Wot the L: Analysis of Real versus Random Placed Nets, and Implications for Steiner Tree Heuristics

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Outline

- Background and Motivation
  - *L-ness* definition
- Related Work
- Pointset Characterization
- Real Pointset Generator
- Our New Lookup Table for RSMT Estimation
- Conclusion

Background

- RSMT Cost (Cheng **1994,** Caldwell **1999**)
  - Use AR and / or cardinality

$c(RSMT)/\sqrt{n \cdot area}$									
	Aspect Ratio (AR)								
n	1	2	4	8	16	32	64	128	256
4	0.64	0.67	0.78	0.98	1.29	1.76	2.44	3.44	4.82
5	0.67	0.70	0.80	0.99	1.30	1.76	2.43	3.39	4.76
6	0.69	0.72	0.81	0.99	1.27	1.73	2.41	3.36	4.68
7	0.71	0.73	0.81	0.98	1.26	1.69	2.33	3.25	4.56
8	0.72	0.74	0.82	0.97	1.24	1.66	2.28	3.16	4.44
9	0.73	0.75	0.81	0.96	1.21	1.62	2.21	3.07	4.33
10	0.74	0.75	0.81	0.95	1.19	1.57	2.15	2.99	4.18
15	0.75	0.76	0.80	0.90	1.10	1.42	1.91	2.62	3.67
20	0.76	0.77	0.80	0.87	1.03	1.30	1.73	2.37	3.29
30	0.76	0.76	0.79	0.84	0.95	1.16	1.51	2.03	2.81

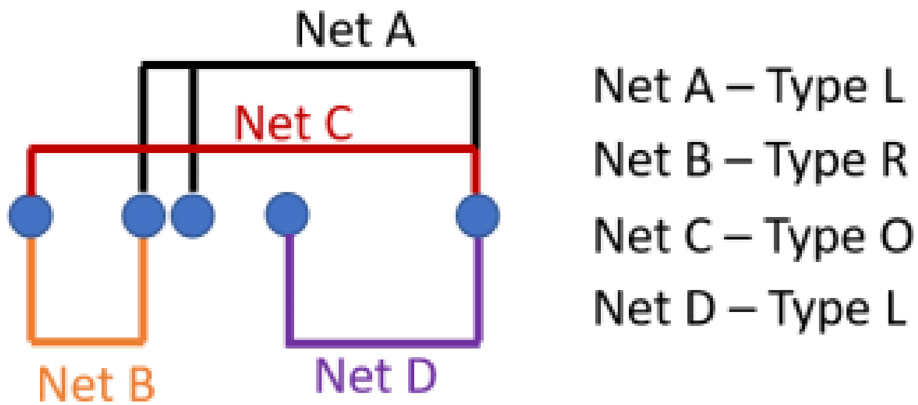
Estimators built using random pointsets.

Tables from Caldwell et al. 1999

Non-Uniformity of Real Placements

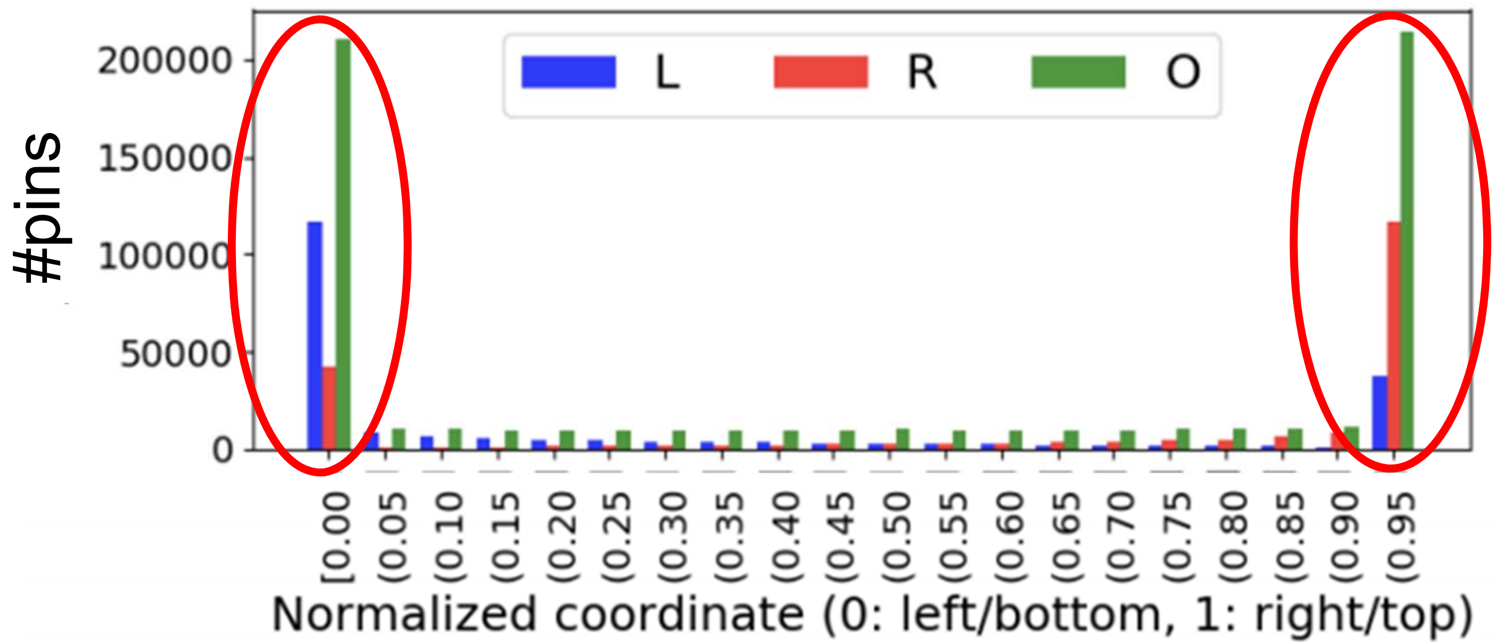
- Real placements
  - Pointsets from leon3mp and theia
  - Commercial P&R tool
  - Non-uniformity in X / Y directions separately

- Three types of net
  - Type L
  - Type R
  - Type O



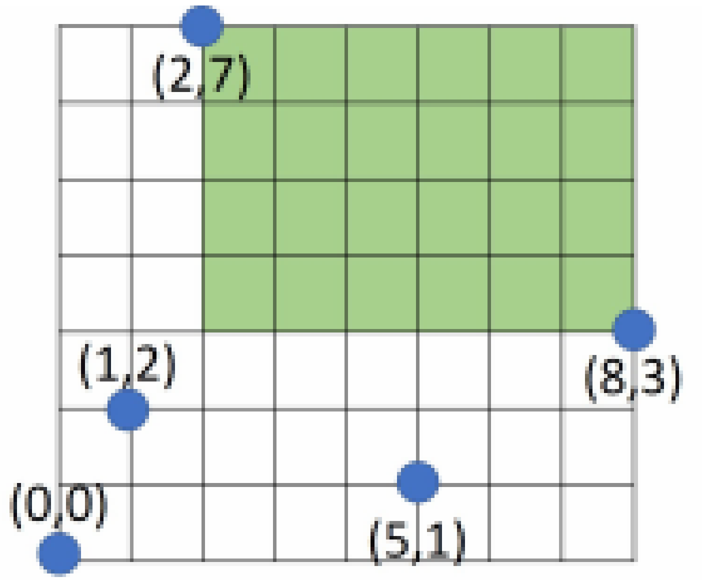
Non-Uniformity of Real Placements

- **Figure below: superposition of 3 distributions**
  - Type L: most pins near the left boundary
  - Type R: most pins near the right boundary
  - Type O: most pins near boundaries
- Non-uniform pin distribution



L-ness

- Given a pointset P
  - B(P): the bounding box of P
  - R(P): the area of the largest empty rectangles
    - Inside B(P)
    - Contain one corner of B(P)
    - No points inside
  - R(P)/B(P) = **L-ness**



$$\frac{R(P)}{B(P)} = \frac{24}{56}$$

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Related Works

RSMT estimation using random pointsets

- [Cheng94][Caldwell99]: RSMT cost depends on cardinality / aspect ratio of a pointset

Spanning and Steiner Tree Constructions

- [Alpert93]: Prim-Dijkstra's Algorithm that "blends" Prim's MST and Dijkstra's SPT algorithms
- [Ho90]: Algorithm for optimal edge-overlapping separable MSTs to obtain Steiner trees
- [Chu08]: FLUTE to generate near-optimal WL Steiner trees using lookup tables

Our work:

- **Propose *L-ness* attribute of a pointset**
- **L-ness distinguishes real from random pointsets**
- **New pointset generator to match real pointsets**
- **New lookup table for RSMT cost estimation.**

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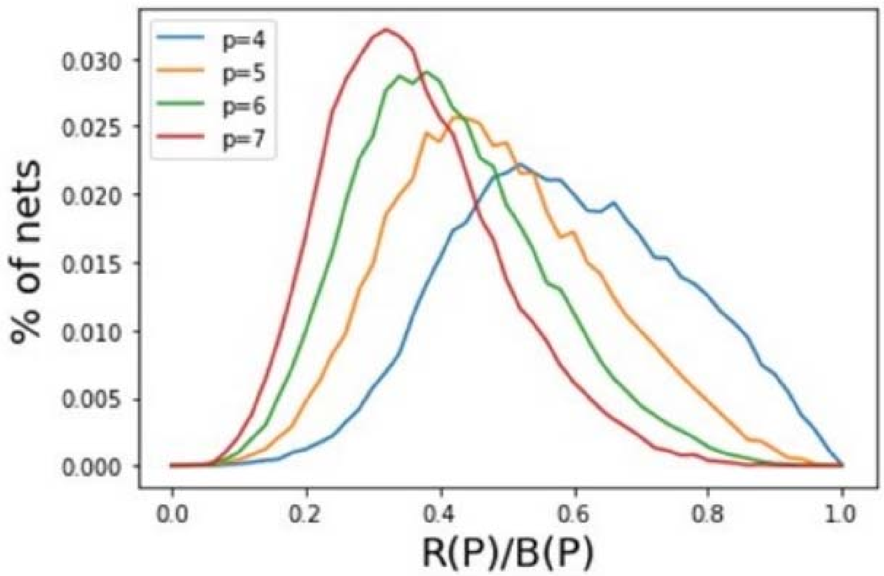
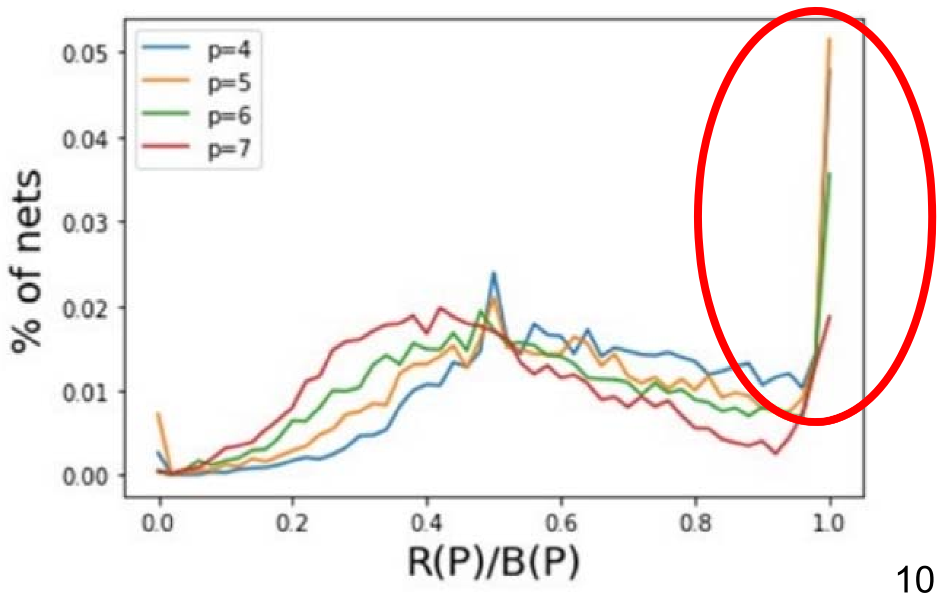
L-ness in Real versus Random Pointsets

- Distributions of *L-ness* (R(P)/B(P))
  - 100K pointsets, cardinality p = {4,5,6,7}
  - Real pointsets from 7 design blocks, two academic and two commercial placers, two technology nodes
  - Significantly larger L-ness for real pointsets

Random pointsets



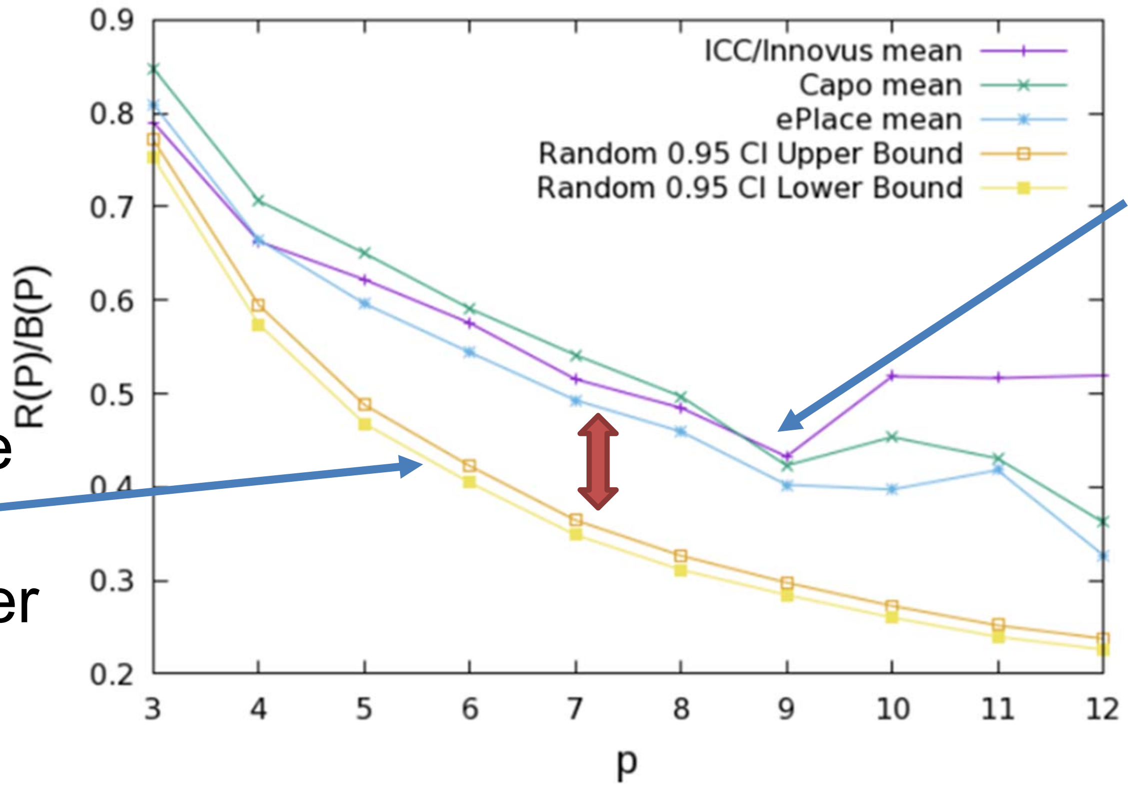
Real pointsets



Statistical Difference (1)

- Bootstrapping with 95% confidence interval

0.95 confidence interval lower/upper bound for random pointsets



Academic and commercial placements

Real pointsets are significantly different than random pointsets!

Statistical Difference (2)

- Two-sample Kolmogorov-Smirnov test
  - Statistically significant different when $D_{nm} > 1.36$

$$D_{nm} = \sqrt{\frac{nm}{n+m}} \cdot \sup(|F(x) - G(x)|)$$

p	KS Statistic
3	3.363
4	3.788
5	5.159
6	4.461
7	3.658
10	4.754
12	7.106

x: R(P)/B(P)

F(x): cumulative distribution for real pointsets

G(x): cumulative distribution for random pointsets

sup: maximum distance

All are greater than 1.36!

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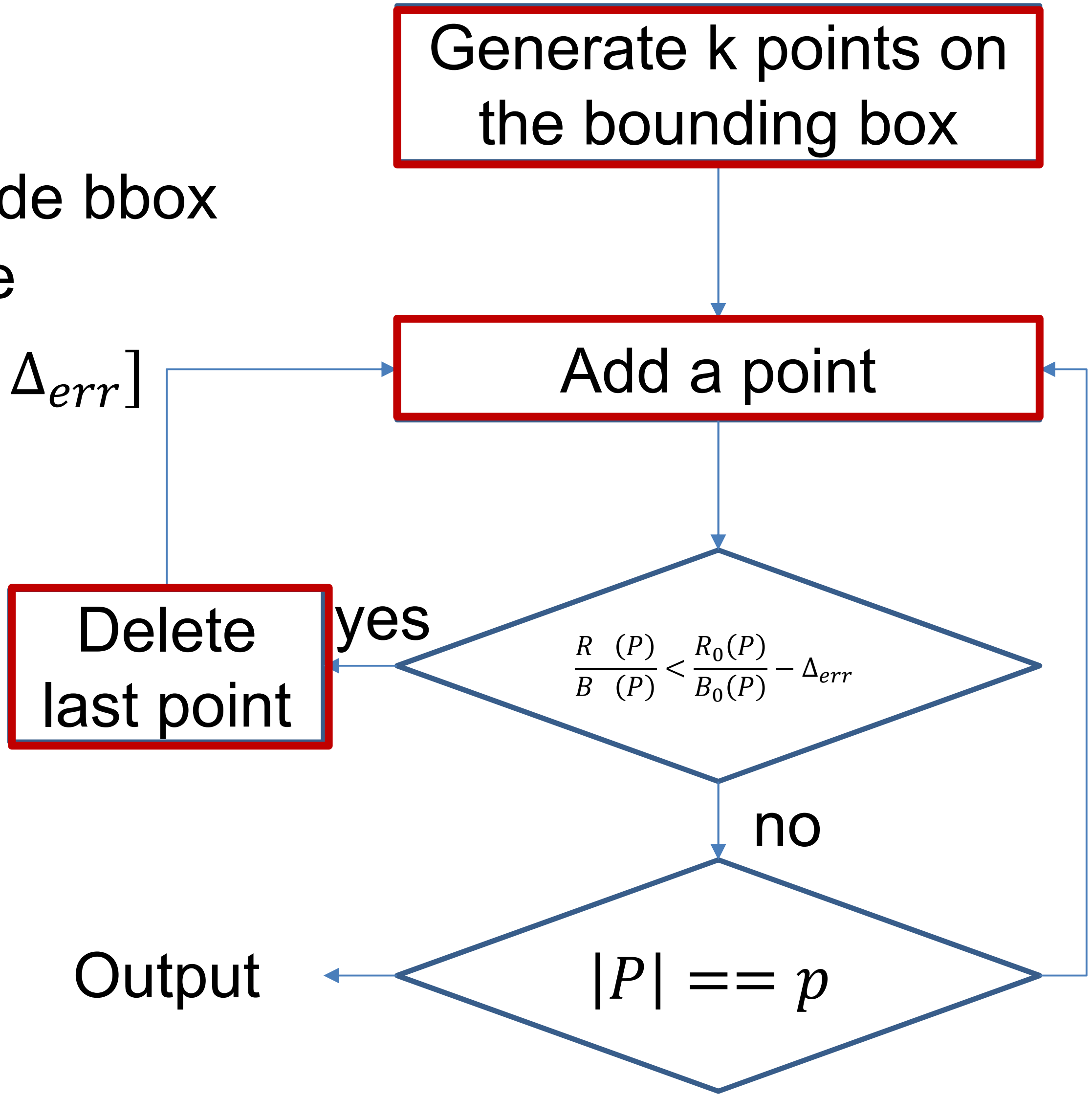
Pointset Generation

- Inputs:
  - cardinality p,
  - #points k on bbox,
    = $(p - k)$ points inside bbox
  - Target L-ness range
    $[\frac{R_0(P)}{B_0(P)} - \Delta_{err}, \frac{R_0(P)}{B_0(P)} + \Delta_{err}]$
  - Aspect ratio AR
- Output:
  - Pointset P

100K pointsets generated using distribution of $p, k, \frac{R_0(P)}{B_0(P)}, AR$ from real placements



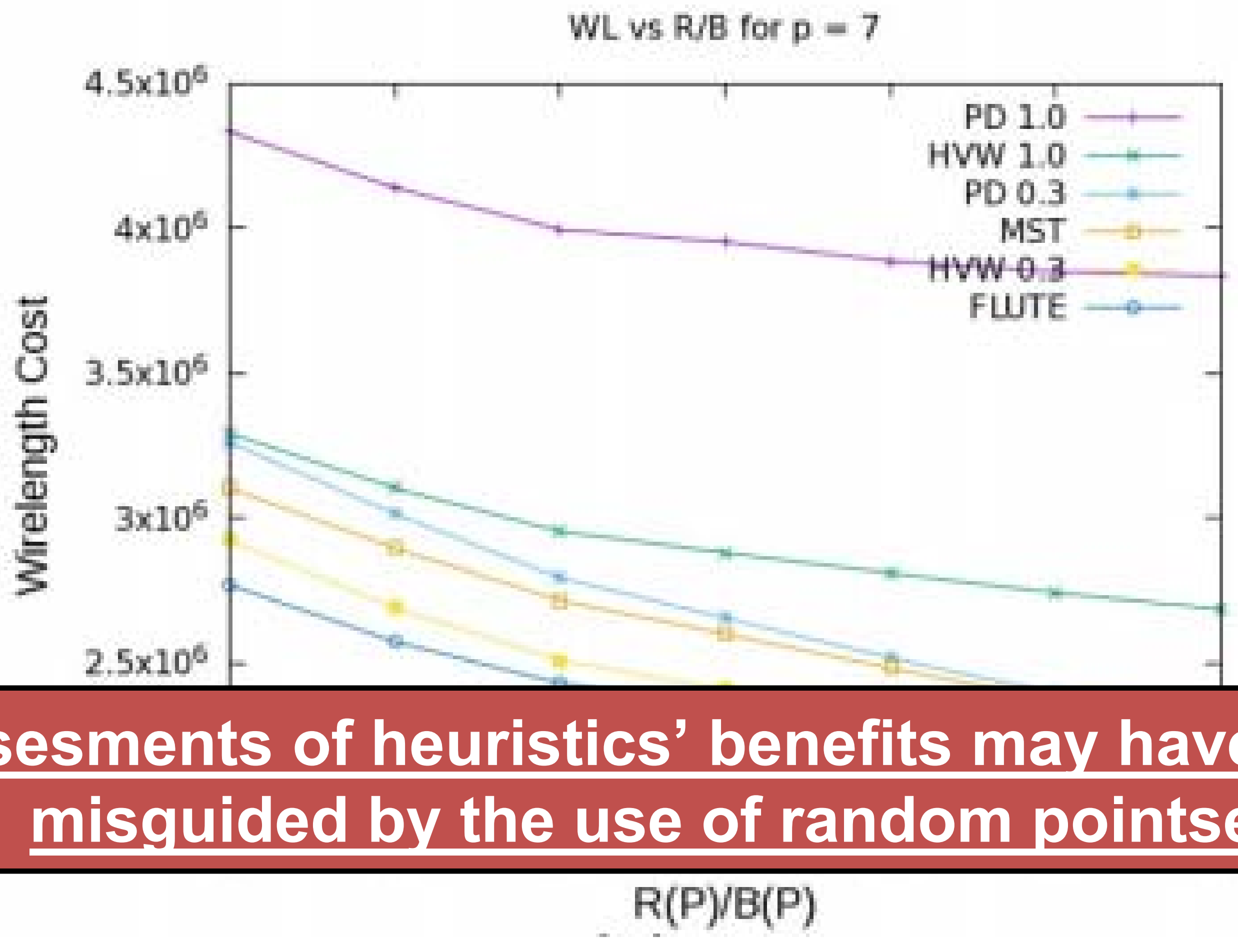
Impact of L-ness on RSMT Heuristics (1)

- Use 10K pointsets per each R(P)/B(P)
  - $0.2 \leq \mathrm{R(P)/B(P)} \leq 0.8$
  - $step = 0.1$
  - $\Delta_{\mathrm{err}} = 0.02$

- Evaluation: 4 RSMT heuristics
  - Rectilinear MST
  - Prim-Dijkstra (PD) [Alpert93] (with parameter α = 0.3, 1)
  - Optimal edge-overlapping PD Steiner trees (HVW) [Ho90]
  - FLUTE [Chu15]

Impact of L-ness on RSMT Heuristics (2)

- Implications
  - Wirelength ↓ as L-ness ↑
  - Difference in WL among heuristics ↓ as L-ness ↑



Assesments of heuristics' benefits may have been misguided by the use of random pointsets

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Improved WL Estimation Lookup Table

- Three parameters in lookup table: AR, R(P)/B(P), p
  - W1: oblivious to L-ness (equivalent to [Caldwell99])
  - W2: our LUT
  - W3: %difference from W2 to W1

AR		1				2				4			
R(P)/B(P)		0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
p=4	W1	2.14				2.25				2.60			
	W2	2.66	2.23	2.10	2.04	2.63	2.32	2.22	2.17	2.86	2.66	2.58	2.54
	W3	24.37	4.24	-2.03	-4.51	16.89	3.31	-1.48	-3.77	9.93	2.20	-0.76	-2.24
p=5	W1	2.27				2.36				2.69			
	W2	2.66	2.30	2.16	2.08	2.63	2.39	2.27	2.20	2.86	2.71	2.63	2.58
	W3	17.02	1.22	-4.80	-8.57	11.41	1.25	-3.67	-6.84	6.38	0.66	-2.12	-4.19
p=6	W1	2.39				2.48				2.78			
	W2	2.71	2.37	2.22	2.10	2.70	2.45	2.34	2.23	2.93	2.77	2.69	2.61
	W3	13.58	-0.90	-7.21	-12.00	8.95	-1.13	-5.81	-10.28	5.39	-0.30	-3.17	-6.21
p=7	W1	2.52				2.59				2.87			
	W2	2.78	2.44	2.27	2.13	2.77	2.53	2.39	2.26	3.00	2.82	2.73	2.64
	W3	10.13	-3.32	-9.84	-15.42	7.12	-2.38	-7.76	-12.70	4.56	-1.58	-4.73	-8.13
p=8	W1	2.63				2.69				2.96			
	W2	2.83	2.50	2.32	2.16	2.86	2.59	2.44	2.29	3.06	2.89	2.79	2.67
	W3	7.57	-4.81	-11.62	-17.96	6.18	-3.72	-9.30	-15.01	3.50	-2.33	-5.86	-9.96

(1) [Caldwell99]

(2) Ours

$$\%diff = 100 \cdot \frac{(2) - (1)}{(1)}$$

Advantages of Improved Lookup Table (1)

- Accuracy
  - Error = $\frac{WL_{heur} - WL_{FLUTE}}{WL_{FLUTE}} \cdot 100\%$
- The entire lookup table is available:
  - http://vlsicad.ucsd.edu/~sriram/Final_WL_estimate_LUT.htm

p	Absolute Error			Std. Dev. of Abs. Error			Max. Absolute Error		
	Impr. LUT	Cald-well	RMST	Impr. LUT	Cald-well	RMST	Impr. LUT	Cald-well	RMST
3	0.00%	0.00%	6.13%	0.00%	0.00%	7.81%	0.00%	0.00%	33.31%
4	4.06%	5.61%	6.01%	3.62%	3.67%	6.49%	24.51%	28.19%	46.17%
5	4.47%	7.14%	6.20%	3.76%	4.48%	6.01%	24.94%	23.44%	42.73%
6	4.70%	8.07%	6.48%	3.95%	5.44%	5.66%	25.53%	25.24%	36.02%
7	4.93%	8.75%	6.82%	4.04%	6.41%	5.36%	28.20%	25.71%	34.60%
8	5.17%	9.85%	7.15%	4.21%	7.66%	5.14%	27.56%	31.46%	32.25%
9	5.28%	9.81%	7.73%	4.21%	7.88%	4.90%	30.95%	37.03%	32.13%
10	5.75%	11.38%	7.35%	4.69%	9.39%	4.76%	32.94%	42.16%	28.06%
11	6.00%	12.47%	7.14%	4.85%	10.37%	4.59%	37.01%	46.94%	27.46%
12	6.46%	12.62%	7.18%	5.32%	10.82%	4.58%	40.35%	52.94%	28.25%

Advantages of Improved Lookup Table (2)

- Runtime: FLUTE, our LUT and RMST
  - 500k real and random pointsets
  - ~2X faster than RMST
  - ~10X faster than FLUTE

p	Random pointsets			Real pointsets		
	FLUTE	Impr. LUT	RMST	FLUTE	Impr. LUT	RMST
2	0.051	0.003	0.012	0.050	0.003	0.012
3	0.185	0.004	0.023	0.254	0.006	0.040
4	0.229	0.047	0.045	0.295	0.065	0.050
5	0.262	0.060	0.061	0.240	0.061	0.063
6	0.299	0.077	0.095	0.328	0.116	0.109
7	0.352	0.093	0.135	0.318	0.089	0.130
8	0.431	0.111	0.173	0.368	0.104	0.171
9	0.576	0.127	0.216	0.492	0.119	0.223

In terms of speed and accuracy, this new LUT is a non-dominated wirelength estimator!

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Conclusion

- Formal definition of L-ness
- Characterization of real and random pointsets
- Pointset generator to match real pointsets
- Implication to RSMT heuristics
- Improved lookup tables for RSMT cost estimation, considering L-ness
- Accuracy and runtime comparison to previous works.
- Ongoing and future works
  - Direct L-ness-aware placement
  - Better wirelength correlation with routing

- Wot the L = Know the L

THANK YOU!