DPlace2.0: A Stable and Efficient Analytical Placement Based on Diffusion

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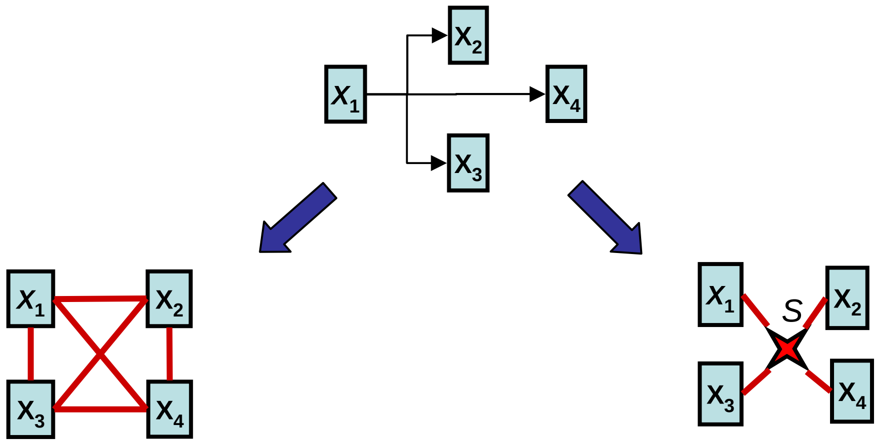
Outline

- Overview of quadratic placement
  - Force directed quadratic placement
- DPlace flow
  - Diffusion based cell spreading
  - Wire length reduction
    - Anchor cell insertion based wire-length minimization
    - Discrete wire length reduction techniques
    - Wire length linearization
- Experimental results
- Conclusions

Overview of Quadratic Placement

- Placement objective:
  - minimize total Half Parameter Wire Length (HPWL), such that no cell overlaps.
- Quadratic placement
  - Mathematical form of HPWL model is not smooth, QP minimizes the quadratic wire-length.
  - All multi-pin nets have to be decomposed into 2-pin nets.



Clique, 6 nets with weight 1/6

Star, 4 nets with weight 1/4

Quadratic Placement (Cont.)

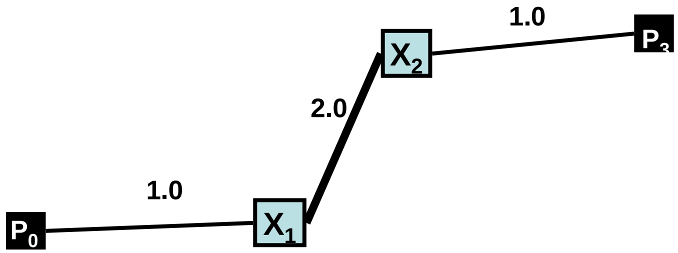
- Minimize the quadratic wire-length (x direction)

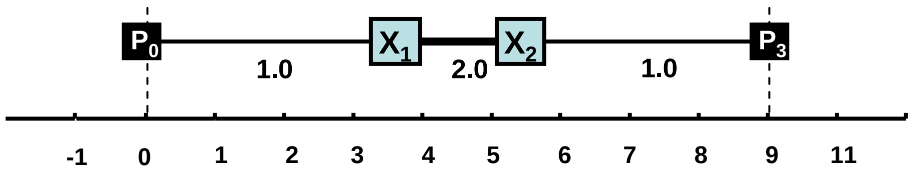
$$\min \sum_{i} w_i((x_i - x_j)^2 + (y_i - y_j)^2).$$

$$\text{x direction} \quad : \phi(x) = \frac{1}{2}\vec{X}^T A\vec{X} + \vec{b}_x^{\,T} X + const$$

$$\text{solve} \quad A\vec{X} = \vec{b} \Rightarrow \vec{X} = A^{-1}\vec{b}$$

- Example (Minimize Quadratic wire in x direction)
  - P_0, P_3 are fixed pins, X_1 and X_2 are movable cells

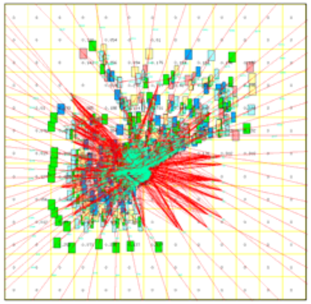




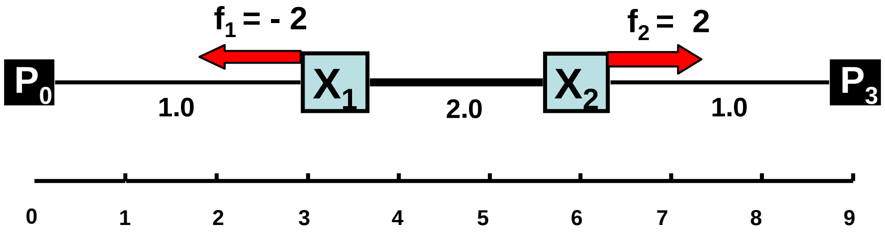
$$\begin{bmatrix} 3 & -2 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} P_0 \\ P_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 9 \end{bmatrix}$$

$$x_1 = 3.6, x_2 = 5.4$$

Force-directed Quadratic Placement



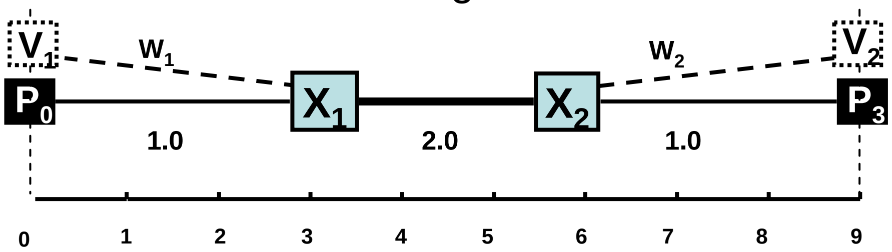
- Without density constraints, cells will congregate in the middle of the placement region.
- Spreading forces are added to pull cells out
  - Constant force (Kraftwerk, DAC'98, FDP, ICCAD'04)
    - Add forces into the ***b*** vector,
    - Issues: non-trivial to add spreading forces (placement stability)



$$\begin{bmatrix} 3 & -2 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} P_0 + f_1 \\ P_3 + f_2 \end{bmatrix} = \begin{bmatrix} -2 \\ 11 \end{bmatrix}$$

$$x_1 = 3.2, x_2 = 5.8$$

  - Fixed point force (mFar,ISPD'02, FastPlace ISPD04)
    - Implement the force by adding virtual connections
    - Issues: adding additional terms changes the netlist



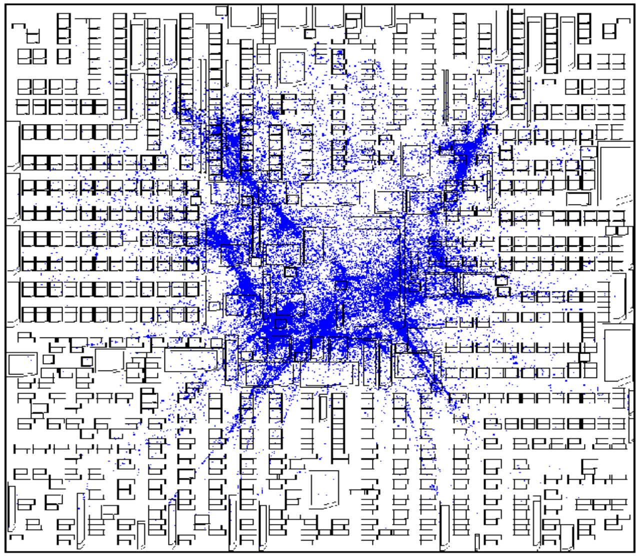
$$\begin{bmatrix} 3+w_1 & -2 \\ -2 & 3+w_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} p_0 + w_1 v_1 \\ p_3 + w_2 v_2 \end{bmatrix}$$

Placement Challenges

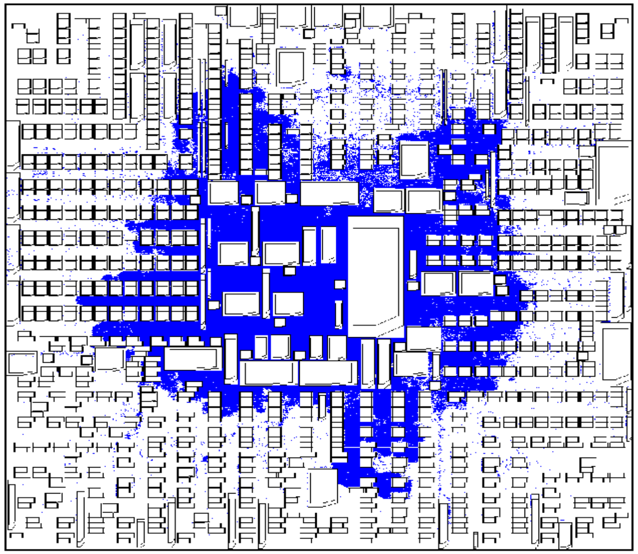
- Placement scalability
  - Placement problem size grows fast. The largest circuit in ISPD2006 has over 2.5 M objects. It is non-trivial to solve the matrix problem with 2.5M by 2.5M dimension
- Solver stability
  - The connectivity matrix is ill-conditioned, force addition is not trivial, especially for constant forces
  - Lots of numerical issues during matrix solving
- Placement stability
  - Small change on circuits may results in completely different placements, while a typical physical design flow is highly iterative

Placement Challenges (cont.)

- Mixed mode placement (Placement with blockages)
- Still a bottleneck of physical design
  - Wire length is far from optimal [Cong et.al., ICCAD03]
  - The gap between the quadratic approximation and the HPWL objective is enlarged in large designs.



Initial placement: HPWL 209×10^6



Final placement: HPWL 160×10^6

Bigblue3: the wirelegnth after the first quadratic placement iteration is worse than that of the final placement

DPlace Framework

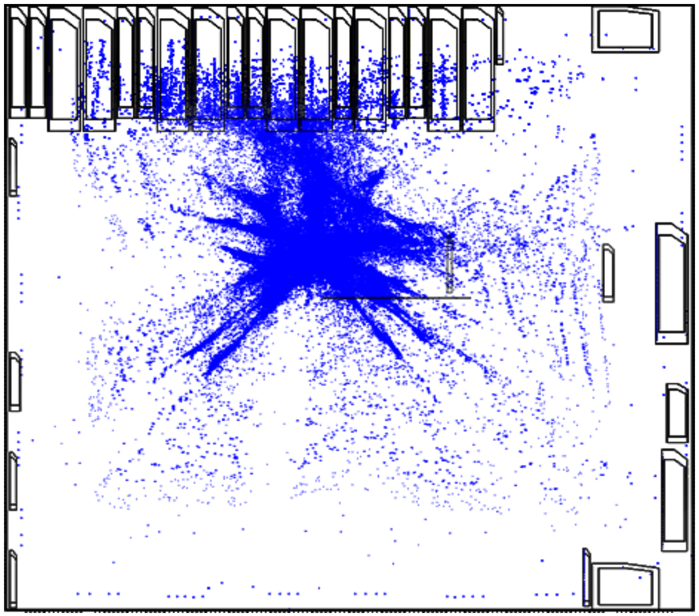
- Start with an initial placement (unconstrained QP)
- Traditional placement flows combines cell spreading and wirelength reduction.
- DPlace separates the density and wire-length optimization tasks in independent steps
  - First, to spread cells by diffusion based spreading
    - Any smooth spreading technique can be used
  - Then, to reduce the wirelength by anchoring cells based wire-length minimization
    - Any wire length minimization technique can be plugged in.
    - DPlace uses quadratic placement, and several wire length minimization heuristics
  - Use a new net weighting method to transform quadratic wire-length into HPWL objective

Advantages

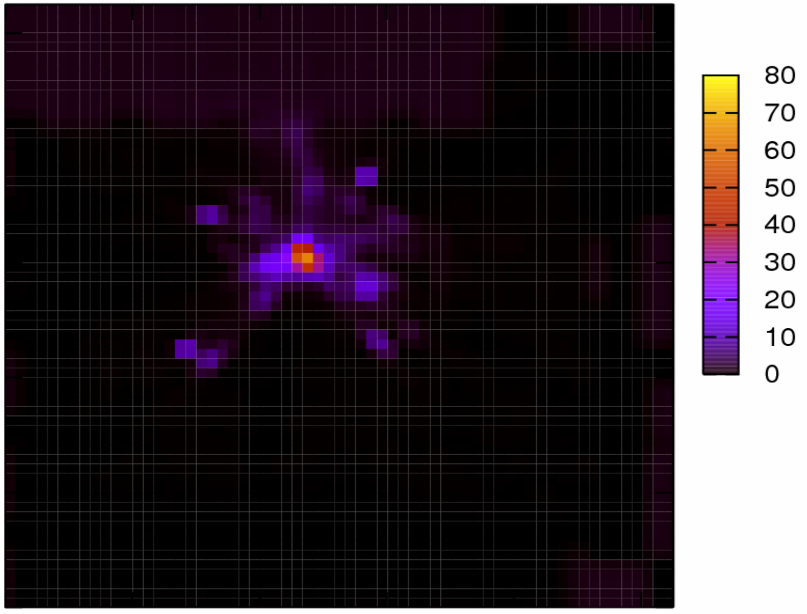
- Do not change the connectivity matrix by adding additional virtual nets into the system
- High stability
  - No solver stability issues
    - No “forces” added into the system
  - Good placement stability
    - It is possible to explicitly control the cell movements in DPlace (During diffusion), two placements won’t be drastically different
- Flexibile and the runtime are good
  - Density optimization is handled separately, every placement iteration is for unconstrained wirelength minimization.
  - Flexible to integrate other WL improvement techniques
  - Speed of matrix solving is improve dramatically
- Ideal for placement with constraints
  - DPlace has explicit control on cell movement
  - Has potential advantages on ECO placement, timing driven placement

DPlace: Initial Placement

- Initial quadratic placement of Bigblue1



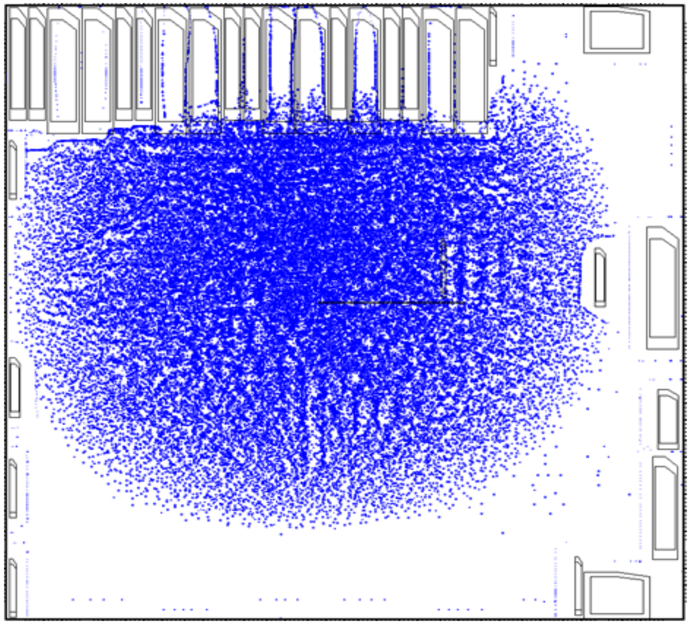
Initial HPWL = 6.84×10^6



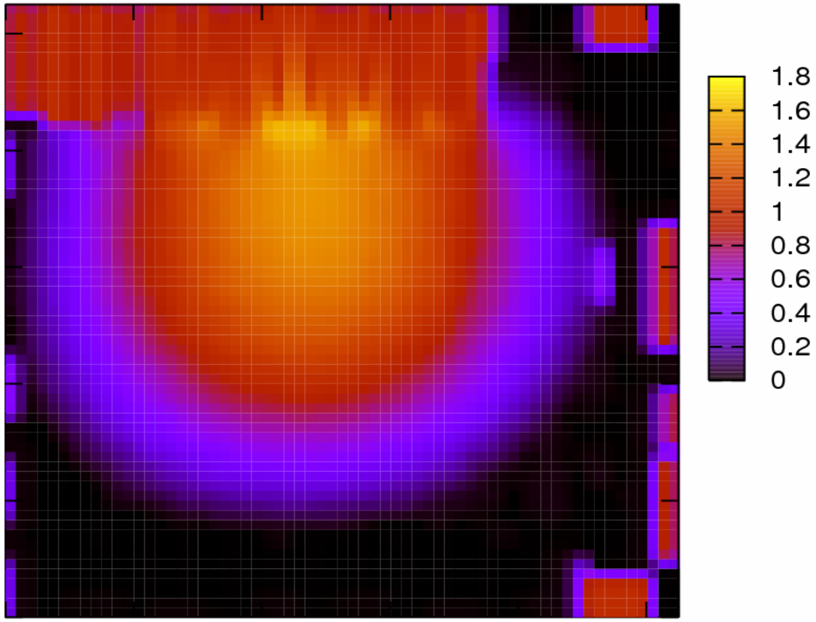
Initial density map, DMax = 80

DPlace: Diffusion Spreading

- Diffusion equation $$\frac{\partial d_{x,y}(t)}{\partial t} = D\nabla^2 d_{x,y}(t)$$
- Use a discrete diffusion solver to even out density distribution



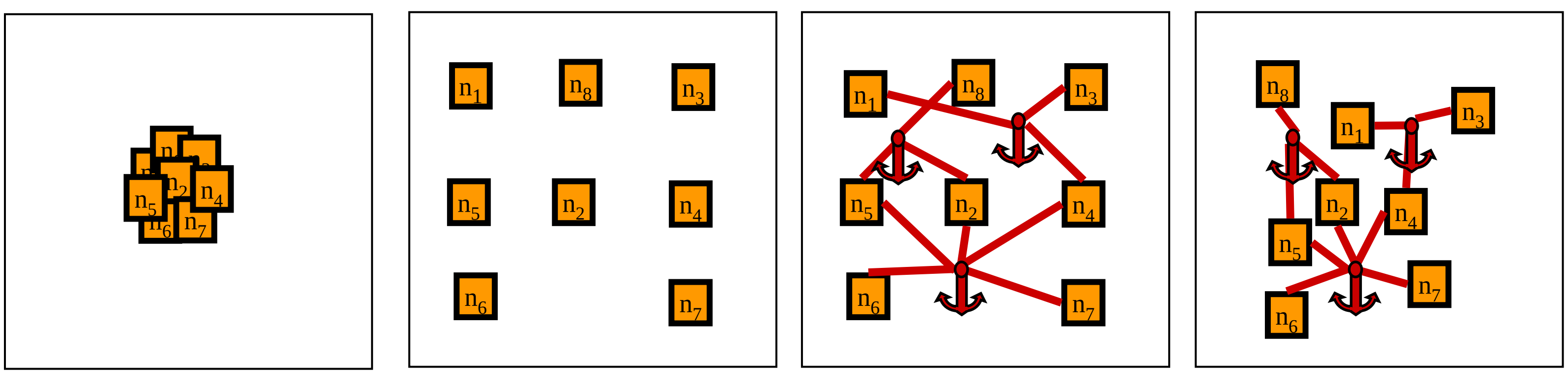
HPWL = $17.3\text{x}10^6$



Density distribution is much smoother, DMax = 1.8

Anchor Cells Insertion

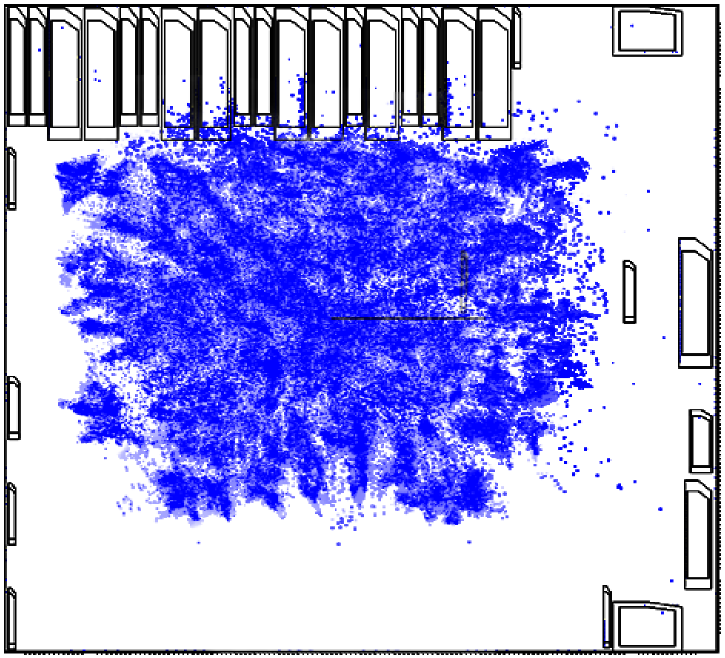
- After the density is improved, repairing the wire length
  - Insert a virtual anchor on every higher-pin net (e.g. pin degree larger than *k*)
  - Solve QP
    - Anchor are fixed pins, so update vector b (Ax = b),
    - Solve an unconstrained QP problem



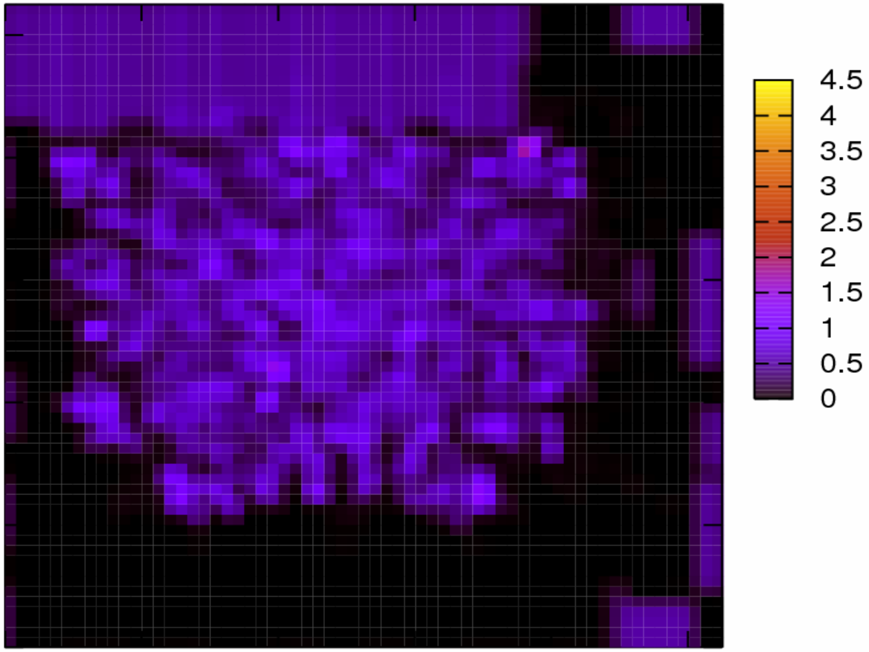
Initial placement | Diffusion spreading | Insert anchors | After QP

DPlace: Wire-Length Reduction

- After Wire-length reduction



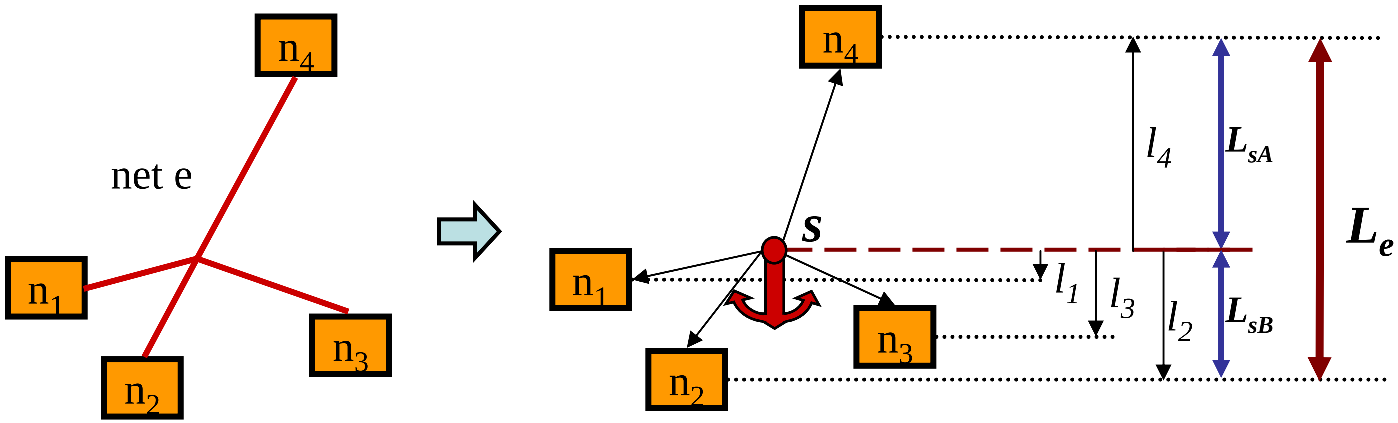
After wire length reduction, HPWL=9.63×10^6



Better density distribution in a global view, DMax = 4.5

New Re-weighting Method

- The quadratic wire length is an indirect estimation of HPWL, use HPWL re-weighting to transform quadratic wire length into HPWL.



$$w_i = \frac{L_{sA}}{S_{AB} \times |y_i - y_s|}, w_i = \frac{L_{sB}}{S_{AB} \times |y_i - y_s|}, \forall n_i \in A, \forall n_i \in B$$

where

$$S_{AB} = 0.5 \sum_{n_i} |y_i - y_s|$$

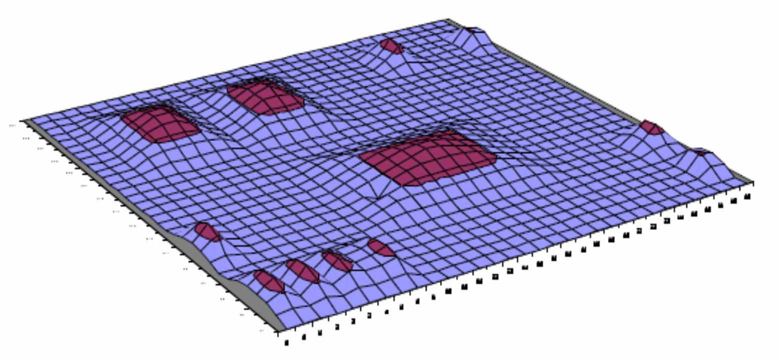
$$L_{sA} = max\{y_i\} - y_s, L_{sB} = y_s - max\{y_i\}$$

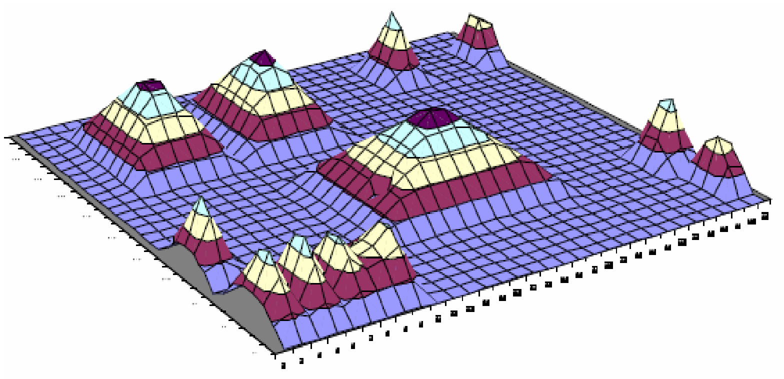
$$L_e = L_{sA} + L_{sB}$$

$$\begin{aligned}\sum_{i=1}^{n} w_i (y_i - y_s)^2 &= \sum_{i \in A} \frac{2(y_i - y_s)^2 \times L_{sA}}{|y_i - y_s| \times S_{AB}} + \sum_{i \in B} \frac{2(y_i - y_s)^2 \times L_{sB}}{|y_i - y_s| \times S_{AB}} \\ &= \frac{2L_{sA}}{S_{AB}} \sum_{i \in A} \frac{(y_i - y_s)^2}{(y_i - y_s)} + \frac{2L_{sB}}{S_{AB}} \sum_{i \in B} \frac{(y_i - y_s)^2}{(y_s - y_i)} \\ &= L_{sA} + L_{sB} = L_e\end{aligned}$$

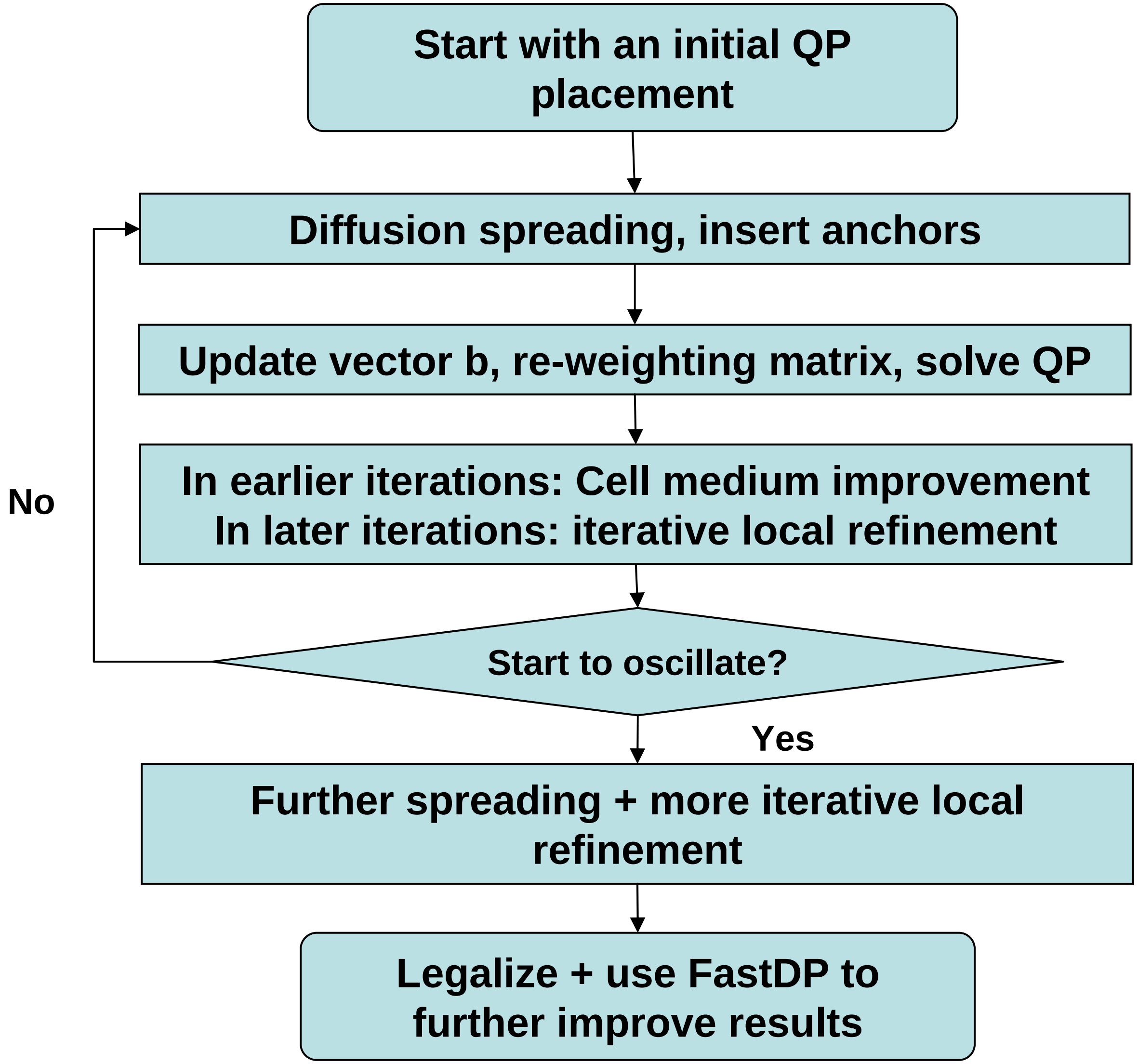
Fixed Blockages

- Contour based smoothing for fixed blockages
  - Initial blockage density is very small to allow cells passing over
  - Density rises gradually to push cells away the center of blockages.



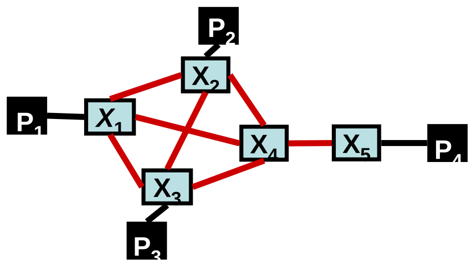


DPlace Flow


Start with an initial QP placement
Diffusion spreading, insert anchors
Update vector b, re-weighting matrix, solve QP
In earlier iterations: Cell medium improvement
In later iterations: iterative local refinement
No
Start to oscillate?
Yes
Further spreading + more iterative local refinement
Legalize + use FastDP to further improve results

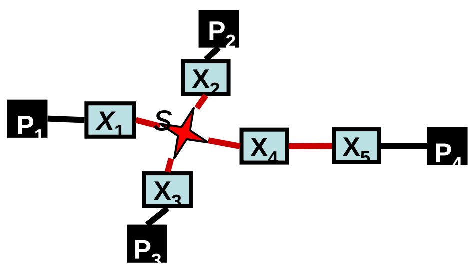
A Matrix Comparison

- Comparisons of A matrix by using the clique, star, and anchor cell model



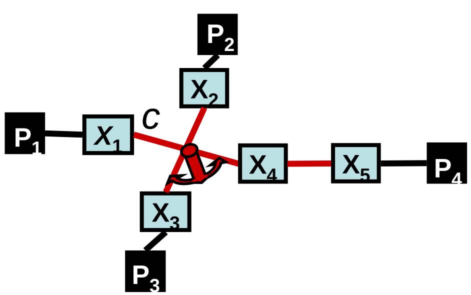
$$\begin{bmatrix} 1.75 & -0.25 & -0.25 & -0.25 & \\ -0.25 & 1.75 & -0.25 & -0.25 & \\ -0.25 & -0.25 & 1.75 & -0.25 & \\ -0.25 & -0.25 & -0.25 & 1.75 & -1 \\ & & & -1 & 2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ \\ p_4 \end{bmatrix}$$

Clique, dense matrix



$$\begin{bmatrix} 1.25 & & & & & -0.25 \\ & 1.25 & & & & -0.25 \\ & & 1.25 & & & -0.25 \\ & & & 1.25 & -1 & -0.25 \\ & & & -1 & 2 & \\ -0.25 & -0.25 & -0.25 & -0.25 & & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ s \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ \\ \\ \end{bmatrix}$$

Star, matrix dimension changes



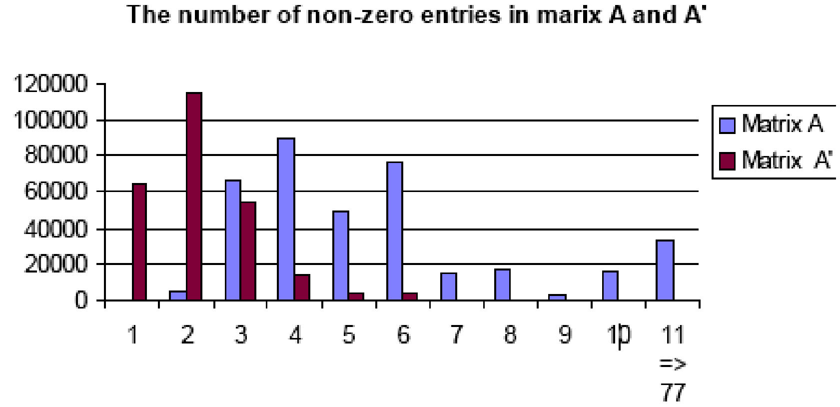
$$\begin{bmatrix} 1.25 & & & & \\ & 1.25 & & & \\ & & 1.25 & & \\ & & & 1.25 & -1 \\ & & & -1 & 2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{bmatrix} p_1 + 0.25c \\ p_2 + 0.25c \\ p_3 + 0.25c \\ \\ p_4 \end{bmatrix}$$

Anchoring

Advantages for Matrix Operations

- Extremely sparse A' matrix due to anchor cell insertions

Circuits	#Obj	#Fix	#Net	Util.%	**#Stars**
adaptec1	211K	543	221K	57.34	**32K**
adaptec2	255K	566	266K	44.32	**100K**
adaptec3	452K	723	466K	33.52	**122K**
adaptec4	496K	1329	516K	27.23	**179K**
bigblue1	278K	560	284K	44.67	**114K**
bigblue2	558K	23084	577K	37.94	**193K**
bigblue3	1097K	1293	112K	56.68	**293K**
bigblue4	2177K	8170	2230K	44.35	**662K**



- Speedup of the matrix solver

Adaptec2 : new matrix A'

	Matrix **A**				Matrix **A'**				Solver speedup
	Size	Entries	Precon(s)	Solve (s)	Size	Entries	Precon(s)	Solve(s)	
adaptec1	243K	196K	15.85	4.65	211K	430K	0.53	0.19	24.5x
adaptec2	355K	2099K	25.61	7.38	254K	557K	0.90	0.30	24.6x
adaptec3	674K	3713K	38.18	15.61	494K	1131K	1.74	0.58	26.9x
adaptec4	508K	3676K	38.42	15.51	451K	997K	1.97	0.49	31.7x
bigblue1	392K	2287K	29.78	6.87	278K	603K	1.16	0.36	19.1x
bigblue2	729K	3937K	47.79	22.78	535K	1178K	2.29	0.82	27.8x
bigblue3	1389K	7290K	103.93	39.32	1096K	2714K	4.54	1.70	23.1x
bigblue4	2831K	16850K	221.47	75.70	2169K	5190K	10.66	3.91	19.4x
									24.6x

Experimental Results

- Compare to ISPD 2005 Placement contest results

Circuits	HPWL $\times 10^6$					Runtime(s)				
	DPlace + fastDP	FastPl3	mPL6	Capo10	APlace2	**DPlace + fastDP**	FastPl3	mPL6	Capo10	Aplace2
adaptec1	78.534	1.011	0.991	1.162	1.001	606	0.69	5.13	10.46	14.99
adaptec2	89.415	1.041	1.031	1.124	1.072	842	0.74	3.56	8.93	14.49
adaptec3	221.817	0.982	0.962	1.031	0.982	1874	0.82	3.12	5.50	9.68
adaptec4	198.506	1.014	0.974	1.045	1.055	1628	0.81	4.68	7.97	17.39
bigblue1	95.339	1.004	1.014	1.144	1.054	903	0.75	4.08	9.98	12.69
bigblue2	160.149	0.962	0.943	1.011	0.953	4656	0.43	2.93	4.99	7.52
bigblue3	363.073	1.046	0.952	1.099	1.130	5409	0.71	1.94	7.01	6.95
bigblue4	869.804	0.958	0.958	1.111	1.005	14026	0.41	1.72	5.61	6.85
Average	**1**	1.002	0.978	1.091	1.031	**1**	0.67x	3.40x	7.56x	11.32x

Experimental Results (Cont.)

- Results from ISPD2005 placement contest

Placers	adaptec1	adaptec2	adaptec3	adaptec4	bigblue1	bigblue2	bigblue3	bigblue4	ratio
DPlace + fastDP	78.53	89.41	221.82	198.51	95.34	161.15	363.07	869.80	**1.034**
Aplace	79.50	87.31	218.00	187.65	94.64	143.82	357.89	833.21	1.00
mFAR	-	91.53	-	190.84	97.70	168.70	379.95	876.28	1.06
dragon	-	94.72	-	200.88	102.39	159.71	380.45	903.96	1.08
mPL	-	97.11	-	200.94	98.31	173.22	369.66	904.19	1.09
FastPlace	-	107.86	-	204.48	101.56	169.89	458.49	889.87	1.16
Capo	-	99.71	-	211.25	108.21	172.30	382.83	1098.76	1.17
NTUP	-	100.31	-	206.45	106.54	190.66	411.81	1154.15	1.21
fs50	-	122.89	-	337.22	114.57	285.43	471.15	1040.05	1.50
K&D	-	157.65	-	352.01	149.44	322.22	656.19	1403.79	1.84

Colusions

- We present a new global placement DPlace
  - Based on diffusion spreading and cell anchoring.
  - Explicit control on cell movement
- Quadratic placement is comparable with log-sum-exp model
  - DPlace has comparable wirelength
  - The runtime is good
- Placement stability/scalability are important
- We believe there are still room for improvement in placement

Thank you!