Homework 02

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Foundations of Data Science

7.11

(1) Example where x minimizing $\sum_{i=1}^{n} |a_i - x|$ is not unique[figure 1 (a)]:
x' can be any number within [-1, 1] and they all minimize $\sum_{i=1}^{n} |a_i - x|$, where $a_1 = -1, a_2 = 1$
(2) Example where centroid is different from x that minimize$\sum_{i=1}^{n} |a_i - x|$ is not unique[figure 1 (b)]:
Data points are $\{-2, -1, 1, 2, 100\}$
Centroid is $\mu = \frac{-2-1+1+2+100}{5} = 20$
$argmin_x \sum_{i=1}^{n} |a_i - x| = 1$ (which is the median of five data points)
The point 1 and 20 are quite far apart.

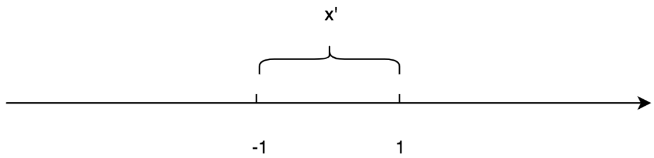

Figure 1 (a)

Figure 1 (b)

7.12

Want to show that $\frac{1}{n^2} \sum_{i,j} a_i a_j^T = \frac{1}{n} \sum_{i=1}^{n} a_i c^T$, $i, j = 1, 2, ..., n$
Known $c = \frac{1}{n} \sum_{i=1}^{n} a_i = \frac{1}{n} \sum_{j=1}^{n} a_j$
Proof:
$RHS = \frac{1}{n} \sum_{i=1}^{n} a_i c^T = \frac{1}{n} \sum_{i=1}^{n} a_i (\frac{1}{n} \sum_{j=1}^{n} a_j^T) = \frac{1}{n^2} \sum_{i=1}^{n} a_i \sum_{j=1}^{n} a_j^T = \frac{1}{n^2} \sum_{i=1}^{n} \sum_{J=1}^{n} a_i a_j^T$
$= \frac{1}{n^2} \sum_{i,j} a_i a_j^T = LHS$
Hence, the average cluster similarity is the same by computing average of all pairs, or average similarity of each point with the centroid of the cluster.

7.17

Mining of Massive Datasets

3.1.1

For {1,2,3,4} and {2,3,5,7}, $J = \frac{2}{6} = \frac{1}{3}$. For {1,2,3,4} and {2,4,6}, $J = \frac{2}{5}$. For {2,3,5,7} and {2,4,6}, $J = \frac{1}{6}$.

3.1.3

3.3.2

The values of the two hash functions applied to the row numbers are given in the last two columns below

Rows	S_1	S_2	S_3	S_4	$2x + 4 \ mod\ 5$	$3x - 1 \ mod\ 5$
0	1	0	0	1	4	4
1	0	0	1	0	1	2
2	0	1	0	1	3	0
3	1	0	1	1	0	3
4	0	0	1	0	2	1

The added signature matrix is

	S_1	S_2	S_3	S_4
h_1	1	3	0	1
h_2	0	2	0	0
h_3	0	3	0	0
h_4	3	0	1	0

The calculating process is as follow

$$\begin{bmatrix} \infty & \infty & \infty & \infty \\ \infty & \infty & \infty & \infty \end{bmatrix} \xrightarrow{\text{row}(0)} \begin{bmatrix} 4 & \infty & \infty & 4 \\ 4 & \infty & \infty & 4 \end{bmatrix} \xrightarrow{\text{row}(1)} \begin{bmatrix} 4 & \infty & 1 & 4 \\ 4 & \infty & 2 & 4 \end{bmatrix} \xrightarrow{\text{row}(2)} \begin{bmatrix} 4 & 3 & 1 & 3 \\ 4 & 0 & 2 & 0 \end{bmatrix} \xrightarrow{\text{row}(3)} \begin{bmatrix} 0 & 3 & 0 & 0 \\ 3 & 0 & 2 & 0 \end{bmatrix} \xrightarrow{\text{row}(4)} \begin{bmatrix} 0 & 3 & 0 & 0 \\ 3 & 0 & 1 & 0 \end{bmatrix}$$

3.3.3

(a) The matrix with hash funstions values is

Element	S_1	S_2	S_3	S_4	$2x + 1 \ mod\ 6$	$3x + 2 \ mod\ 6$	$5x + 2 \ mod\ 6$
0	0	1	0	1	1	2	2
1	0	1	0	0	3	5	1
2	1	0	0	1	5	2	0
3	0	0	1	0	1	5	5
4	0	0	1	1	3	2	4
5	1	0	0	0	5	5	3

The signature matrix is

	S_1	S_2	S_3	S_4
h_1	5	1	1	1
h_2	2	2	2	2
h_3	0	1	4	0

The calculating process is as follow

$$\begin{bmatrix}\infty & \infty & \infty & \infty\\ \infty & \infty & \infty & \infty\\ \infty & \infty & \infty & \infty\end{bmatrix} \xrightarrow{\text{row}(0)} \begin{bmatrix}\infty & 1 & \infty & 1\\ \infty & 2 & \infty & 2\\ \infty & 2 & \infty & 2\end{bmatrix} \xrightarrow{\text{row}(1)} \begin{bmatrix}\infty & 1 & \infty & 1\\ \infty & 2 & \infty & 2\\ \infty & 1 & \infty & 2\end{bmatrix} \xrightarrow{\text{row}(2)} \begin{bmatrix}5 & 1 & \infty & 1\\ 2 & 2 & \infty & 2\\ 0 & 1 & \infty & 0\end{bmatrix} \xrightarrow{\text{row}(3)}$$
$$\begin{bmatrix}5 & 1 & 1 & 1\\ 2 & 2 & 5 & 2\\ 0 & 1 & 5 & 0\end{bmatrix} \xrightarrow{\text{row}(4)} \begin{bmatrix}5 & 1 & 1 & 1\\ 2 & 2 & 2 & 2\\ 0 & 1 & 4 & 0\end{bmatrix} \xrightarrow{\text{row}(5)} \begin{bmatrix}5 & 1 & 1 & 1\\ 2 & 2 & 2 & 2\\ 0 & 1 & 4 & 0\end{bmatrix}$$

(b) Only $\{h_3(x) = 5x + 2 \ mod \ 6\}$ is a true permutation, since there is no collision, i.e. no two rows get the same hash value.
(c) Thematrix of true Jaccard similarities and estimated Jaccard similarities matrix is

Pairs	(S_1, S_2)	(S_1, S_3)	(S_1, S_4)	(S_2, S_3)	(S_2, S_4)	(S_3, S_4)
True Jaccard Similarity	0	0	$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{4}$
Estimated Jaccard Similarity	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$

10.4.1

(a) The adjacency matrix:

$$A = \begin{bmatrix}0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0\\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0\\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 0\\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1\\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1\\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0\end{bmatrix}$$

(b) The degree matrix:

$$D = \begin{bmatrix}2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2\end{bmatrix}$$

(c) The Laplacian matrix

$$L = D - A = \begin{bmatrix} 2 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 3 & -1 & 0 & 0 & 0 & 0 & -1 & 0 \\ -1 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 3 & -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 3 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & -1 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 3 & -1 & -1 \\ 0 & -1 & 0 & 0 & 0 & 0 & -1 & 3 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 2 \end{bmatrix}$$

10.4.2

(Code: q10_4_2.py)
For the Laplacian matrix above, implement eigendecomposition, obtain the second-smallest eigenvalue is 0.69722436226800433, the corresponding vector is [-0.15728598, -0.16666667, 0.29389153, -0.33333333, 0.28305594, -0.40824829, 0.50834187, 0.00210742, -0.48643259].
The second eigenvector has four positive and five negative components, which suggests that one group should be {C,E,G,H}, the nodes with positive components; and the other group should be {A,B,D,F,I}, the nodes with positive components.
[**Unsolved Question** (the third eigenvalue is very close to the second, and the partition above is rather unbalanced)]

Coding Assignment

7.4

Attachments

q7_14.py, q10_4_2.py