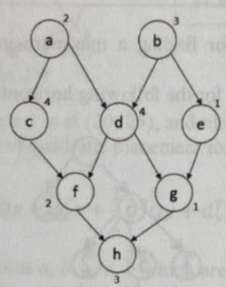
CS 6135 VLSI Physical Design Automation
Final Exam: 10:10 a.m. - 13:10 p.m., December 31, 2019

1. (15 points) Assume the area of each gate is 1 unit, the area constraint of each cluster is 3 units, and the interconnection delay between two clusters is 4 units. The gate delay is given next to each gate. Show your work by applying the clustering algorithm discussed in class to the following circuit.



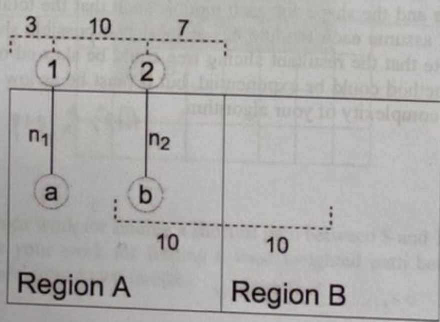
	inter	extern
a	5	1
b.	4	7

2. (5 points) Vertex a and vertex b are two vertices in an edge-weighted complete graph, where the weight of each edge is a non-negative integer. Suppose that the vertex set of this graph is partitioned into two subsets, and vertices a and b are not in the same subset. Assume that the respective internal and external costs of vertex a are 5 and 1, and the respective internal and external costs of vertex b are 4 and 7. Can the cut cost be reduced by swapping vertices a and b? Justify your answer.

2. 能不能 swap.

3. (5 points) Consider the following figure where 1 and 2 are fixed cells that are placed at the given locations, a and b be movable cells that can be moved to the center of either region A or B, net n_1 connects cells 1 and a, and net n_2 connects cells 2 and b. The center-to-center distance between regions A and B is 20. The distances related to cell 1 and cell 2 are shown below. Use the exact net-weight model discussed in class to find the cut weights for nets n_1 and n_2 for capturing the horizontal wirelength cost precisely.

Ans 給一個 weight.

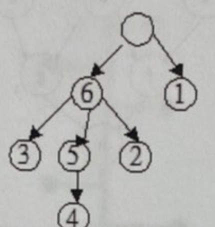


✓4. Consider a set of modules in the following table. Assume that each module cannot be rotated.

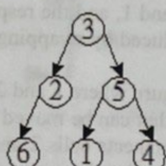
Module	Width	Height
1	4	5
2	3	7
3	6	4
4	7	7
5	5	2
6	2	6

(a) (7 points) Show your work for finding a minimum-area placement for the sequence-pair (123456, 654321).

(b) (4 points) Show the placement for the following horizontal O-tree.

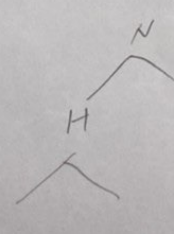


(c) (4 points) Show the placement for the following B*-tree.

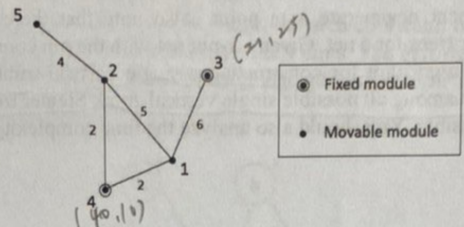


5. (10 points) Given a slicing floorplan tree where the cut direction of each internal node is undecided yet, describe how to extend Stockmeyer algorithm to simultaneously determine the cut direction for each internal node and the shape for each module such that the total area of the floorplan is minimized. You may assume each module has at most two possible shapes (the ones with and without rotation). Note that the resultant slicing tree could be skewed or non-skewed. The time complexity of your method could be exponential, but it must be as low as possible. You should also analyze the time complexity of your algorithm.

exp



6. (10 points) Consider a circuit with movable and fixed modules as represented by the following graph. In the graph, each vertex denotes a module, while each edge denotes a two-pin net and is associated with a weight next to it. Q, dx, dy.



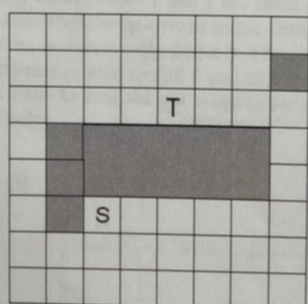
For the two fixed modules, module 3 is at (20, 25), and module 4 is at (10, 10). Determine Q, d_x, and d_y such that the cost function of quadratic placement for this circuit can be written as follows:

$$\frac{1}{2}x^T Q x + d_x^T x + \frac{1}{2}y^T Q y + d_y^T y + \text{const}$$

7. (5 points) Given a net with five pins a, b, c, d, e which are located at (2, 5), (3, 8), (6, 1), (9, 3), (5, 5), estimate its wire lengths by using the half perimeter wire length (HPWL) method and the minimum spanning tree method, respectively. 5pin net + MST.

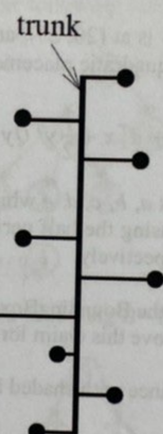
8. (10 points) In class we claimed that the BoundingBox net model can accurately model HPWL in a quadratic placement framework. Prove this claim for the x direction. →BB

9. Consider the following routing instance with shaded blockages.



(a) (5 points) Show your work for finding a shortest path between S and T using the Lee algorithm.
(b) (10 points) Show your work for finding a least weighted path between S and T using the weighted grid model introduced in class. → 所有先畫 weight 再走.

10. (10 points) For a net with all its pins located on a two-dimensional plane, a single vertical-trunk Steiner tree for the net consists of a signal vertical trunk (i.e., a vertical line segment) and all the pins of the net are connected to the trunk by horizontal line segments. See the following figure for an example. Note that it is possible for a single vertical-trunk Steiner tree to have the trunk or a horizontal line segment degenerate as a point. Also note that there are many possible single vertical-trunk Steiner trees for a net. Given a k-pin net with the pin coordinates, (x_i, y_i), $1 \leq i \leq k$, in a plane, develop an algorithm for constructing a single vertical-trunk Steiner tree that has the minimum wirelength among all possible single vertical-trunk Steiner trees. Your algorithm should be as efficient as possible. You should also analyze the time complexity of your algorithm.

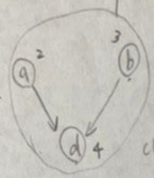


$|x_1-x'|+\cdots |x_k-x'|$ min.

1. $l(a) = 2$, $l(b) = 3$, $\begin{cases} l(c) = 2+4=6 \\ cluster(c) = \{a, c\} \end{cases}$, $\begin{cases} l(e) = 3+1=4 \\ cluster(e) = \{b, e\} \end{cases}$.

① $l(d) = \max\{l_1(d), l_2(d)\} = \max\{\max\{6, 7\}, 0\} = 7$.

$l'(a) = 2+4=6$.



$l'(b)=3+4=7$

cluster(d)

cluster(d) = {a, b, d}

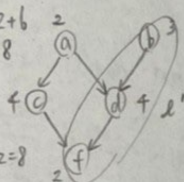
②

$l(f) = \max\{l_1(f), l_2(f)\} = \max\{9, \max\{8+4, 8+4\}\} = 12$.

最大那個

$l'(a)=2+6=8$

$l'(b)=3+6=9$



$l'(d) = 7+2=9$.

把有9的都cluster

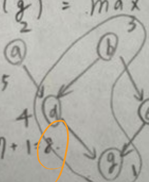
$l'(c) = 6+2=8$

cluster(f) = {b, d, f}

③ $l(g) = \max\{l_1(g), l_2(g)\} = \max\{8, \max\{7+4, 5+4\}\} = 11$

$l'(b) = 3+5=8$

$l'(a)=2+5=7$



$l'(e) = 4+1=5$

把有8的都cluster

$l'(d)=7+1=8$

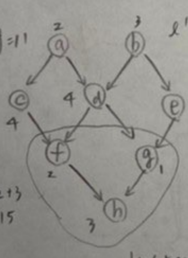
cluster(g) = {b, d, g}

④ $l(h) = \max\{l_1(h), l_2(h)\} = \max\{0, \max\{11+4, 11+4, 12+4, 12+4, 8+4\}\}$

$= 16$ #.

$l'(a)=2+9=11$

$l'(b) = 3+9=12$



$l'(d) = 7+5=12$

$l'(e) = 4+4=8$

$l'(g) = 11+3=14$

$l'(c) = 6+5=11$

$l'(f) = 12+3 = 15$

cluster(h) = {f, g, h}

no cluster −4

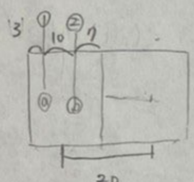
2.

	internal cost	external cost	D value
a	5	1	$1-5=-4=D_a$
b	4	7	$7-4=3=D_b$

$\because g_{ab} = D_a + D_b - 2c_{ab} = -1 - 2C_{ab}$，且 $C_{ab} \geq 0$.

$\therefore g_{ab} < 0$，執行 swap 使效果更差，所以不做 swap.

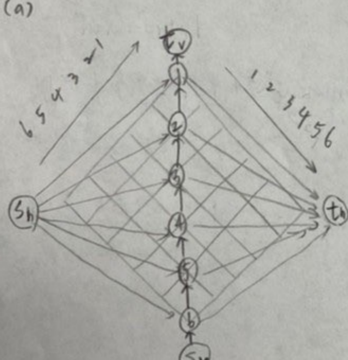
3.

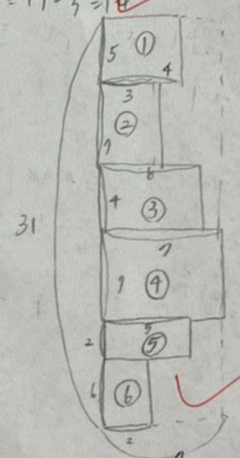


$$\text{weight}(n_1) = WL(n_1 \text{ is cut}) - WL(n_1 \text{ is not cut}) = 27 - 7 = 20.$$

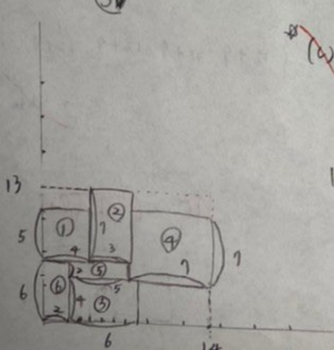
$$\text{Weight}(n_2) = WL(n_2 \text{ is cut}) - WL(n_2 \text{ is not cut}) = 17 - 3 = 14$$

4. (a)

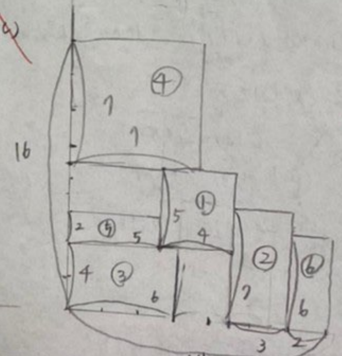




(b)



(c)



-4

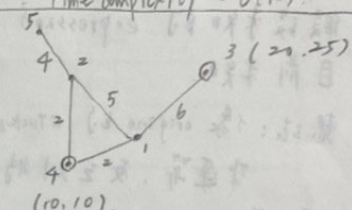
10. ①

1. construct VTST(P) // P is a set of all pins
2. sum = 0
3. for i = 1 to k do
4. sum += x(p_i) // $p_i \in P$, x(p_i) return x-coordination of p_i
5. trunk_coordination = ~~sum/k~~ // y(p_i) return y-coordination of p_i
6. construct a null tree vtst. −10
7. for i = 1 to k do
8. construct a Steiner point sp_i with coordination (trunk_coordination, y(p_i))
9. add the edge (sp_i, p_i) to vtst
10. Sort all sp in vtst into list sp-list // sp_list 為 (sp_1, sp_2 … sp_K)，已經排序 // 且重命名
11. for i = 1 to (k−1)
12. add edge (sp_i, sp_{i+1}) to vtst ☆ 會3個一維 for loop，
13. return vtst

time complexity = O(K)

6.

$$C = \begin{array}{c|ccc} & 1 & 2 & 5 \\ \hline 1 & 0 & 1 & 0 \\ 2 & 1 & 0 & 1 \\ 5 & 0 & 1 & 0 \end{array} \Rightarrow D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



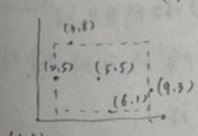
$$Q = D - C = \begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}$$

$$dx^T = \begin{bmatrix} dx_1 \\ dx_2 \\ dx_5 \end{bmatrix} = \begin{bmatrix} -(6\cdot 20 + 2\cdot 10) \\ -(2\cdot 10) \\ 0 \end{bmatrix} = \begin{bmatrix} -140 \\ -20 \\ 0 \end{bmatrix} \Rightarrow dx = [-140 \ \ -20 \ \ 0]$$ −1

$$dy^T = \begin{bmatrix} dy_1 \\ dy_2 \\ dy_5 \end{bmatrix} = \begin{bmatrix} -(6\times 25 + 2\cdot 10) \\ -(2\cdot 10) \\ 0 \end{bmatrix} = \begin{bmatrix} -170 \\ -20 \\ 0 \end{bmatrix} \Rightarrow dy = [-170 \ \ -20 \ \ 0]$$ −1

7.

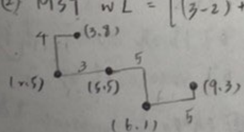
① HPWL = (9−2)+(8−1) = 14



② MST WL = [(3−2)+(8−5)] + [(5−2)+(5−5)] + [(6−5)+(5−1)] + [(9−6)+(3−1)]

= 4+3+5+5

= 17



8. $$L^{\sim BB} = \frac{1}{2} \sum_{\{i,j\} \in N} W_{\{i,j\}} \times (x_i - x_j)^2$$

$$= \frac{1}{2} \sum_{\{i,j\} \in N} \frac{2}{k-1} \times \frac{1}{l_{\{i,j\}}} \times (x_i - x_j)^2 \text{, if } l_{\{i,j\}} = |x_i - x_j| \ \forall \{i,j\} \in N$$

$$L^{\sim BB} = \frac{1}{k-1} \left\{ |x_1 - x_k| + \sum_{2 \le m \le k-1} \big(|x_1 - x_m| + |x_m - x_k| \big) \right\}$$

$$= \frac{1}{k-1} \left\{ |x_1 - x_k| + (k-2) \cdot |x_1 - x_k| \right\}$$

$$= \frac{1}{k-1} (k-1) \cdot |x_1 - x_k| = |x_1 - x_k|$$ #.

5. 假設未知的 expression 像 1 2 N 3 N 4 5 N 6 ⋯⋯ N，N ∈ {V, H}，但目前未知。

想法：像 origine 的 stuckmeyer 用 stack 去做運算。(讀到 N 就 pop 2個 operand 出來運算，反之則將 operand push in。當 operand 為 a.b，operator 為 N，做以下動作：

A: 如果 a.b 且為 cell (非 module)，做 ①~③。

① 將 a (有無 rotate)，b (有無 rotate)，N (V or H) 做所有可能的排列，會有 2×2×2 種情形
Not Stockmeyer -2

② 去除掉其結果之長寬皆大於某一 other 結果的 module。

③ 儲存剩餘可能的排列情形，並將 module push 回

B: 如果 a.b 有 module 存在，一般性假設 a 是 module，b 是 cell (當然可以皆是 module)。做④~⑥

④ 將 a (所有可能的排列)，b (有無 rotate)，N (V or H) 做所有可能的排列，共 $n_a \times 2 \times 2$ (n_a 為 a module 未被排除的可能排列數)。(若 a.b 皆為 module，最差情況下有 $n_a \times n_b \times 2$ 種可能)。

⑤ 同②。

⑥ 同③

C: 直到 stack 為空，則以最後 module 之最小 area 的情況為解，去往前推出所有子 module 的 operator 為 H or V 及 cell 的 rotate 情形 #.

☆ time complexity: n is # of modules, d is the depth of tree，因 shape 為 constant，考慮 H 及 V 個數為 (n-1)，所以 time complexity 應為 $O(n^{\cancel{2}}\cancel{\cdot d})$ -2

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ID: 108062611.

9(a).

Route:

9	10	11				11	
8	9	10	11		11	10	
7	8	9	10	T	10	9	8
6							7
5							6
4		S	1	2	3	4	5
3	2	1	2	3	4	5	6
4	3	2	3	4	5	6	7

有2條 shortest path，端看演算法 retrace 之方向決定實際順序.

9(b)

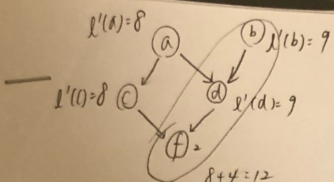
Weight:

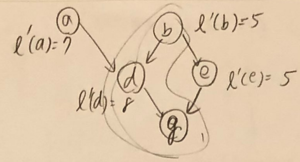
3	3	3	3	3	3	3	2
3	3	3	3	2	3	2	
3	2	2	1	T	1	2	2
2							2
2							2
2		S	1	2	2	2	3
3	2	2	3	3	3	3	3
3	3	3	3	3	3	3	3

Route:

−1

22	24	26					
19	21	23	24				
16	18	20	21	T	19	18	16
13							14
11							12
9		S	1	3	5	7	10
7	4	2	4	6	8	10	13
10	7	5	7	9	11	13	16





CS 6135 VLSI Physical Design Automation

Final Exam: 10:10 a.m. - 13:10 p.m., December 31, 2019

1\. (15 points) Assume the area of each gate is 1 unit, the area constraint of each cluster is 3 units, and the interconnection delay between two clusters is 4 units. The gate delay is given next to each gate. Show your work by applying the clustering algorithm discussed in class to the following circuit.

1.

① $l(a)=2$ $l(b)=3$

$l(c)=2+4=6$ $l(e)=3+1=4$

cluster(c) = {a, c} cluster(e) = {b, e}

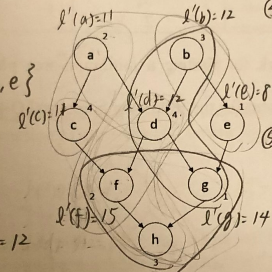
② $l(d)=\max\{6,7\}=7$

cluster(d) = {a, b, d}

③ $l(f)=\max\{l_1(f), l_2(f)\}$

$=\max\{9, \max\{7+4, 8+4\}\}=12$

cluster(f) = {b, d, f}



④ $l(g)=\max\{l_1(g), l_2(g)\}$

$=\max\{8, \max\{7+4, 5+4\}\}=11$

cluster(g) = {b, d, g}

⑤ $l(h)=\max\{0, \max\{11+4, 11+4, 12+4, 12+4, 8+4\}\}$

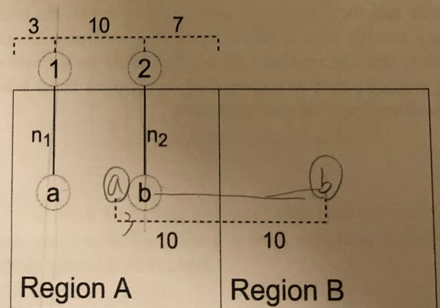
$=16$

cluster(h) = {f, g, h}

2\. (5 points) Vertex a and vertex b are two vertices in an edge-weighted complete graph, where the weight of each edge is a non-negative integer. Suppose that the vertex set of this graph is partitioned into two subsets, and vertices a and b are not in the same subset. Assume that the respective internal and external costs of vertex a are 5 and 1, and the respective internal and external costs of vertex b are 4 and 7. Can the cut cost be reduced by swapping vertices a and b? Justify your answer.

Unit 3 p.8

3\. (5 points) Consider the following figure where 1 and 2 are fixed cells that are placed at the given locations, a and b be movable cells that can be moved to the center of either region A or B, net n_1 connects cells 1 and a, and net n_2 connects cells 2 and b. The center-to-center distance between regions A and B is 20. The distances related to cell 1 and cell 2 are shown below. Use the exact net-weight model discussed in class to find the cut weights for nets n_1 and n_2 for capturing the horizontal wirelength cost precisely.



2.

$\#D_a=E_a-I_a$

$D_a=1-5=-4$

$D_b=7-4=3$

$g_{ab}=D_a+D_b-2C_{ab}$ edge weight

$=-4+3-2C_{ab}$

$=-1-2C_{ab}$，且 $C_{ab}\geq 0$

$\because g_{ab}<0 \Rightarrow$ 更差 不 swap #

3\. Unit 3 p.43.

weight(n_1)

$=WL(n_1 \text{ is cut})-WL(n_1 \text{ not cut})$

$=27-7=20$ #

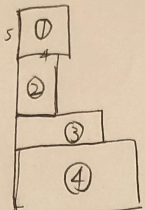
weight(n_2)

$=WL(n_2 \text{ is cut})-WL(n_2 \text{ not cut})$

$=17-3=14$ #

(a.) (123456, 654321)

1
2
3
4
5
6



4. Consider a set of modules in the following table. Assume that each module cannot be rotated.

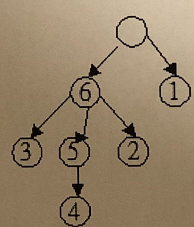
Module	Width	Height
1	4	5
2	3	7
3	6	4
4	7	7
5	5	2
6	2	6

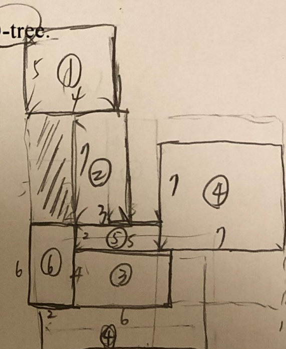
(a) (7 points) Show your work for finding a minimum-area placement for the sequence-pair (123456, 654321).

Unit 4 p40.

(b) (4 points) Show the placement for the following horizontal O-tree.

635421



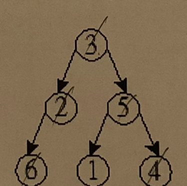


(c) (4 points) Show the placement for the following B*-tree.

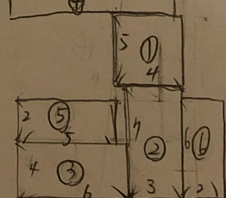
B*-tree

左子在父右且能多低就多低

右子在父之上且X同



(c)



5. (10 points) Given a slicing floorplan tree where the cut direction of each internal node is undecided yet, describe how to extend Stockmeyer algorithm to simultaneously determine the cut direction for each internal node and the shape for each module such that the total area of the floorplan is minimized. You may assume each module has at most two possible shapes (the ones with and without rotation). Note that the resultant slicing tree could be skewed or non-skewed. The time complexity of your method could be exponential, but it must be as low as possible. You should also analyze the time complexity of your algorithm.

看解答.

6. $Qx = Dx - Cx$

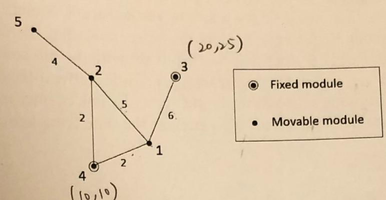
$$= \begin{bmatrix} 13 & 0 & 0 \\ 0 & 11 & 0 \\ 0 & 0 & 4 \end{bmatrix} - \begin{array}{c|ccc} & 1 & 2 & 5 \\ \hline 1 & 0 & 5 & 0 \\ 2 & 5 & 0 & 4 \\ 5 & 0 & 4 & 0 \end{array} = \begin{bmatrix} 13 & -5 & 0 \\ -5 & 11 & -4 \\ 0 & -4 & 4 \end{bmatrix} = Q$$

#

Unit 5 p.42 $\quad d_{ii} = \sum_{i=1}^{r} C_{ij}$

6. (10 points) Consider a circuit with movable and fixed modules as represented by the following graph. In the graph, each vertex denotes a module, while each edge denotes a two-pin net and is associated with a weight next to it.

$$dx = \begin{bmatrix} -6\times 20 - 2\times 10 \\ -2\times 10 \\ 0 \end{bmatrix} = \begin{bmatrix} -140 \\ -20 \\ 0 \end{bmatrix} \#$$

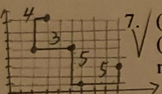


$$dy = \begin{bmatrix} -6\times 25 - 2\times 10 \\ -2\times 10 \\ 0 \end{bmatrix} = \begin{bmatrix} -170 \\ -20 \\ 0 \end{bmatrix} \#$$

For the two fixed modules, module 3 is at (20, 25), and module 4 is at (10, 10). Determine Q, d_x, and d_y such that the cost function of quadratic placement for this circuit can be written as follows:

7.
① HPWL = (9-2)+(8-1) = 7+7 = 14 #
② MST: 4+3+5+5 = 17 #

$$\frac{1}{2}x^T Qx + d_x^T x + \frac{1}{2}y^T Qy + d_y^T y + \text{const}$$



7. (5 points) Given a net with five pins a, b, c, d, e which are located at (2, 5), (3, 8), (6, 1), (9, 3), (5, 5), estimate its wire lengths by using the half perimeter wire length (HPWL) method and the minimum spanning tree method, respectively.

8. (10 points) In class we claimed that the BoundingBox net model can accurately model HPWL in a quadratic placement framework. Prove this claim for the x direction.

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9. Consider the following routing instance with shaded blockages.

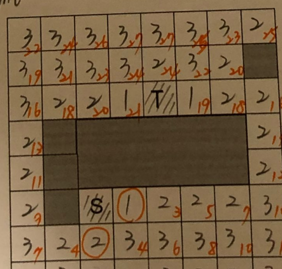
8.
$$L^{\sim BB} = \frac{1}{2}\sum_{\{i,j\}\in N} W_{\{i,j\}} \times (X_i - X_j)^2$$

where $W_{\{i,j\}} = \frac{2}{k-1} \times \frac{1}{l_{\{i,j\}}}$

If $l_{\{i,j\}}$ is set to $|X_i - X_j|$ for all $\{i,j\} \in N$, $L^{\sim BB} = |X_1 - X_k|$

#

weight



Unit 6 p.5

(a) (5 points) Show your work for finding a shortest path between S and T using the Lee algorithm.

(b) (10 points) Show your work for finding a least weighted path between S and T using the weighted grid model introduced in class.

Unit 6 p.20 $\Rightarrow \Sigma$ weight