COMPSCI 753

Algorithms for Massive Data

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Tutorial 1: Locality-sensitive Hashing

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1 Computing MinHash signatures and estimating Jaccard similarities

Given the 4 sets $S_1 = \{c, f\}, S_2 = \{a, b\}, S_3 = \{d, e\}, S_4 = \{a, c, e\}$.

1. Present these sets as a binary matrix.
2. Compute the minhash values of each set using the permutation $\pi = \{b, e, a, f, c, d\}$.

Solution:

Elements	Integers	S_1	S_2	S_3	S_4
a	0	0	1	0	1
b	1	0	1	0	0
c	2	1	0	0	1
d	3	0	0	1	0
e	4	0	0	1	1
f	5	1	0	0	0

Table 1: Binary matrix presents the sets.

Integer	π	Elements	S_1	S_2	S_3	S_4
1	b	a	0	1	0	1
4	e	b	0	1	0	0
0	a	c	1	0	0	1
5	f	d	0	0	1	0
2	c	e	0	0	1	1
3	d	f	1	0	0	0

Following the procedure from the lecture note, we have the answer:

Hash function	S_1	S_2	S_3	S_4
π	a	b	c	a

2 Fast computing MinHash signatures

Since it is not feasible to permute a very large matrix explicitly, we will simulate random permutations by using random universal hash functions below:

$h_1(x) = 2x + 1 \mod 6$, $h_2(x) = 3x + 2 \mod 6$, and $h_3(x) = 5x + 2 \mod 6$.

1. Compute the minhash values using these universal hash functions. Note that you have to map a string to an integer, e.g. $a \mapsto 0, b \mapsto 1, \ldots$
2. Which of these hash functions are true permutations?
3. How close are the estimated Jaccard similarities of the six pairs of columns to the true Jaccard similarities?

Solution:

Integers	S_1	S_2	S_3	S_4	$h_1(x) = 2x + 1 \mod 6$	$h_2(x) = 3x + 2 \mod 6$	$h_3(x) = 5x + 2 \mod 6$
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**

Hash functions	S_1	S_2	S_3	S_4
$h_1(x)$	5	1	1	1
$h_2(x)$	2	2	2	2
$h_3(x)$	0	1	4	0

Table 4: The minhash values with universal hash functions.

	S_1	S_2	S_3	S_4
S_1	1	0	0	1/4
S_2	0	1	0	1/3
S_3	0	0	1	1/4
S_4	1/4	1/3	1/4	1

Table 5: The actual Jaccard similarity values

	S_1	S_2	S_3	S_4
S_1	1	1/3	1/3	2/3
S_2	1/3	1	2/3	2/3
S_3	1/3	2/3	1	2/3
S_4	2/3	2/3	2/3	1

Table 6: The estimated Jaccard similarity using these 3 hash functions.

3 Tuning the parameters for LSH

Evaluate the S-curve $1-(1-s^r)^b$, i.e. the probability of being a candidate pair, for $s = \{0.1, 0.2, \dots, 0.9\}$ using the following values of r and b.

1. $r = 3$ and $b = 10$.
2. $r = 6$ and $b = 20$.
3. $r = 5$ and $b = 50$.

For each value (r, b) above, compute the threshold, that is the value of s which the value of $1-(1-s^r)^b$ is exactly 1/2. How is it different from our approximation $(1/b)^{1/r}$? Which setting we should use in order to achieve the false negatives of 70%-similar pairs at most 5% and false positives of 30%-similar pairs at most 15%.

Solution:

s	$(3,10)$	$(6,20)$	$(5,50)$
0.1	0.0100	0.0000	0.0005
0.2	0.0772	0.0013	0.0159
0.3	0.2394	0.0145	0.1145
0.4	0.4839	0.0788	0.4023
0.5	0.7369	0.2702	0.7956
0.6	0.9123	0.6154	0.9825
0.7	0.9850	0.9182	0.9999
0.8	0.9992	0.9977	1.0000
0.9	1.0000	1.0000	1.0000

	$(3,10)$	$(6,20)$	$(5,50)$
Exact s	0.4062	0.5694	0.4244
Estimate $(1/b)^{1/r}$	0.4642	0.6070	0.4573

It is clearly that we need to use $r = 5$ and $b = 50$ since the probability of collision of 70%-similar pairs is 0.9999 and 30%-similar pairs is 0.1145.