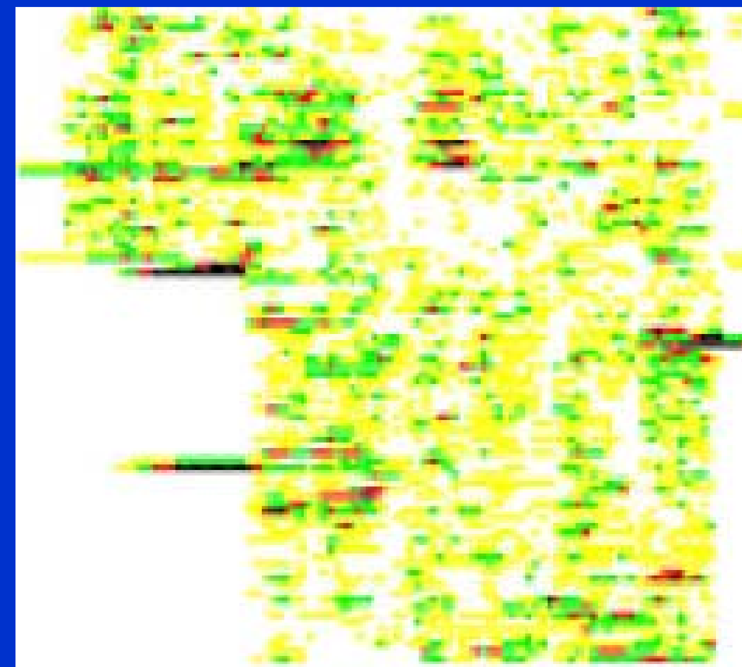
$$improve = \frac{|RSMT\_WL - Actual\_WL| - |Est\_WL - Actual\_WL|}{|RSMT\_WL - Actual\_WL|}$$

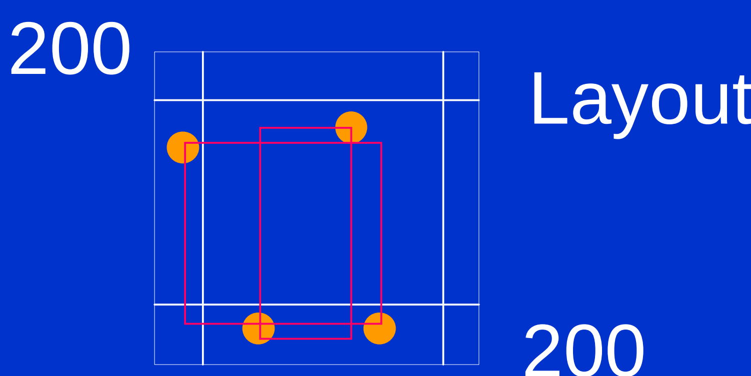
Comparison of Congestion Maps

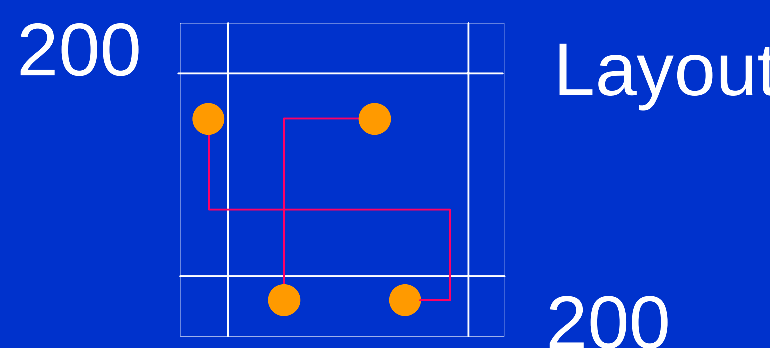
Estimated



Actual







Comparison of Estimation Quality

Testcase		A	B	C	D	E
Lou's Model	μ	0.903	0.878	0.911	0.923	1.235
	σ	1.227	1.352	1.124	0.946	1.672
	CPU	15.24	7.56	4.67	22.65	8.13
New Model	μ	0.951	1.037	0.962	0.981	1.102
	σ	1.134	0.621	0.721	0.545	1.024
	CPU	6.89	3.12	1.36	9.27	3.28
New Model +CF	μ	0.963	1.031	0.991	0.987	1.057
	σ	0.689	0.566	0.707	0.323	0.813
	CPU	15.69	7.64	3.37	23.51	7.91

$$\mu \equiv \frac{\sum_{i=1}^{40000} \left(\frac{\sum_{x,y\in r_i} C(x,y)}{\sum_{x,y\in r_i} \delta(x,y)} \right)}{40000}$$

$$\sigma \equiv \sqrt{\frac{\sum_{i=1}^{40000} \left(\frac{\sum_{x,y\in r_i} C(x,y)}{\sum_{x,y\in r_i} \delta(x,y)} - 1 \right)^2}{40000-1}}$$

Ideal values: μ=1 and σ =0

Metrics proposed in Kannan et al. DAC-2002

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Conclusions / Future Work

- New, accurate wirelength and congestion estimation methods
- Improve the wirelength estimation accuracy by 90% on average with respect to the traditional RSMT wirelength estimate
- More accurate congestion maps than current estimation methods

- Include new estimator into a placer