Estimation of Wirelength Reduction for λ-Geometry vs. Manhattan Placement and Routing

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Outline

- Introduction
- λ-Geometry Routing on Manhattan Placements
- λ-Geometry Placement and Routing
- Conclusion

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- Introduction
  - Motivation
  - Previous estimation methods
  - Summary of previous results
- λ-Geometry Routing on Manhattan Placements
- λ-Geometry Placement and Routing
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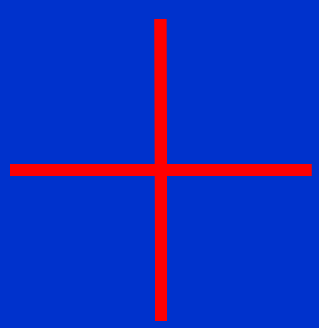
Motivation

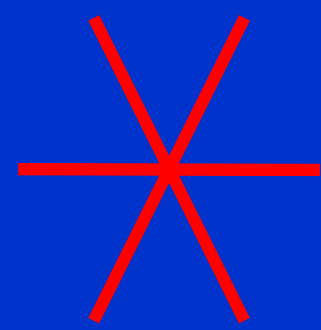
- Prevalent interconnect architecture = Manhattan routing
  - 2 orthogonal routing directions
  - Significant added WL beyond Euclidean optimum (up to 30% longer connections)
- Non-Manhattan routing
  - Requires non-trivial changes to design tools
- Are the WL savings worth the trouble?
  - Problem: Estimate WL reduction when switching from Manhattan to Non-Manhattan routing

λ-Geometry Routing

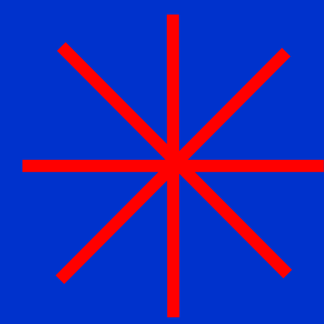
- Introduced by [Burman et al. 1991]
  - λ uniformly distributed routing directions
  - Approximates Euclidean routing as λ approaches infinity



$\lambda = 2$
Manhattan routing



$\lambda = 3$
Hexagonal routing



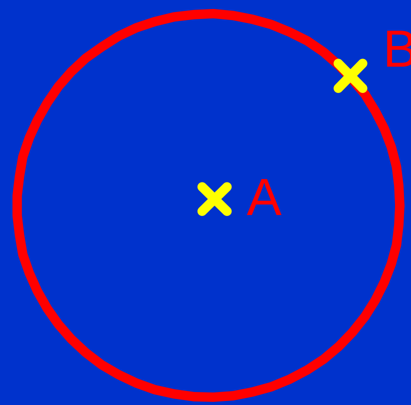
$\lambda = 4$
Octilinear routing

Previous Estimates (I)

- LSI patent [Scepanovic et al. 1996]
  - Analysis of average WL improvement with hexagonal and octilinear routing for randomly distributed 2-pin nets
  - 2-pin net model: one pin at the center, second pin **uniformly distributed on unit Euclidean circle**

➔ **13.4%** improvement with hexagonal routing

➔ **17.2%** improvement with octilinear routing



Previous Estimates (II)

- [Chen et al. 2003]
  - Analysis of average WL with λ-geometry routing for **randomly distributed 2-pin nets**

→ratio of expected WL in λ-geometry to expected Euclidean length:

$$\frac{2\lambda(1-\cos(\pi/\lambda))}{\pi\sin(\pi/\lambda)}$$

→average WL overhead over Euclidean

λ = 2	λ = 3	λ = 4
27.3%	**10.3%**	**5.5%**

Previous Estimates (III)

- [Nielsen et al. 2002]
  - **Real VLSI chip (Manhattan-driven placement)**
  - 180,129 nets ranging in size from 2 to 86 pins (99.5% of the nets with 20 or fewer pins)
  - Compute for each net **λ-geometry Steiner minimum tree (SMT)** using GeoSteiner 4.0

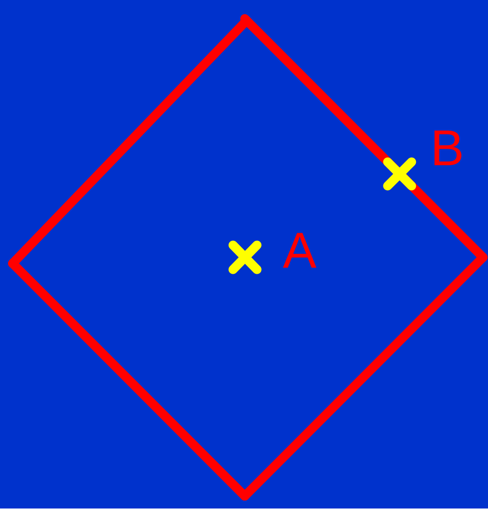
  ➔ WL reduction of λ-geometry SMT vs. rectilinear SMT:

$\lambda = 3$	$\lambda = 4$	$\lambda = \infty$
5.9%	**10.6%**	**14.3%**

Previous Estimates (IV)

- [Teig 2002]
  - Notes that placement is not random, but driven by Steiner tree length minimization in the prevailing geometry
  - Manhattan WL-driven placed 2-pin net model: one pin at center, second pin **uniformly distributed on rectilinear unit circle**

  ➔ **14.6%** improvement with octilinear routing



$$1 - \frac{\int_0^{1/2} ((\sqrt{2}-2)y+1)\,dy}{\int_0^{1/2} 1\,dy} \approx 14.6\%$$

Previous Estimates (V)

- [Igarashi et al. 2002], [Teig 2002]
  - **Full commercial design** (Toshiba microprocessor core)
  - **Placed and routed with octilinear-aware tools**

  ➔ **>20%** wire length reduction

Which Estimate Is Correct?

Reference	$\lambda = 3$ (hexagonal)	$\lambda = 4$ (octilinear)	Model
Scepanovic, Chen et al.	**13.4%**	**17.2%**	2-pin nets Random
Nielsen et al.	**5.9%**	**10.6%**	Full chip, Manhattan placement SMT routing
Teig	--	**14.6%**	2-pin nets Manhattan circle
Igarashi et al.	--	**>20%**	Full chip, octilinear placement & routing

Our Contributions

- Estimation models combining analytic elements with constructive methods
- Separate models for
  - λ-geometry routing on Manhattan placements
  - λ-geometry routing on λ-geometry-driven placements
- Novel model features:
  - Consideration of net size distribution (2,3,4 pins)
  - Uniform estimation model for arbitrary λ

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  - 2-pin nets
  - 3-pin nets
  - 4-pin nets
  - Estimation results
- λ-Geometry Placement and Routing
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λ-Geometry Routing on Manhattan Placements

- We extend Teig's idea to K-pin nets
  - Assuming Manhattan WL-driven placer

  ➔ Placements with the same rectilinear SMT cost are equally likely
- High-level idea:
  - Choose uniform sample from placements with the same rectilinear SMT cost
  - Compute the average reduction for λ-geometry routing vs. Manhattan routing using GeoSteiner

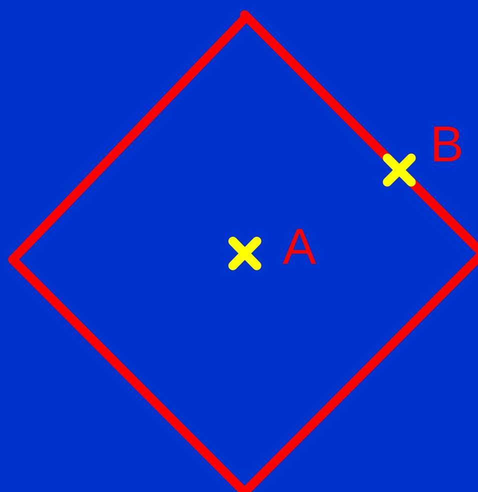
2-Pin Nets

- Average λ-geometry WL computed by integrals:

$$\lambda = 3: \int_{0}^{\frac{1}{1+\frac{1}{\sqrt{3}}}} \left(1 - y + \frac{y}{\sqrt{3}}\right) dy + \int_{\frac{1}{1+\frac{1}{\sqrt{3}}}}^{1} \frac{2y}{\sqrt{3}} dy \approx 0.89434$$

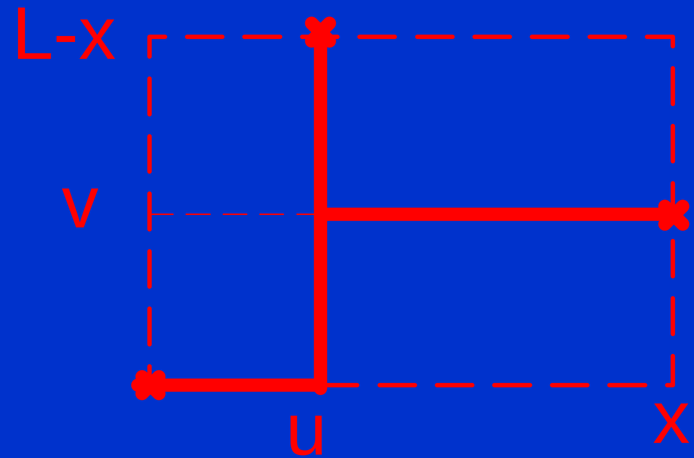
$$\lambda = 4: 2\int_{0}^{\frac{1}{2}} (1 - y + (\sqrt{2} - 1)y) dy \approx 0.85355$$

$$\lambda = \infty: \int_{0}^{1} \sqrt{(1-y)^2 + y^2} dy \approx 0.81161$$

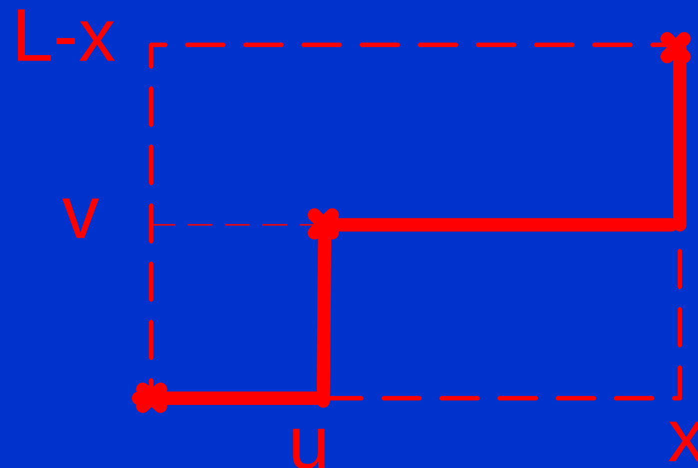


3-Pin Nets (I)

- SMT cost L = half perimeter of bounding box
- Given a bounding box (length x ≤ L), uniformly sample all 3-pin nets within this bounding box by selecting (u, v) (u ≤ x; v ≤ L-x) uniformly at random
- Each pair (u, v) specifies two 3-pin nets
  - canonical case
  - degenerate case



Canonical case



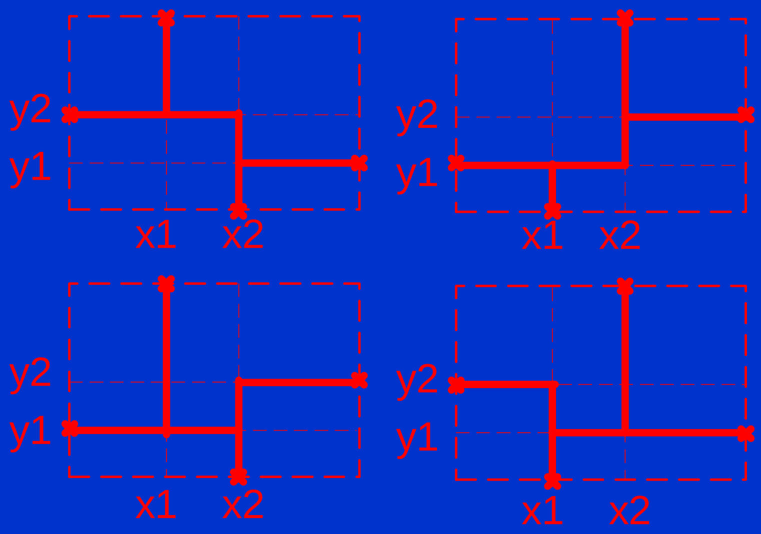
Degenerate case

3-Pin Nets (II)

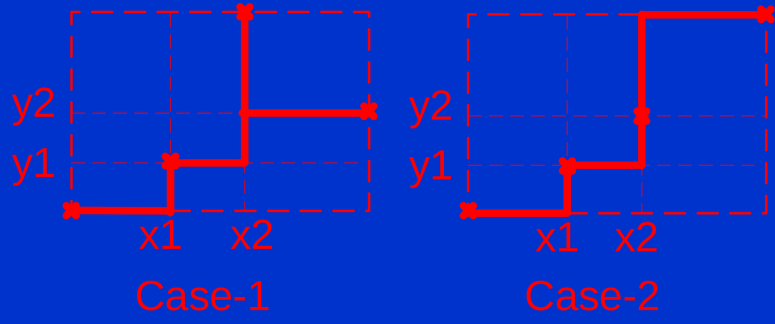
- (u, v) : a point in the rectangle with area x(L-x)
  - Probability for a 3-pin net within this bounding box to be sampled: inverse to x(L-x)
  - Sample the bounding box (length x) with probability proportional to x(L-x)
- Symmetric orientations of 3-pin nets
  - Multiply the WL of canonical nets by 4
  - Multiply the WL of degenerate nets by 2

4-Pin Nets (I)

- Given a bounding box with unit half perimeter and length x ($x \le 1$), each tuple (x1, x2, y1, y2) ($x1 \le x2 \le x$; $y1 \le y2 \le 1-x$) specifies
  - Four canonical 4-pin nets
  - Four degenerate case-1 4-pin nets
  - Two degenerate case-2 4-pin nets



Canonical case



Degenerate cases

4-Pin Nets (II)

Procedure:

- Sample the bounding box (unit half perimeter and length x) with probability proportional to $x^2(1-x)^2$
  - (x1, x2, y1, y2) : two points in the rectangle with area x(1-x)
- Uniformly sample 4-pin nets with the same bounding box aspect ratio:
  - by selecting (x1, x2, y1, y2) uniformly at random
- Scale all 4-pin nets: same SMT cost L
- Compute WL using GeoSteiner
- Weight the WLs for different cases to account for orientation

Estimated % Improvement Over Manhattan Routing

Net size	λ = 3		λ = 4		λ = ∞	
	M-driven	Rand	M-driven	Rand.	M-driven	Rand.
k = 2	10.57	13.52	14.65	17.14	18.84	21.47
k = 3	5.86	7.55	10.75	12.41	14.61	16.21
k = 4	5.45	6.56	9.89	11.26	13.30	14.80
Average	8.70	11.05	13.00	15.11	16.97	19.19

- “M-driven” = our sampling methodology simulating Manhattan WL-driven placement
- “Rand” = pointsets chosen randomly from unit square
- “Average” = Expected WL improvement based on net size distribution in [Stroobandt et al. 98]

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λ-Geometry Placement and Routing

- Manhattan vs. λ-geometry-aware placer
  - Manhattan placer tends to align circuit elements either vertically or horizontally

    ➔ impairs WL improvement of λ-geometry routing
  - λ-geometry-aware placer leads to better placements of nets for λ-geometry routing

Simulated Annealing Placer

- Objective: Min total λ-geometry SMT length
- Random initial placement
- Randomly select two cells and decide whether to swap based on the current annealing temperature and new SMT cost
- Time spent at current temperature:

  # swaps ~= 100 * #cells [Sechen 1987]
- Cooling schedule:
  - Next temperature = current temperature * 0.95

%WL Improvement for λ-Geometry over Manhattan Place&Route

Instance	#nets	λ = 3	λ = 4	λ = ∞
C2	601	3.43	8.92	11.04
BALU	658	3.96	9.29	11.07
PRIMARY1	695	5.67	10.31	13.03
C5	1438	6.24	11.48	12.73

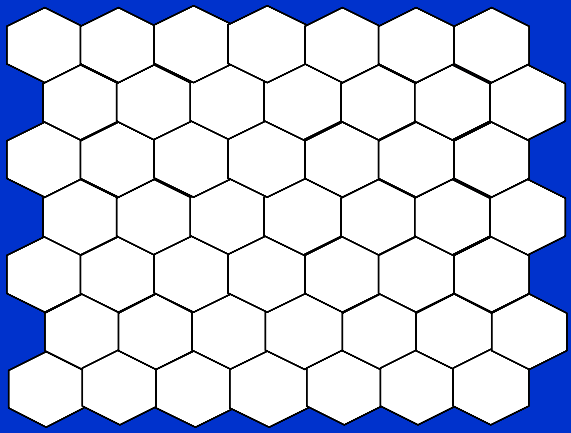
- For λ = 3, WL improvement up to 6%
- For λ = 4, WL improvement up to 11%

Cell Shape Effect for λ = 3

Instance	#nets	square cell	hex. cell
C2	601	3.43	4.81
BALU	658	3.96	7.13
PRIMARY1	695	5.67	7.32
C5	1438	6.24	8.34

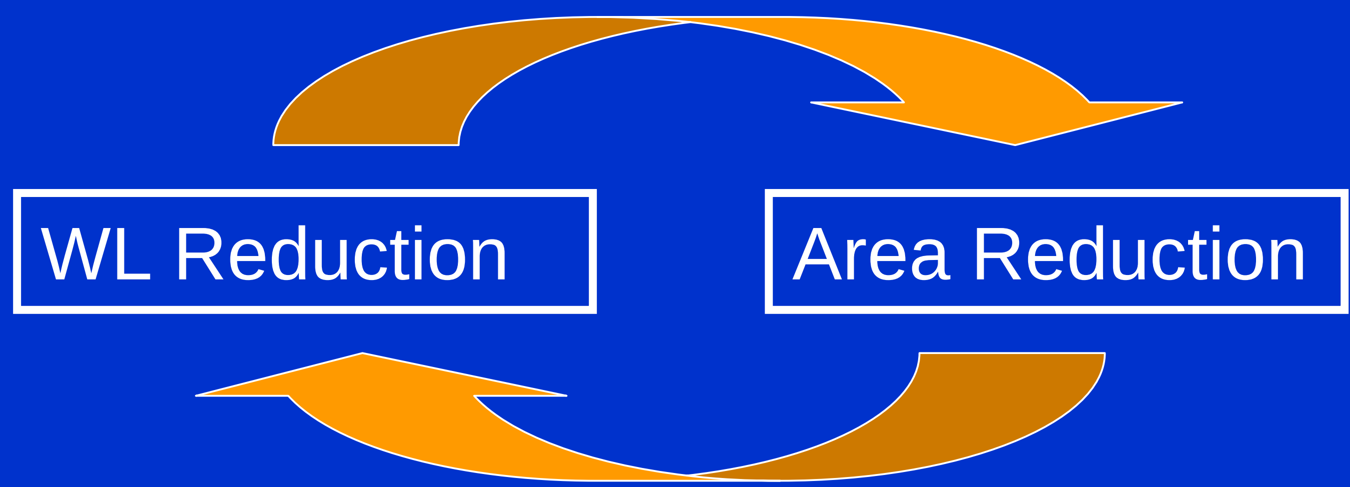
- Square cell
  - Relatively small WL improvements compared to λ = 4 and ∞
- Hexagonal cell [Scepanovic et al. 1996]
  - WL reduction improved
  - WL improvement up to 8%

Layout of hexagonal cells on a rectangular chip



“Virtuous Cycle” Effect (I)

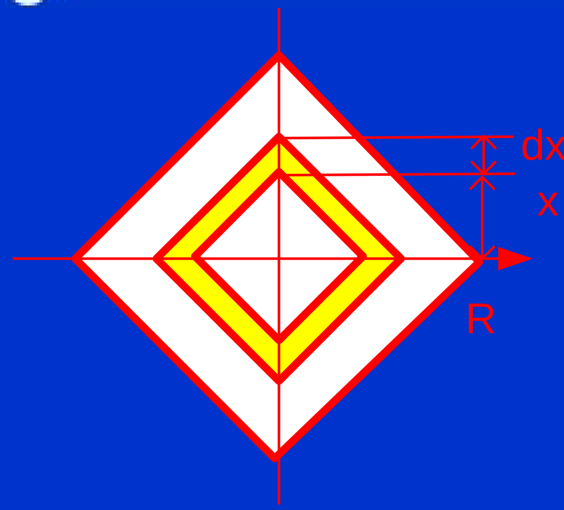
- Estimates still far from >20% reported in practice
- Previous model does not take into account the “virtuous cycle effect”



"Virtuous Cycle" Effect (II)

- Simplified model:
  - Cluster of N two-pin nets connected to one common pin
  - Pins evenly distributed in λ-geometry circle with radius R
- $\lambda = 2$
  - area of the circle $A = 2R^2$
  - total routing area: $A_{routing}$ = $= (2/3)\,RN$

$$\int_0^R x \cdot \left(\frac{4x\,dx}{A} N\right)$$



- Assume that $A_{routing} \sim A$
  - ➔ $(2/3)RN \sim 2R^2$
  - ➔ $R \sim N/3$
  - ➔ $A_{routing} \sim (2/9)N^2$

“Virtuous Cycle” Effect (III)

- $\lambda = 2$: $A_{routing} \sim 2/9\ N^2$
- $\lambda = 3$: $A_{routing} \sim 8\sqrt{3}/81\ N^2$
- $\lambda = 4$: $A_{routing} \sim \sqrt{2}/9\ N^2$
- $\lambda = \infty$: $A_{routing} \sim 4/9\pi\ N^2$

→ Routing area reductions over Manhattan geometry:

$\lambda = 3$	$\lambda = 4$	$\lambda = \infty$
23.0%	29.3%	36.3%

Conclusions

- Proposed more accurate estimation models for WL reduction of λ-geometry routing vs. Manhattan routing
  - Effect of placement (Manhattan vs. λ-geometry-driven placement)
  - Net size distribution
  - Virtuous cycle effect
- Ongoing work:
  - More accurate model for λ-geometry-driven placement

Thank You !