EE582
Physical Design Automation of VLSI Circuits and Systems

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Placement

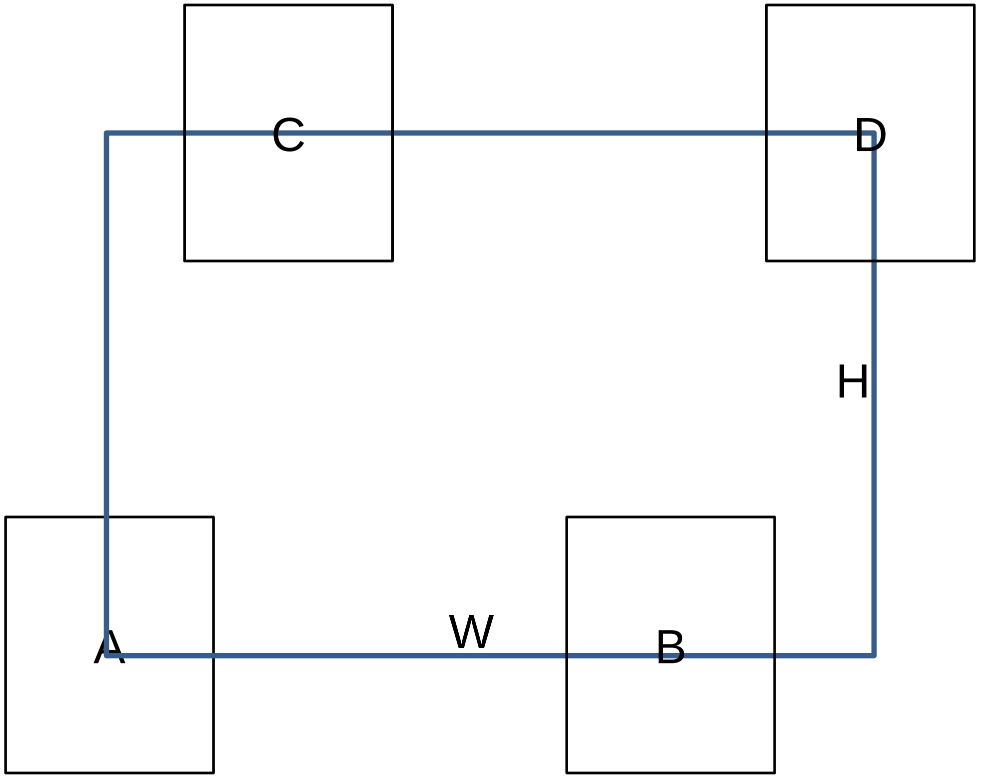
Washington State University

Metrics for Placement

- Wirelength
- Timing
- Power
- Routing congestion

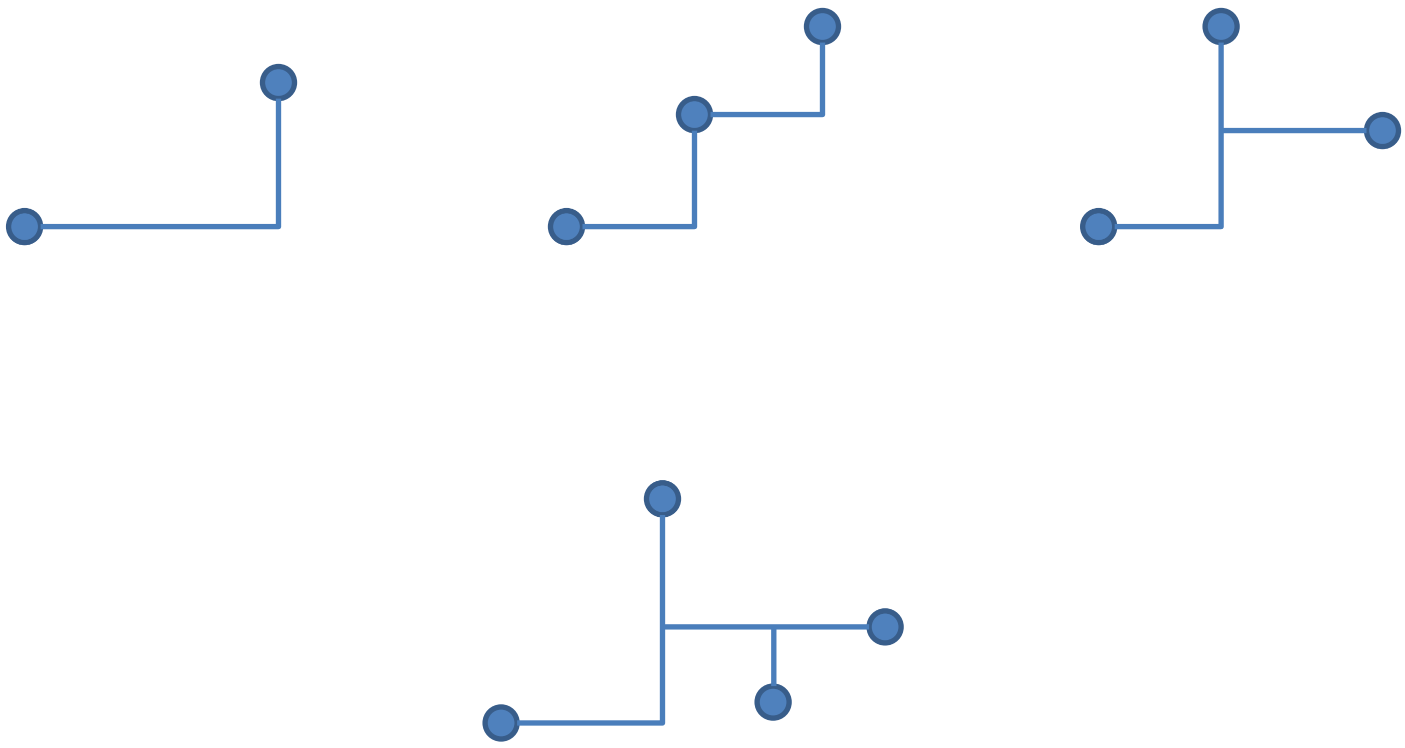
Wirelength Estimation

- Half-perimeter wirelength (HPWL)



HPWL = W + H

Wirelength Estimation

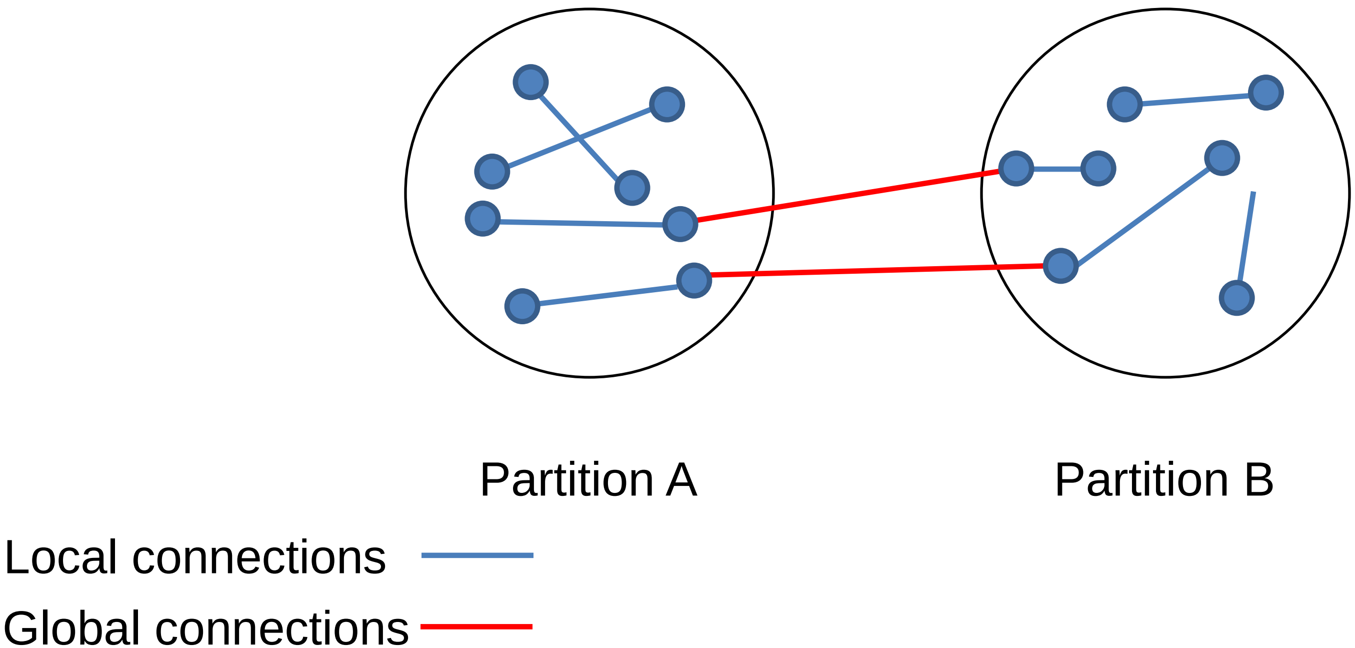


Placement Algorithms

- Constructive
  - Min-cut based placement
  - Force-directed
- Analytical
  - Gordian
  - Kraftwerk
- Iterative improvement
  - Simulated annealing (Timberwolf)
  - Pairwise exchange

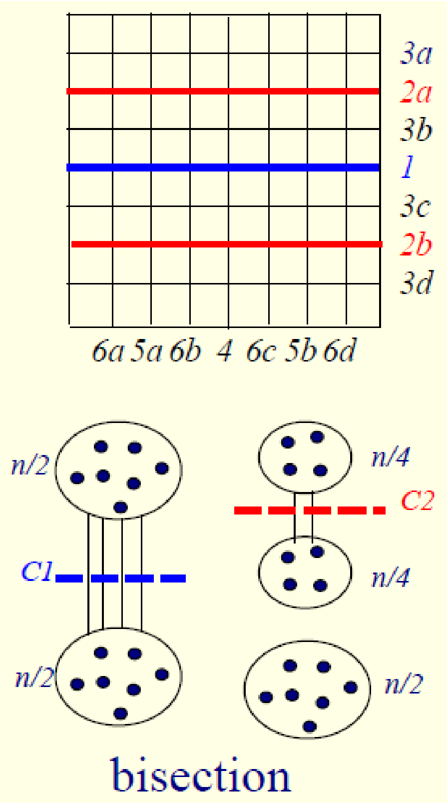
Min-Cut-Based Placement

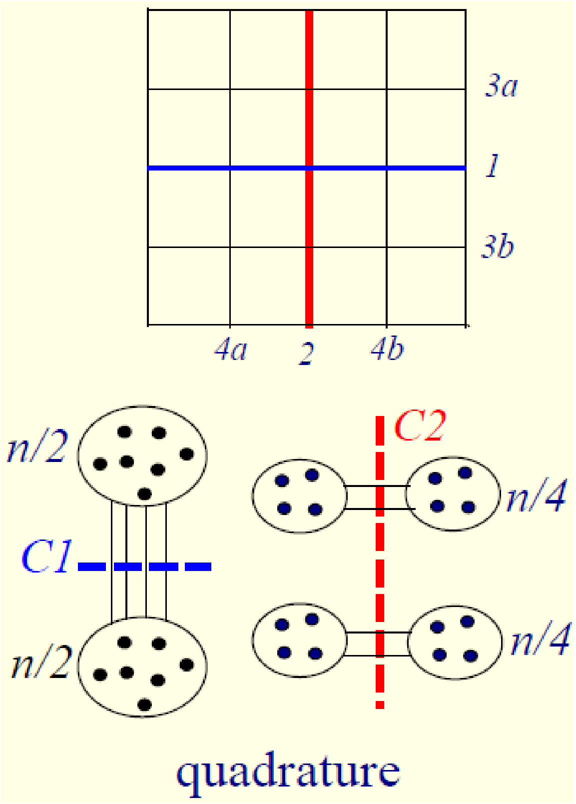
- Idea
  - Cutsize minimization ≈ Reduction of global wires



Min-Cut-Based Placement

- Partitioning





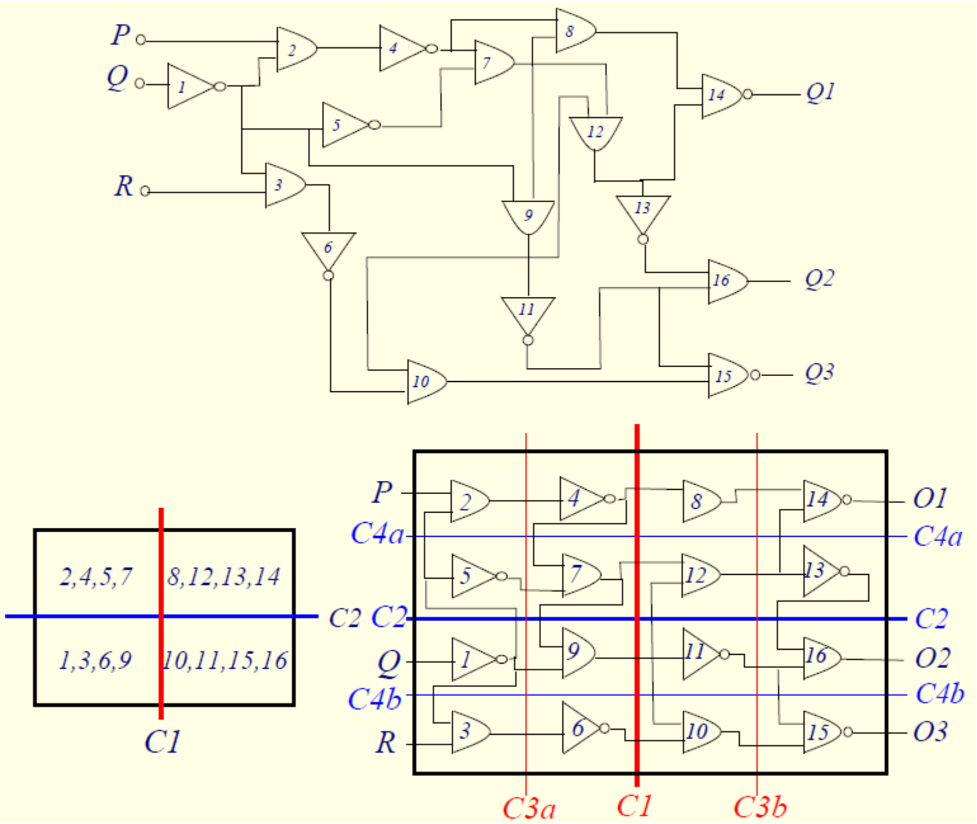
Min-Cut-Based Placement

- Algorithm
  - Min_Cut_Placement (N, n, C)

```
/* N: layout
   n: # cells to be placed
   n_0: # cells in a slot
   C: connectivity matrix (netlist) */
begin
if ( n ≤ n_0 ) then
   place_cells (N, n, C);
else
   (N_1, N_2) = cut_surface (N);
   (n_1, C_1), (n_2, C_2) = partition (n, C);
   Min_Cut_Placement (N_1, n_1, C_1);
   Min_Cut_Placement (N_2, n_2, C_2);
end
```

Min-Cut-Based Placement

- Example (Quadrature placement)
  - KL partitioning + Quadrature placement



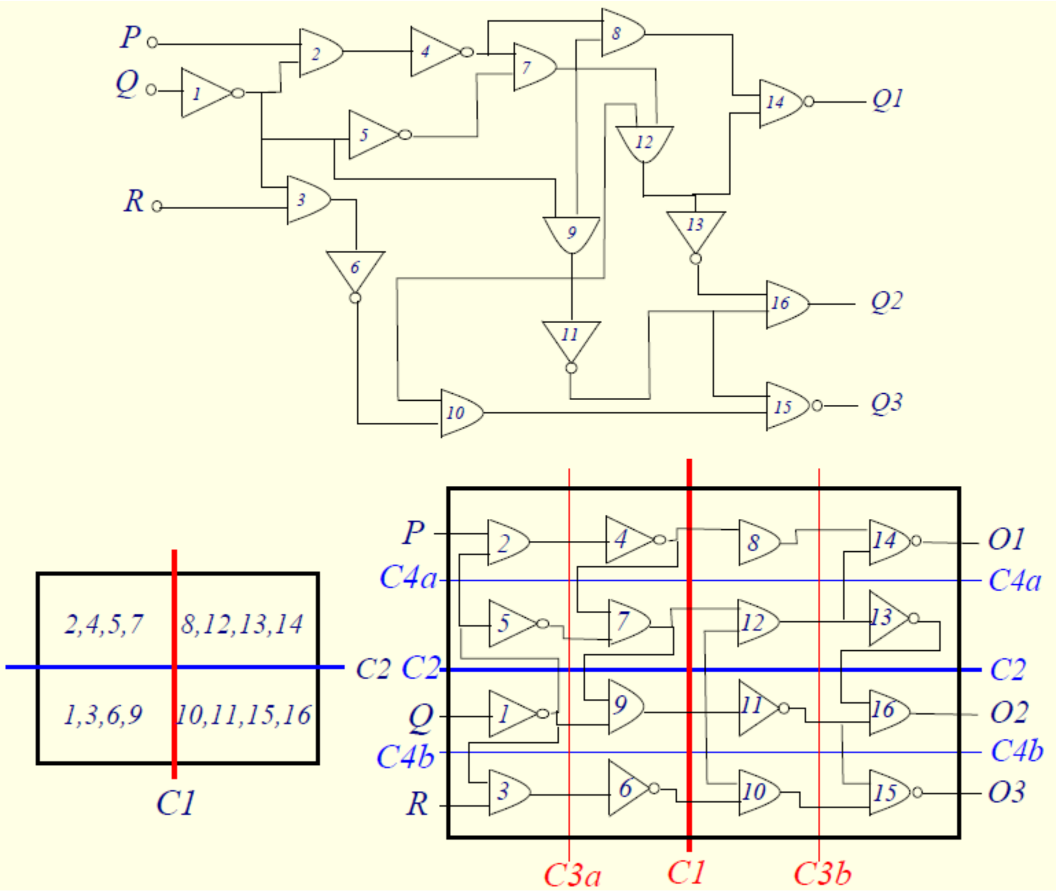
Min-Cut-Based Placement

- Terminal propagation
  - Dunlop and Kernighan, TCAD'85

- Original min-cut placement algorithm
  - Does not consider the locations of terminal pins.

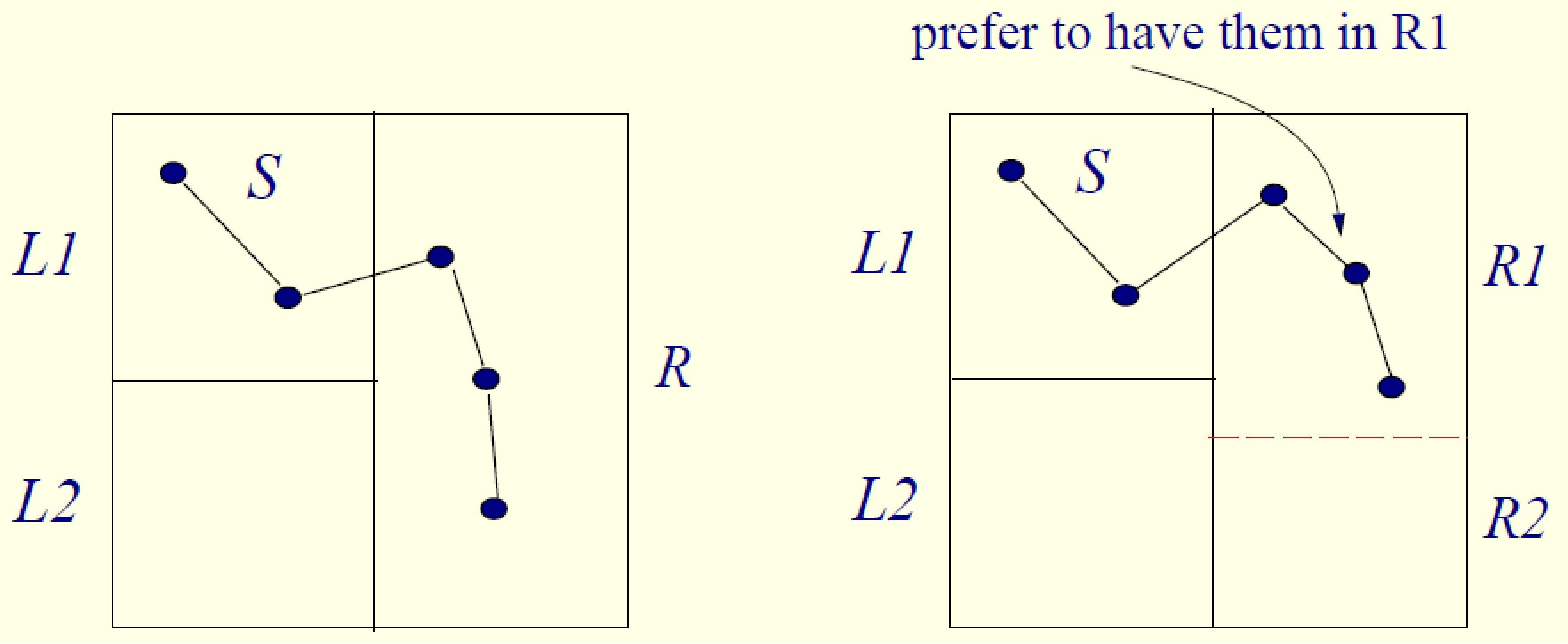
Min-Cut-Based Placement

- What if we swap {1,3,6,9} and {2,4,5,7}?



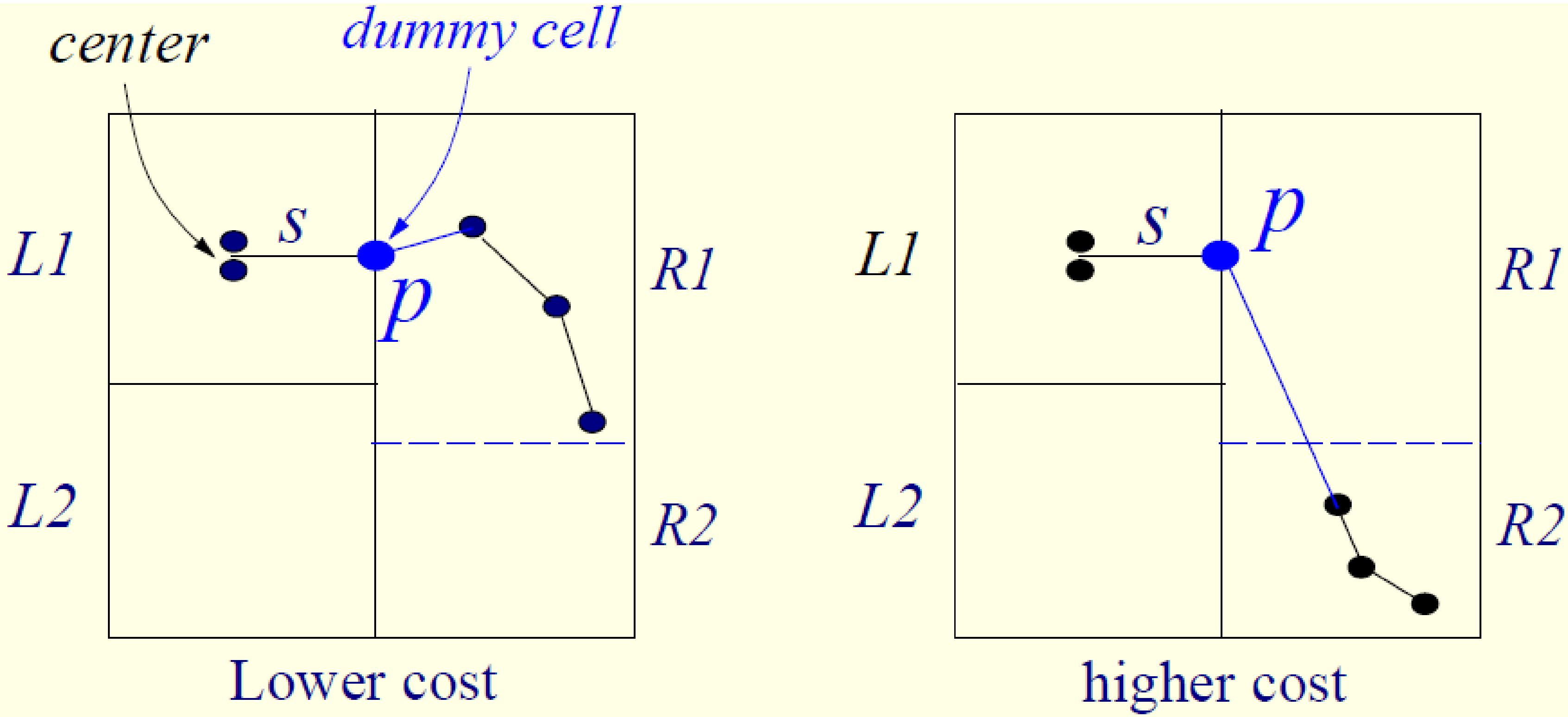
Min-Cut-Based Placement

- Terminal propagation



Min-Cut-Based Placement

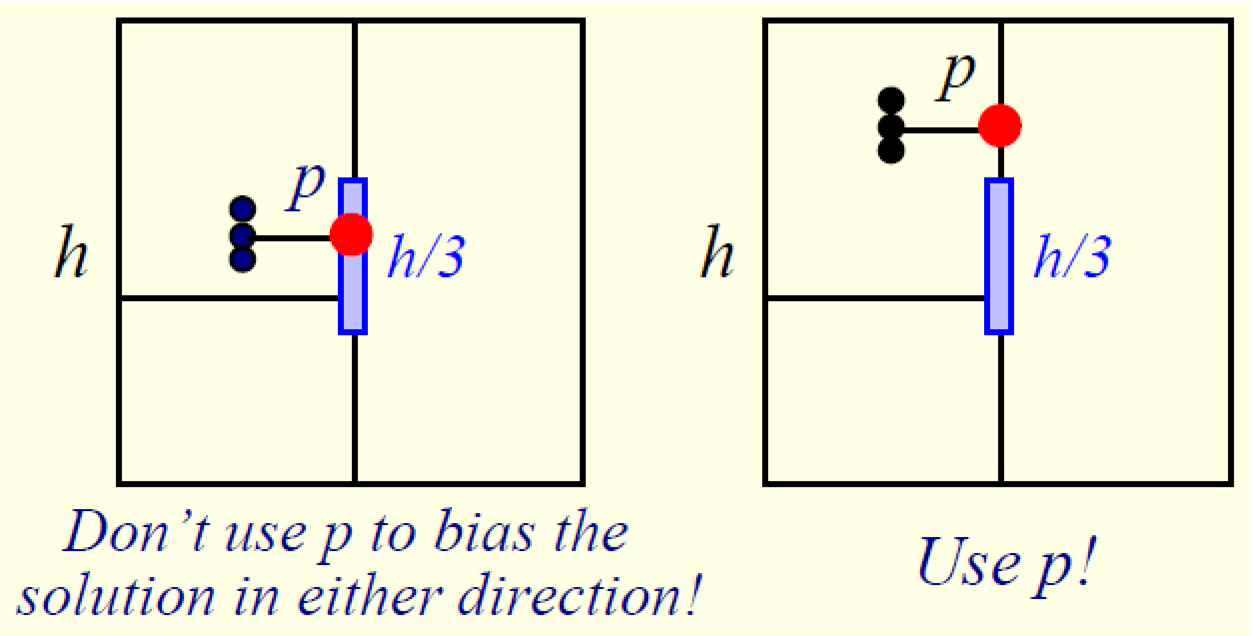
- Terminal propagation



P will stay in R1 for the rest of partitioning!

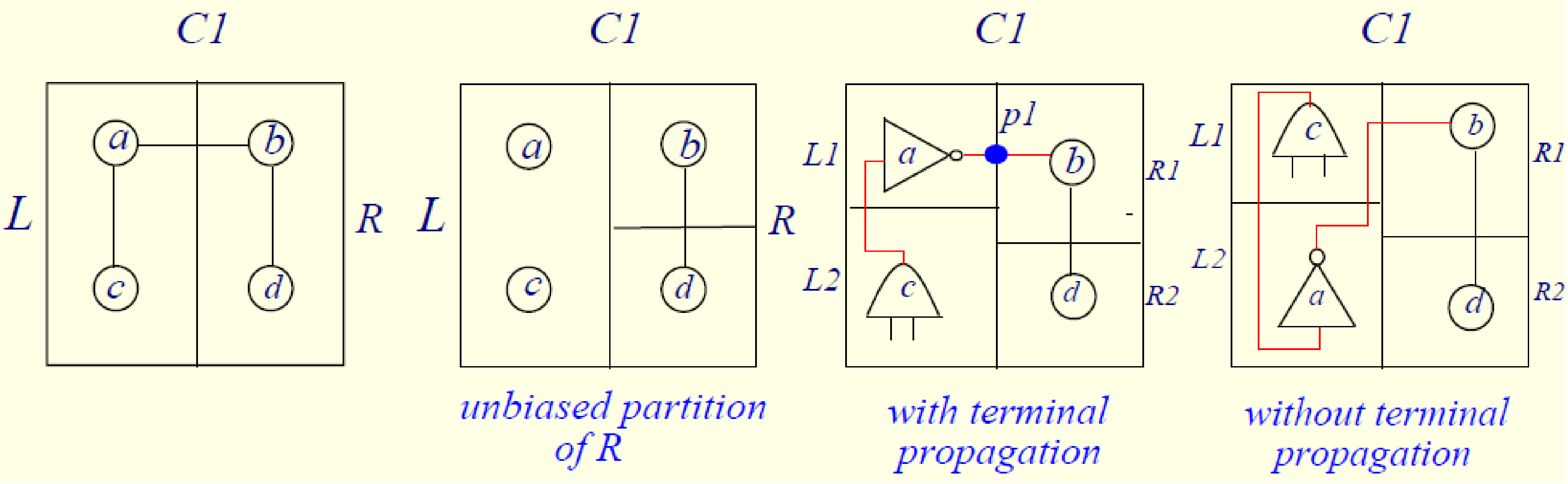
Min-Cut-Based Placement

- Terminal propagation



Min-Cut-Based Placement

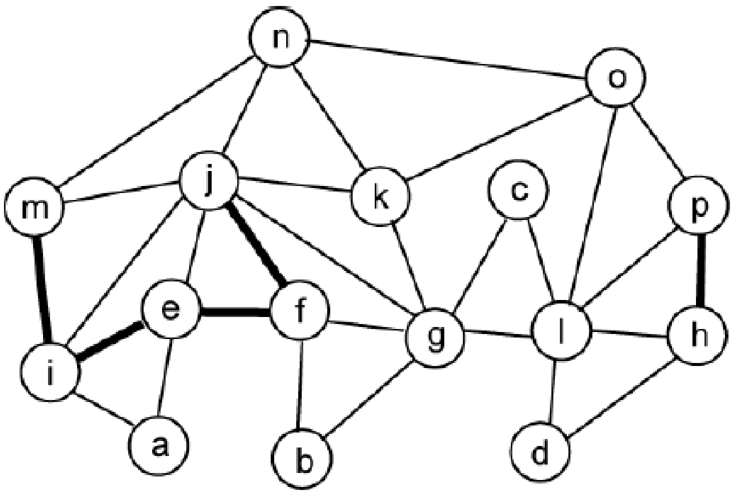
- Terminal propagation



Min-Cut-Based Placement

- Example

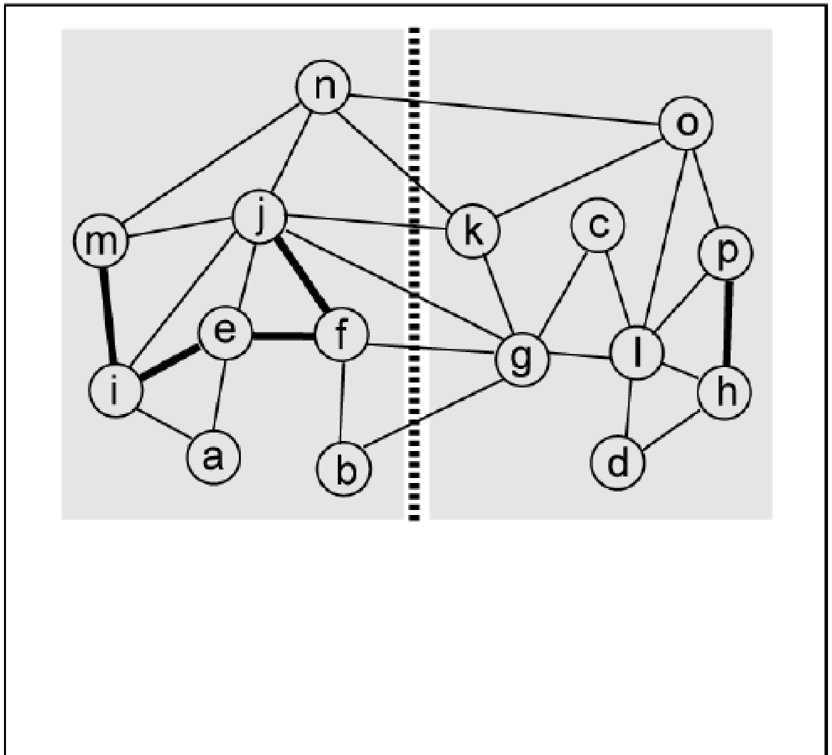
$n_1 = \{e, f\}$
$n_2 = \{a, e, i\}$
$n_3 = \{b, f, g\}$
$n_4 = \{c, g, l\}$
$n_5 = \{d, l, h\}$
$n_6 = \{e, i, j\}$
$n_7 = \{f, j\}$
$n_8 = \{g, j, k\}$
$n_9 = \{l, o, p\}$
$n_{10} = \{h, p\}$
$n_{11} = \{i, m\}$
$n_{12} = \{j, m, n\}$
$n_{13} = \{k, n, o\}$



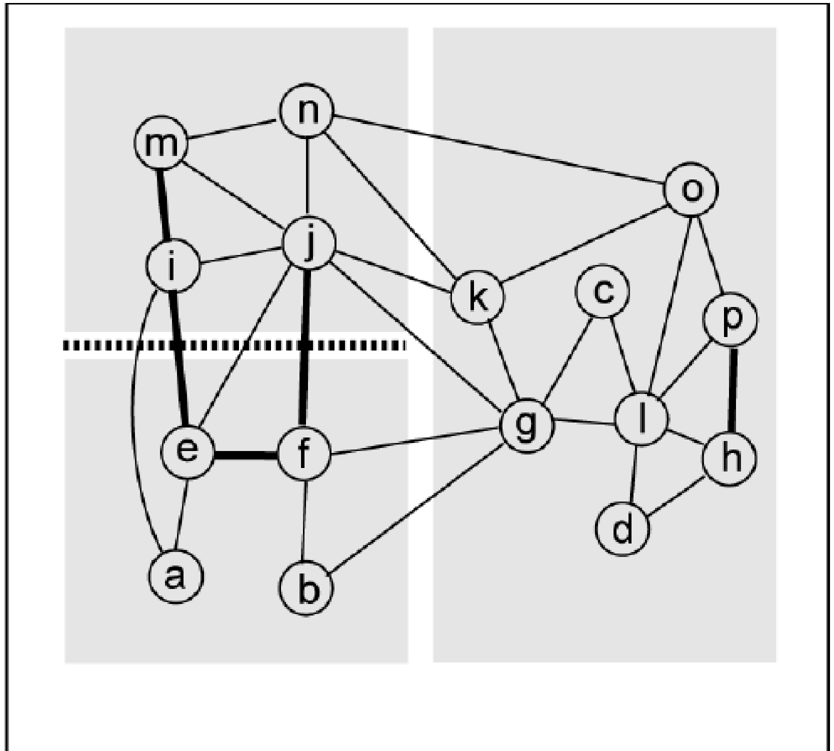
undirected graph model w/ k-clique weighting
thin edges = weight 0.5, thick edges = weight 1

Min-Cut-Based Placement

- Example



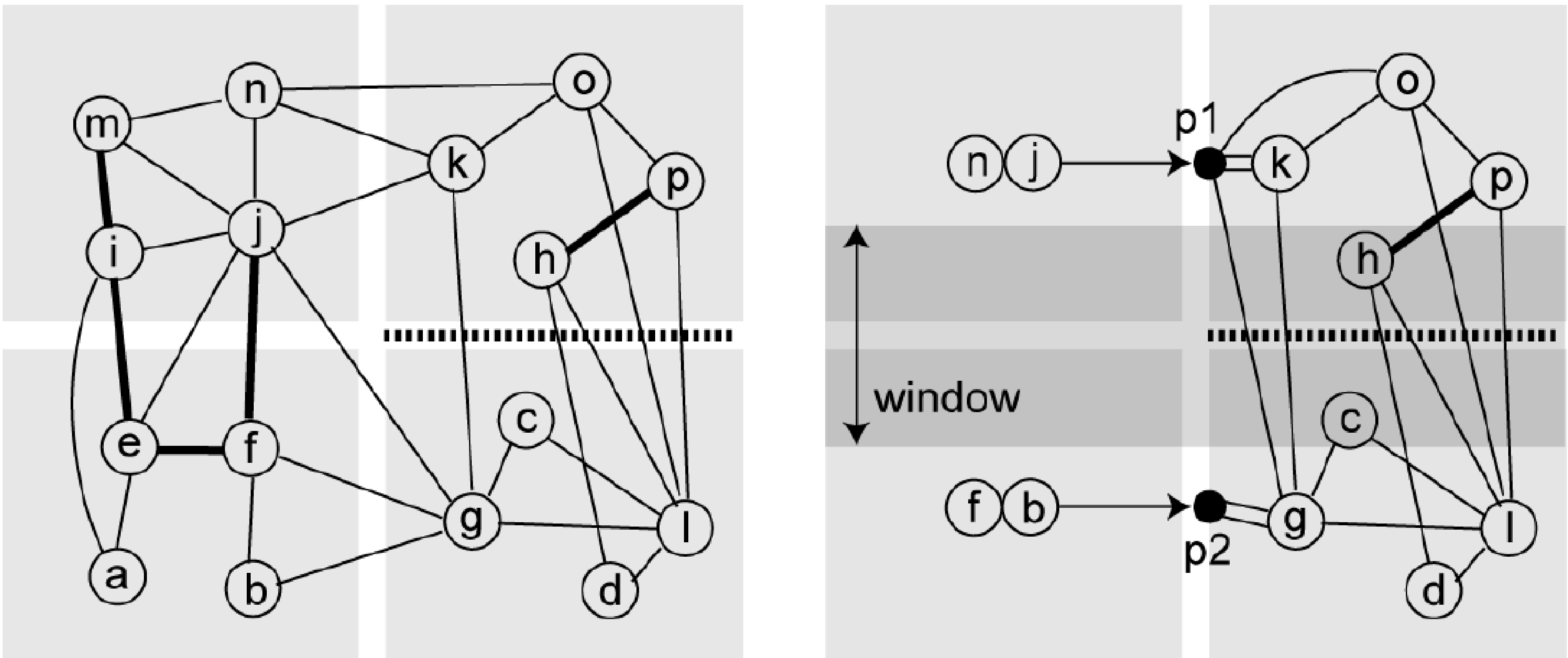
(a) cut 1



(b) cut 2

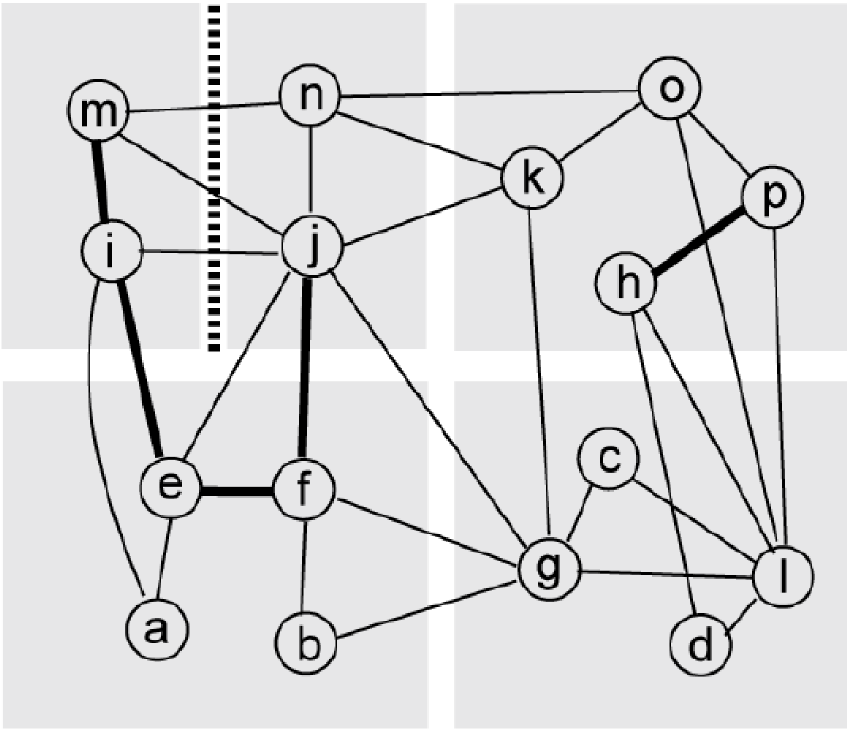
Min-Cut-Based Placement

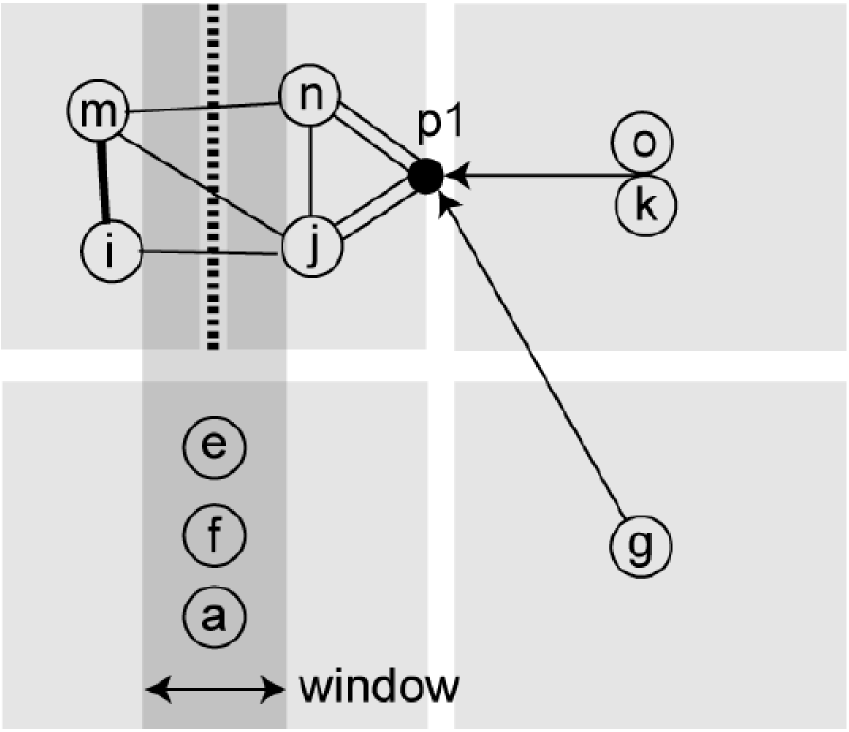
- Example



Min-Cut-Based Placement

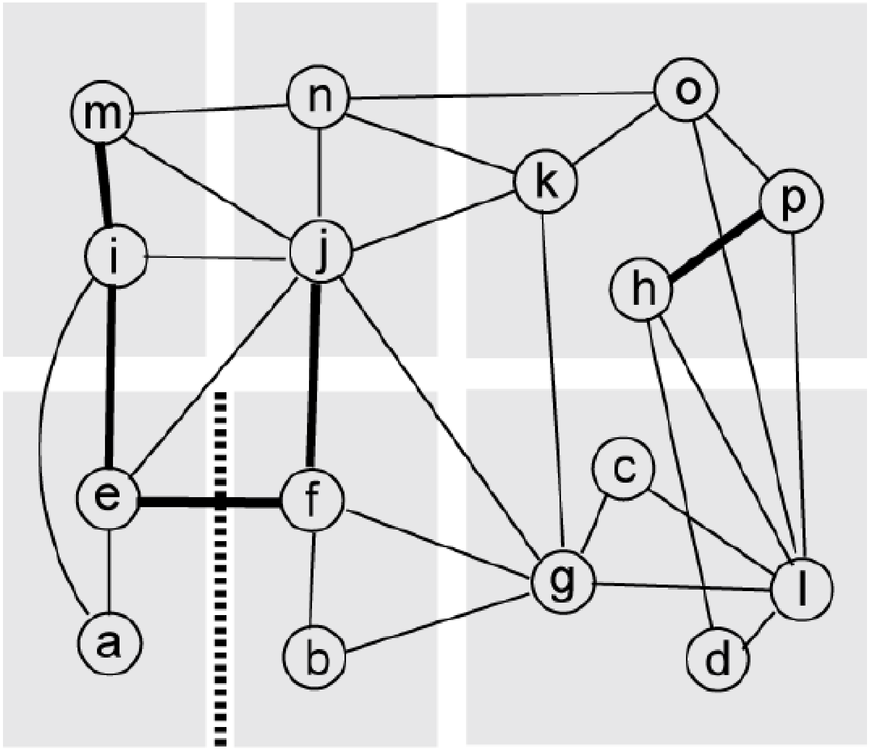
- Example

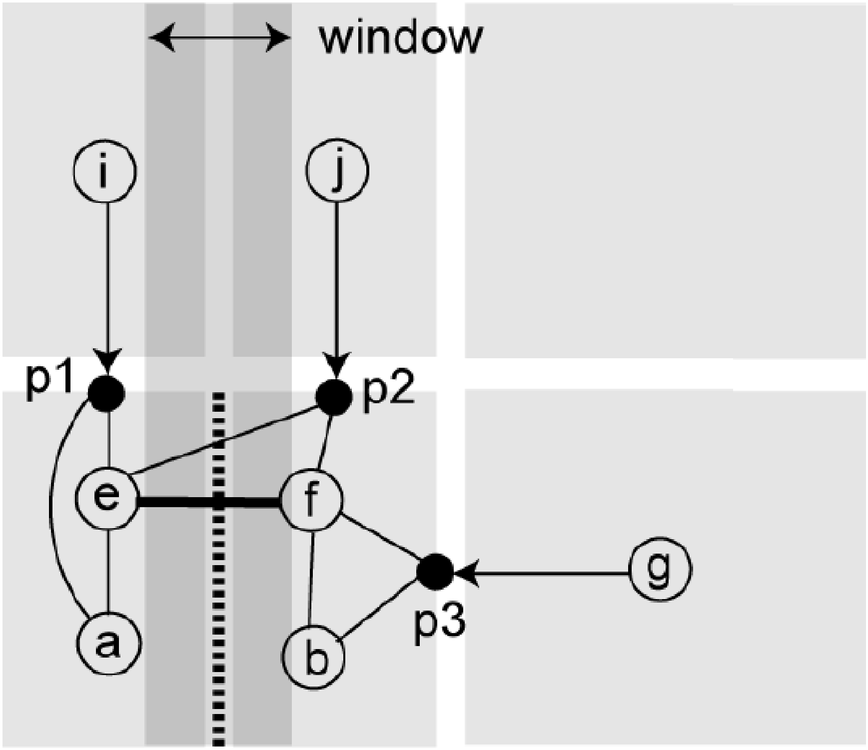




Min-Cut-Based Placement

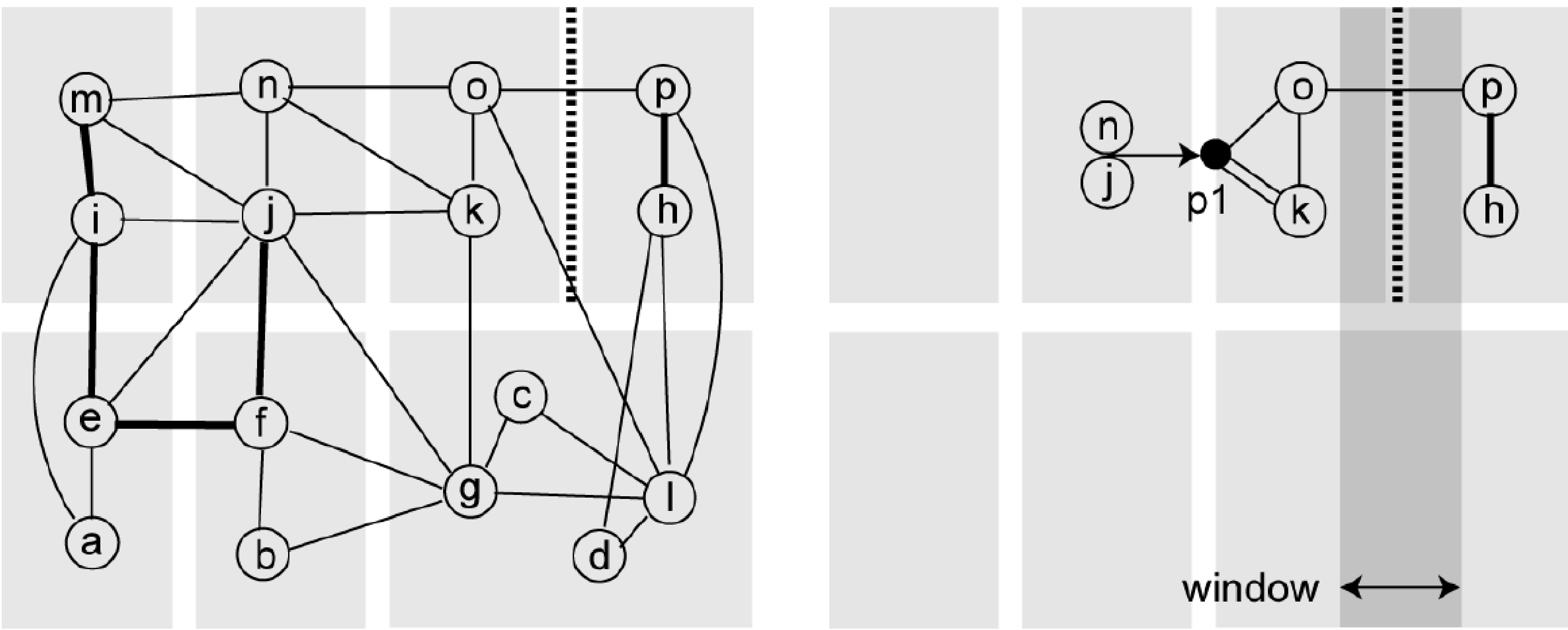
- Example





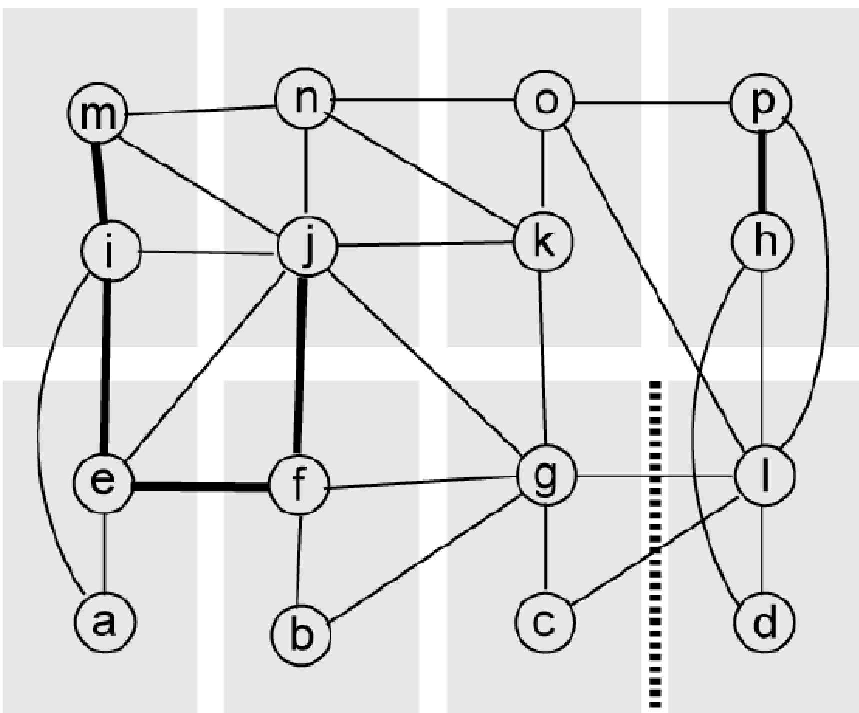
Min-Cut-Based Placement

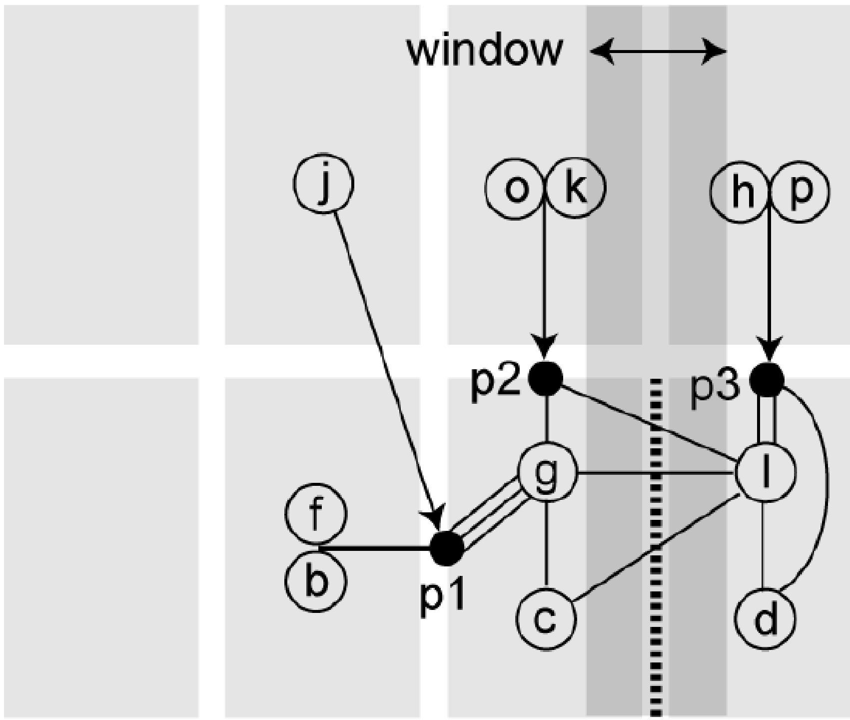
- Example



Min-Cut-Based Placement

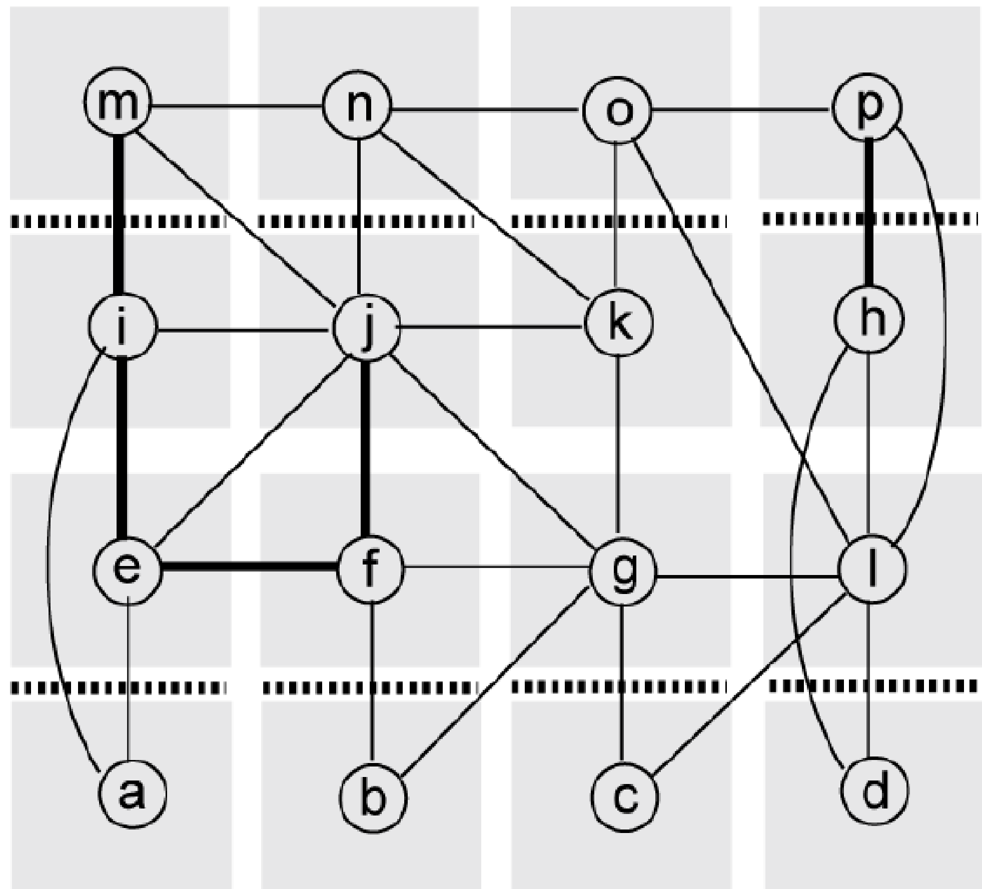
- Example





Min-Cut-Based Placement

- Example



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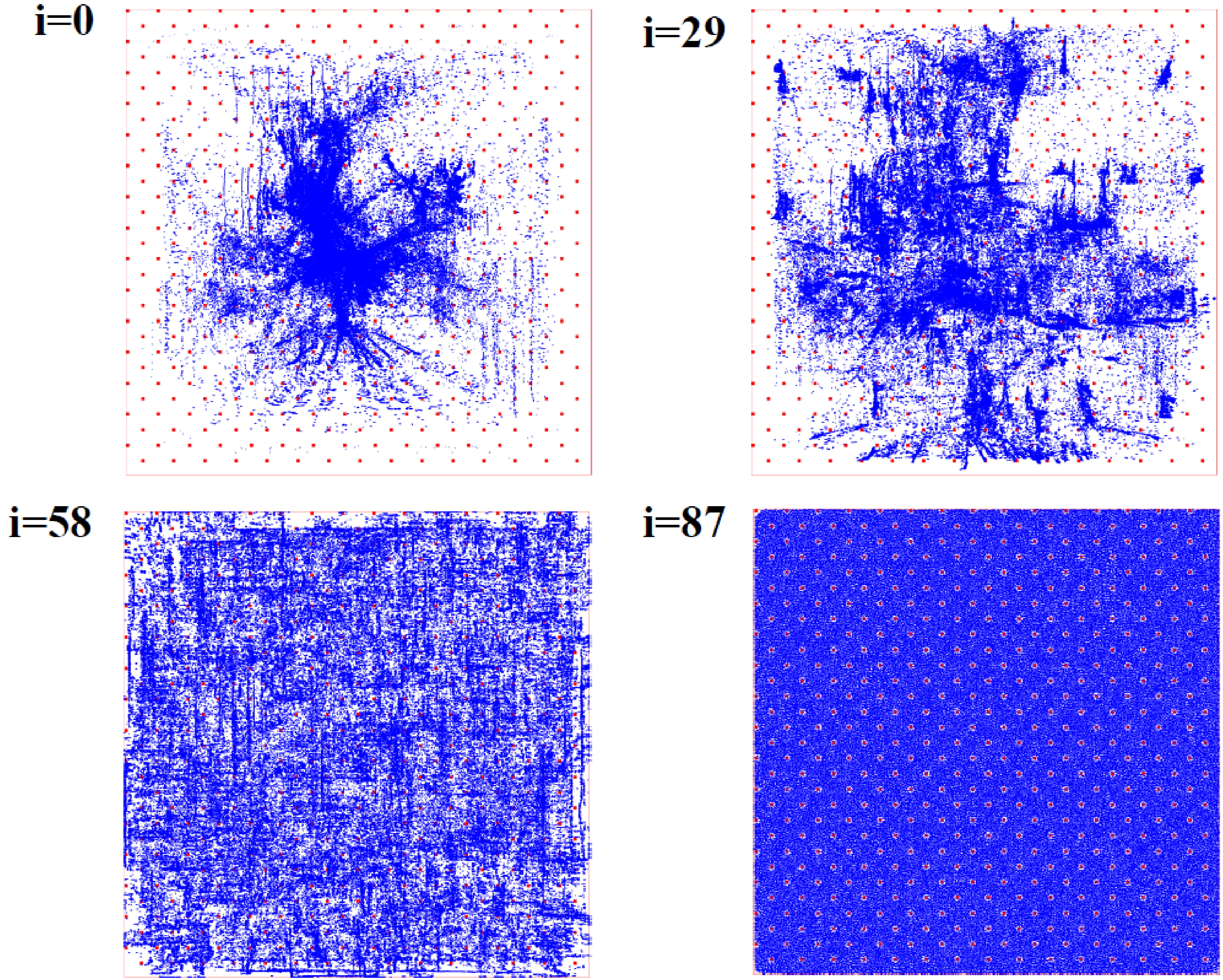
Analytical Placement

- Kraftwerk2
  - Spindler, “Kraftwerk2 – A Fast Force-Directed Quadratic Placement Approach Using an Accurate Net Model”, TCAD’08



i=0
i=29
i=58
i=87

Kraftwerk2

- Net model
  - Two-pin nets
- Connectivity matrix $\begin{pmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \end{pmatrix}$
- Ideal wirelength cost function
  - $\Gamma = |x_1 - x_2| + |y_1 - y_2|$
- Quadratic placement
  - Cost function Γ is quadratic.

Kraftwerk2

- Quadratic cost function
  - $\Gamma = (x_1 - x_2)^2 + (y_1 - y_2)^2 = \Gamma_x + \Gamma_y$

- Γ_x: x-component
- Γ_y: y-component

- How can we optimize the cost function?
  - $\frac{\partial \Gamma_x}{\partial x_1} = 0, \frac{\partial \Gamma_x}{\partial x_2} = 0$
  - $\frac{\partial \Gamma_y}{\partial y_1} = 0, \frac{\partial \Gamma_y}{\partial y_2} = 0$

Kraftwerk2

- Example

$$\Gamma_x = (x - p_1)^2 + (x - p_2)^2$$

$$\frac{\partial \Gamma_x}{\partial x} = 0 = 2(x - p_1) + 2(x - p_2)$$

$$x = \frac{p_1 + p_2}{2}$$

Kraftwerk2

- Example

$$\Gamma_x = (x_1 - p_1)^2 + (x_1 - x_2)^2 + (x_2 - p_2)^2$$

$$\frac{\partial \Gamma_x}{\partial x_1} = 0 = 2(x_1 - p_1) + 2(x_1 - x_2)$$

$$\frac{\partial \Gamma_x}{\partial x_2} = 0 = -2(x_1 - x_2) + 2(x_2 - p_2)$$

$$x_1 = \frac{2p_1 + p_2}{3}$$

$$x_2 = \frac{p_1 + 2p_2}{3}$$

Kraftwerk2

- The location of each cell is represented by
  - (x, y)

- The x-locations of M movable cells
  - $x = (x_1, x_2, \ldots, x_M)^T$
  - C_x: cell-to-cell connectivity matrix
  - d_x: cell-to-pin connectivity matrix (constant)

$$\Gamma_x = 0.5\, x^T C_x x + x^T d_x + \text{const.}$$

Kraftwerk2

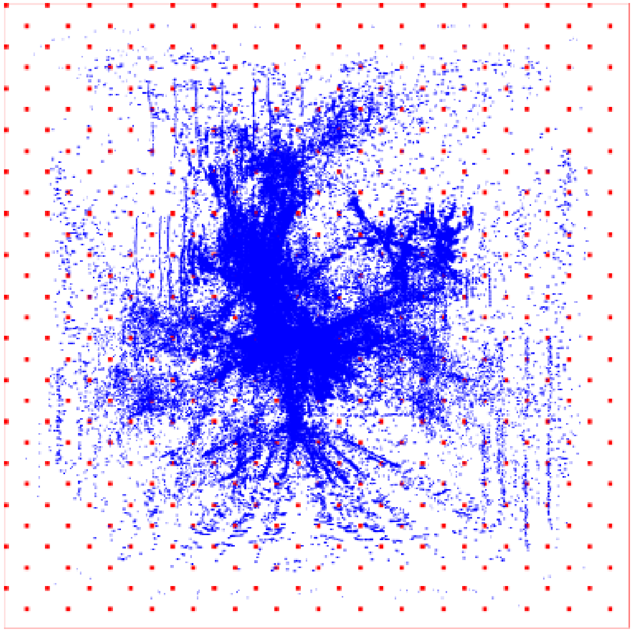
- Wirelength minimization
  - $\frac{\partial \Gamma_x}{\partial x_1} = 0, \frac{\partial \Gamma_x}{\partial x_2} = 0, \ldots, \frac{\partial \Gamma_x}{\partial xM} = 0$
  - i.e., $\nabla_x \Gamma_x = C_x x + d_x = 0$
    - where $\nabla_x = (\frac{\partial}{\partial x_1}, \frac{\partial}{\partial x_2}, \ldots, \frac{\partial}{\partial xM})^T$
  - Net force: $F_x^{net} = \nabla_x \Gamma_x = C_x x + d_x$

$$\Gamma_x = 0.5\, x^T C_x x + x^T d_x + \text{const.}$$

Kraftwerk2

- Applying only the net force makes a lot of overlaps.

i=0



Kraftwerk2

- Move force
  - Removes overlaps = spread cells out.

- x: current location (to be computed)
- x': last location
- Change in the cell location
  - $\Delta x = x - x'$

Kraftwerk2

- Density function
  - $D^{cell}(x, y)$
    - Cell density at each location

- Move force
  - $F_{x,i}^{move} = w_i \cdot (x_i - x_i^o)$
    - x_i: current location (to be computed)
    - x_i^o: target location

$$\overset{\circ}{x}_i = x'_i - \frac{\partial}{\partial x} \underline{\Phi(x,y)} \Big|_{(x'_i, y'_i)}$$

Density

Kraftwerk2

- Net force

$$F_x^{net} = C_x x + d_x$$

- Move force

$$F_x^{move} = C_x^o (x - x^o) = C_x^o (x - x' + \Phi_x)$$

Kraftwerk2

- Net force is used for wirelength minimization
- Do not collapse the cells back to their initial locations.

- Hold force

$$F_x^{hold} = -(C_x x' + d_x)$$

Kraftwerk2

- Final equation

$$F_x^{net} + F_x^{move} + F_x^{hold} = 0$$

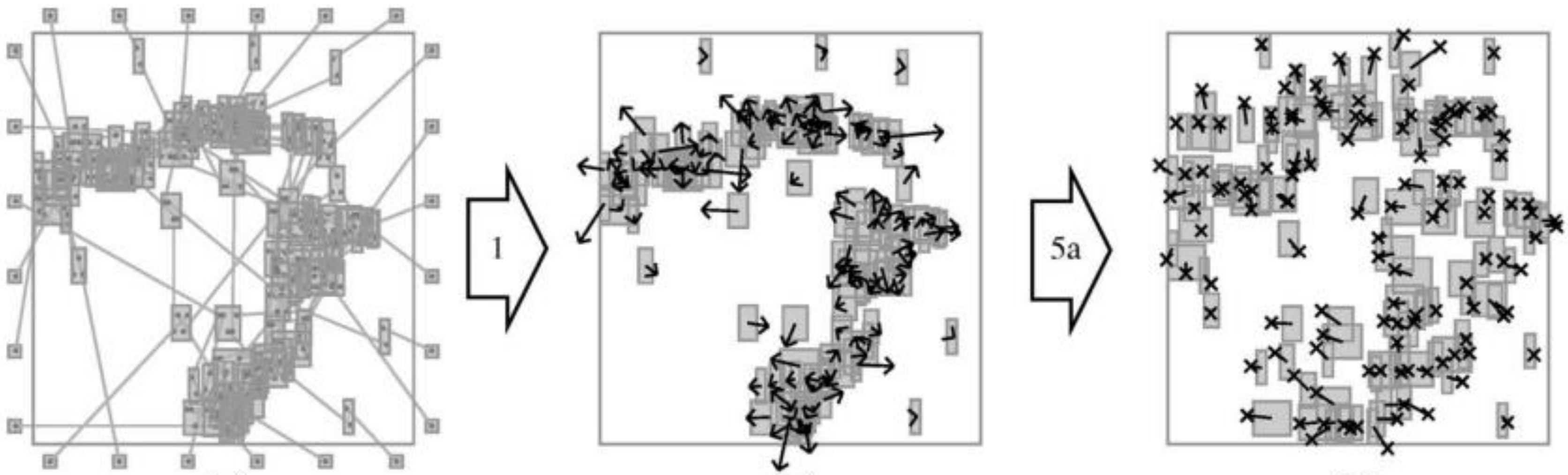
$$[C_x x + d_x] + [C_x^o\,(x - x' + \Phi_x)] + [-(C_x x' + d_x)] = 0$$

$$(C_x + C_x^o)\cdot(x - x') = -C_x^o\cdot\Phi_x$$

$$(C_x + C_x^o)\cdot\Delta x = -C_x^o\cdot\Phi_x$$

$$x = x' + \Delta x$$

Kraftwerk2



(a) (b) (c)

Kraftwerk2

TABLE II
RESULTS IN THE ISPD 2005 CONTEST BENCHMARK SUITE

Circuit	Kraftwerk2		FastPlace3		RQL		NTUPlace3		APlace2	mFAR	Dragon	mPL5	Capo	FengShui
	HPWL	CPU	HPWL	CPU	HPWL	CPU	HPWL	CPU	HPWL	HPWL	HPWL	HPWL	HPWL	HPWL
adaptec1	82.43	262	79.38	353	77.82	751	80.93	883	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
adaptec2	92.85	349	93.08	559	88.51	1247	89.85	906	87.31	91.53	94.72	97.11	99.71	122.99
adaptec3	227.22	713	217.80	2275	210.96	2405	214.20	1944	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
adaptec4	199.43	709	201.36	1411	188.86	2096	193.74	2325	187.65	190.84	200.88	200.94	211.25	337.22
bigblue1	97.67	407	95.68	604	94.98	1160	97.28	1675	94.64	97.70	102.39	98.31	108.21	114.57
bigblue2	154.74	559	155.10	1380	150.03	2261	152.20	3352	143.82	168.70	159.71	173.22	172.30	285.43
bigblue3	343.32	2070	379.88	4642	323.09	4864	348.48	6256	357.89	379.95	380.45	369.66	382.63	471.15
bigblue4	852.40	4147	832.88	6862	797.66	12410	829.16	11308	833.21	876.28	903.96	904.19	1098.76	1040.05
Average	**1.000**	**1.00**	**1.000**	**2.00**	**0.959**	**3.12**	**0.979**	**3.48**	**0.967**	**1.028**	**1.046**	**1.053**	**1.126**	**1.438**

Kraftwerk2

TABLE III

RESULTS IN THE ISPD 2006 CONTEST BENCHMARK SUITE. (a) KRAFTWERK'S RESULTS. AS REQUIRED IN THIS BENCHMARK SUITE, THE CPU FACTOR IS LIMITED TO ±10%. THE "RAW" CPU FACTORS ARE −13.50% AND −10.98%, RESPECTIVELY. (b) RESULTS OF OTHER PLACERS

Circuit	HPWL	Overflow factor	CPU	CPU factor	Score: HPWL	Score: HPWL+ Overflow	Score: HPWL+ Overflow+ CPU
adaptec5	433.84	3.606%	1618	– 9.35%	1.071	1.032	0.939
newblue1	65.92	0.415%	603	– 8.38%	1.057	1.043	0.956
newblue2	203.91	1.286%	508	– 10.00%*	1.033	1.082	0.975
newblue3	278.51	0.382%	526	– 10.00%*	1.018	1.067	0.961
newblue4	304.24	1.709%	1553	– 8.63%	1.068	1.033	0.945
newblue5	548.38	2.694%	2622	– 9.50%	1.109	1.054	0.957
newblue6	528.59	1.702%	2579	– 9.89%	1.048	1.036	0.936
newblue7	1126.58	3.155%	4828	– 9.06%	1.053	1.051	0.958
Average		**1.869%**		**– 9.35%**	**1.057**	**1.050**	**0.953**

(a)

Placer	Overflow factor	CPU factor	Score: HPWL	Score: HPWL+ Overflow	Score: HPWL+ Overflow+ CPU
Kraftwerk2	1.87 %	– 9.35 %	1.057	1.050	0.953
NTUPlace3	6.26 %	– 2.61 %	0.976	1.007	0.990
RQL	6.80 %	n.a. %	0.981	1.018	n.a.
Fastplace3	n.a.	– 8.17 %	n.a.	n.a.	1.040
mPL6	1.36 %	1.58 %	1.035	1.020	1.040
mFAR	2.71 %	– 0.12 %	1.108	1.107	1.108
APlace3	3.83 %	5.31 %	1.097	1.107	1.165
Dragon	0.12 %	– 5.90 %	1.331	1.300	1.232
DPlace	9.32 %	– 4.54 %	1.343	1.414	1.364
Capo	0.32 %	2.69 %	1.375	1.344	1.385

(b)

Kraftwerk2

TABLE IV

RESULTS IN MIXED-SIZE AND FLOORPLACEMENT BENCHMARK SUITES. (a) ICCAD 2004 MIXED-SIZED BENCHMARK SUITE. (b) IBM-HB$^+$ FLOORPLACEMENT BENCHMARK SUITE

Circuit	Kraftwerk2		FDP		NTUPlace3		APlace2		mPL5	
	HPWL	CPU	HPWL	CPU	HPWL	CPU	HPWL	CPU	HPWL	CPU
ibm01	2.24	11	2.42	145	2.17	33	2.14	381	2.22	91
ibm02	4.90	27	5.11	284	4.63	63	4.65	872	4.68	264
ibm03	6.61	24	7.08	337	6.65	72	6.71	1015	6.86	300
ibm04	7.63	29	7.69	317	7.21	89	7.57	977	7.69	261
ibm05	9.79	33	n.a.	n.a.	9.66	160	9.69	766	10.09	130
ibm06	6.11	40	6.20	389	5.94	95	6.02	967	6.16	520
ibm07	10.42	52	10.57	607	9.90	219	10.00	1296	9.96	692
ibm08	12.97	85	13.30	719	12.29	235	12.50	1484	11.92	1133
ibm09	11.98	71	13.30	713	12.00	213	12.13	1837	13.15	1363
ibm10	30.15	232	30.70	924	28.49	351	28.83	2649	29.36	1654
ibm11	17.59	107	18.41	950	17.54	336	18.67	3814	17.87	1071
ibm12	31.42	124	36.46	1472	32.07	332	33.42	3663	33.43	1419
ibm13	22.48	147	23.60	1175	22.16	536	22.80	3845	22.52	1079
ibm14	35.13	308	37.84	2185	35.36	1274	35.92	4723	34.99	1588
ibm15	47.58	468	47.69	2468	45.38	1251	46.81	5419	50.88	4989
ibm16	54.17	527	61.27	2792	57.59	1595	54.53	6109	55.21	6200
ibm17	66.63	474	69.45	3577	66.73	2123	65.67	6635	66.96	2131
ibm18	42.36	609	44.88	4369	41.58	2874	41.99	10925	43.99	2477
Average	**1.000**	**1.00**	**1.056**	**9.02**	**0.982**	**3.25**	**0.995**	**23.93**	**1.010**	**9.67**

(a)

Circuit	Kraftwerk2		SCAMPI	
	HPWL	CPU	HPWL	CPU
ibm-HB$^+$01	2.82	10	3.4	68
ibm-HB$^+$02	5.87	26	8.0	154
ibm-HB$^+$03	9.23	16	9.5	115
ibm-HB$^+$04	9.98	21	12.3	158
ibm-HB$^+$06	8.79	12	11.0	187
ibm-HB$^+$07	14.80	16	15.7	110
ibm-HB$^+$08	21.27	19	20.5	207
ibm-HB$^+$09	17.44	18	22.2	200
ibm-HB$^+$10	47.51	47	55.2	351
ibm-HB$^+$11	25.92	23	27.8	159
ibm-HB$^+$12	51.38	43	67.6	447
ibm-HB$^+$13	34.90	23	42.2	231
ibm-HB$^+$14	63.11	42	66.4	295
ibm-HB$^+$15	92.88	46	88.2	414
ibm-HB$^+$16	95.60	54	106.2	337
ibm-HB$^+$17	148.16	96	152.7	424
ibm-HB$^+$18	73.95	52	77.8	211
Average	**1.000**	**1.00**	**1.140**	**8.03**

(b)