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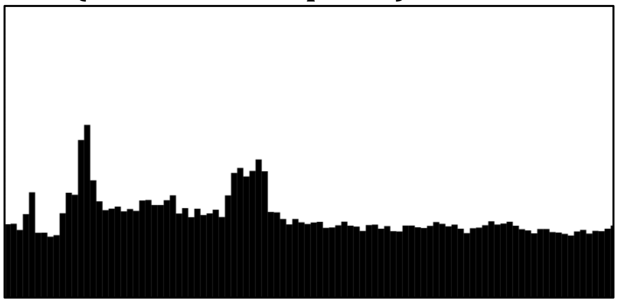
Assignment: Evaluate the effectiveness of four different hash functions and find which works best for the corresponding data sets provided.

Collaboration Statement: I worked on this alone.
Note: I made no changes to HashEvaluation.Java and therefore have not included it in this file

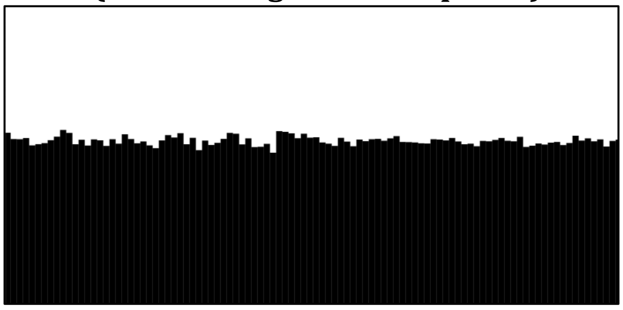
Words. Txt – case where all inputs are distinct

M-Hash
Spread of Hash values (100 bins)

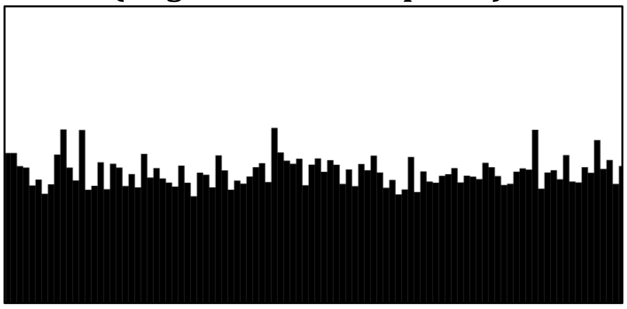
R = 3 (small number, prime)



R = 31 (middle range number, prime)



R = 140 (large number, non prime)



Amongst the 3 multiplier values for R, R = 31 performs the best with the most even distribution of hash values.

<u>"Time to collision" for 100 experiments</u>

R = 3

```
      N      min          mean        stdev         max
-------------------------------------------------------------------
     100   210.000   2764.720   1323.659   6860.000
```

R = 31 (Time to collision is vastly higher)

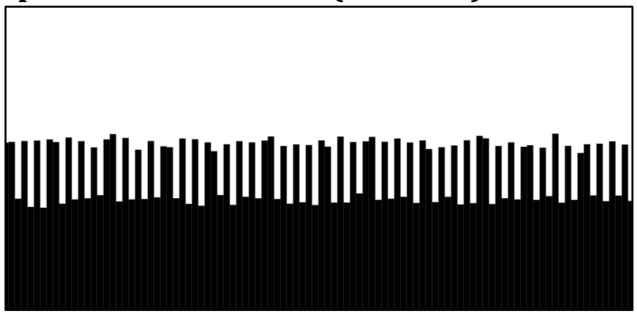
```
      N         min            mean         stdev           max
-------------------------------------------------------------------------
     100   10071.000   77987.880  37797.191   168031.000
```

R = 140

```
      N        min         mean         stdev        max
-------------------------------------------------------------------
     100  1544.000   8771.030   4632.829   21870.000
```

Based on the above data, M hash using a prime number within the approximate range of 20<x<80, should be optimal in delivering both a high time to collision as well.

P-Hash
<u>Spread of Hash values (100 bins)</u>



P-hash has an uneven distribution of hash values even where every input string is unique, making it unsuitable to be used. There is a pattern observed of certain equally spaced ranges where hash values occur more frequently.

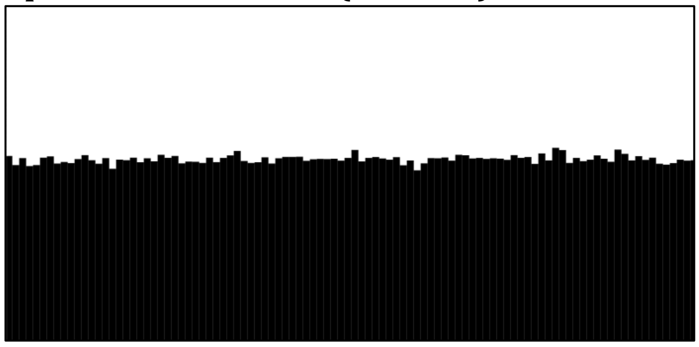
<u>"Time to collision" for 100 experiments</u>

```
      N        min      mean       stdev       max
-------------------------------------------------------------------
     100     2.000    21.300     9.485    45.000
```

Compare to M hash, the time to collision is far smaller, implying that collisions appear very frequently even when the input is distinct. As a result, this version of P hash is not viable in this situation

Q-Hash (P-Hash Variant)

Spread of Hash values (100 bins)



For Q-Hash, the distribution is far more uniform than its P-Hash counterpart, comparable to that of M-hash with an optimal choosing of the multiplier R.

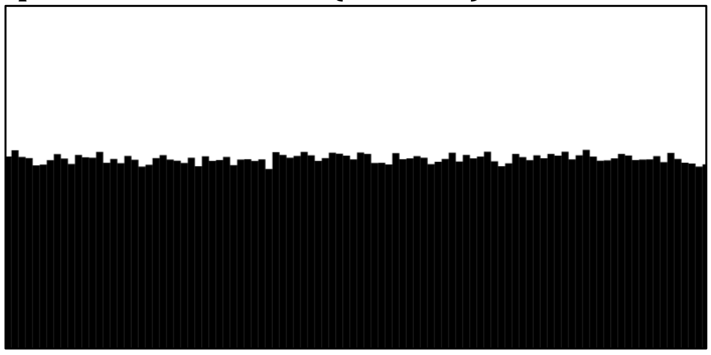
"Time to collision" for 100 experiments

```
    N       min           mean          stdev           max
-----------------------------------------------------------------------
   100  8756.000   94533.560  45049.104  201674.000
```

Furthermore, the time to collision for this version of P-Hash is better than the earlier data from M-Hash.

J-Hash

Spread of Hash values (100 bins)



J-Hash also appears to have a fairly uniform distribution of hash values comparable to that of M-Hash and Q-Hash.

"Time to collision" for 100 experiments

```
    N       min         mean         stdev         max
------------------------------------------------------------------
   100  2604.000  17594.270   9455.062  46689.000
```

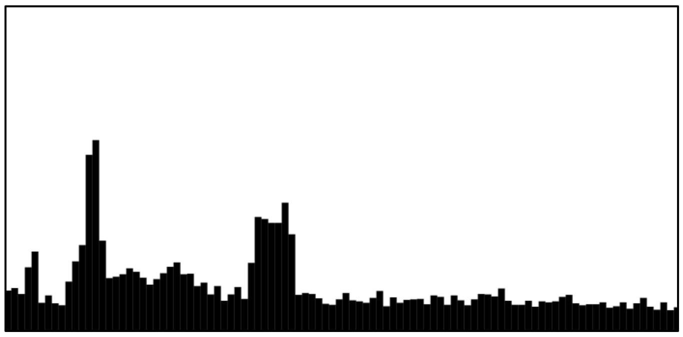
Despite its visible uniformity, J-Hash still falls short compared to Q-Hash with respect to its time to collision Statistic. **As a result, Q-hash seems to be the best option for use in words.txt due to an equal distribution of hash values as well as the highest time to collision in a set of fully distinct inputs.**

<u>Tale.txt – case for distinct inputs but also some frequently repeated inputs</u>

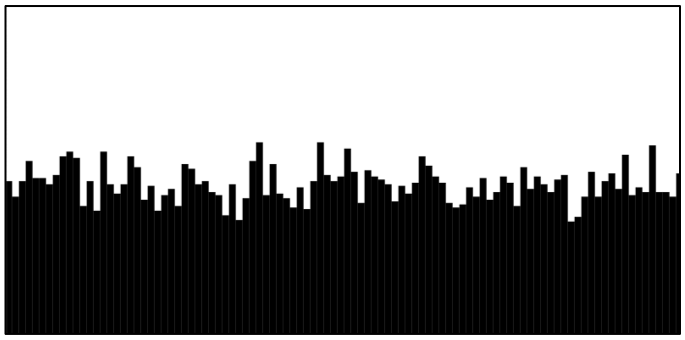
M-Hash

<u>Spread of Hash values (100 bins)</u>

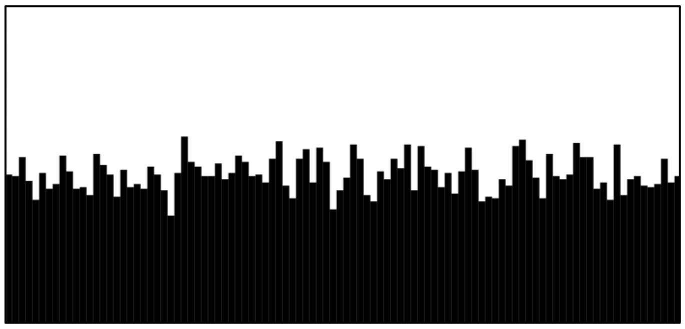
R = 3



R = 31



R = 140



Note: Apart from the images above, I also checked R values of 7,19,67,91. All led to similar distributed hash values as the R = 31 and R = 140 case.

Reviewing the 3 cases above, M-hash seems to work best when R = 31 as the hash values are the most uniform of the three. However, with the introduction of the file “tale.txt” which has regular sentences compared to a dictionary of distinct words, the values are no longer as well distributed as before.

<u>“Time to collision” for 100 experiments</u>

R = 3

```
      N       min         mean        stdev      max
------------------------------------------------------------------
     100    24.000    111.480    56.987    298.000
```

R = 31

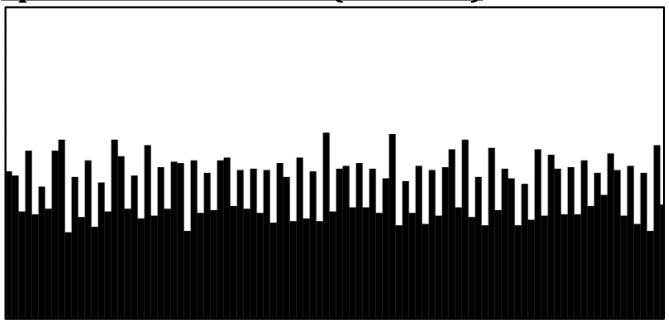
```
      N       min         mean        stdev      max
------------------------------------------------------------------
     100    93.000   2549.440   1550.258   8312.000
```

R = 140

```
      N       min          mean          stdev          max
------------------------------------------------------------------
     100   3833.000  12719.180   3645.146  19191.000
```

In this scenario, our arbitrary case of R = 140 has the best time till collision. It is possible that in this case, words that are used in regular sentences might be smaller and simpler than those in the dictionary and hash to similar values . Thus using a large value of R may spread them out.

P-Hash
<u>Spread of Hash values (100 bins)</u>



Again, this version of P hash has an uneven distribution of hash values. With a pattern observed of certain equally spaced ranges of hash values occurring more frequently.

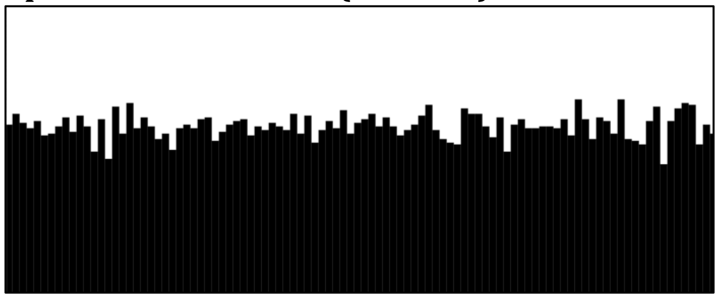
<u>“Time to collision” for 100 experiments</u>

```
      N
```

```
    min       mean       stdev     max
-------------------------------------------------------------------
      100     2.000     16.780     7.618    39.000
```

The time to collision for this hash function is still very small even though there are still a significant number of distinct inputs.

Q-Hash
Spread of Hash values (100 bins)



For Q-hash, the hash values seem relatively well distributed, more so than any of the M-hash histograms.

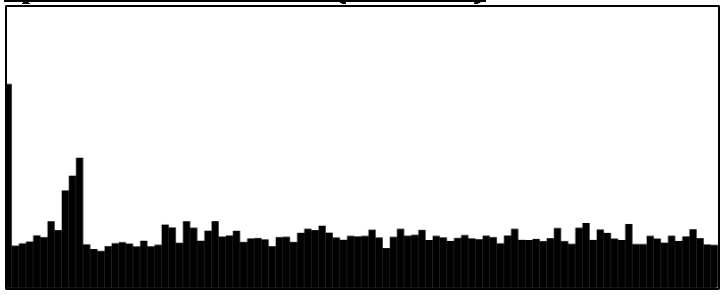
"Time to collision" for 100 experiments

```
        N         min            mean          stdev       max
-------------------------------------------------------------------
      100   19696.000  19696.000      0.000  19696.000
```

The results for time to collision in the case of Q-hash for "tale.txt" suggests that there are no collisions whatsoever.

Using the Zipf and frequency counter classes from Lab 8&9, I verified that the file tale.txt has 19695 distinct words. Q-hash spreads these values over the 2^31 range for any positive integer value (primitive type). Therefore it is definitely viable that Q-hash in this case prevents the case of collisions completely.

J-Hash
Spread of Hash values (100 bins)



For J-hash, the hash values seem to be very well distributed amongst the larger hash values values, but poorly distributed for smaller hash values.

"Time to collision" for 100 experiments

```
      N        min           mean         stdev       max
--------------------------------------------------------------------
     100   1045.000   6495.850   3381.027  15475.000
```

Compared to the case of R = 140, J hash a similar standard deviation, but it's mean time to collision value is almost half as small, suggesting that both M-hash and Q-hash are superior.

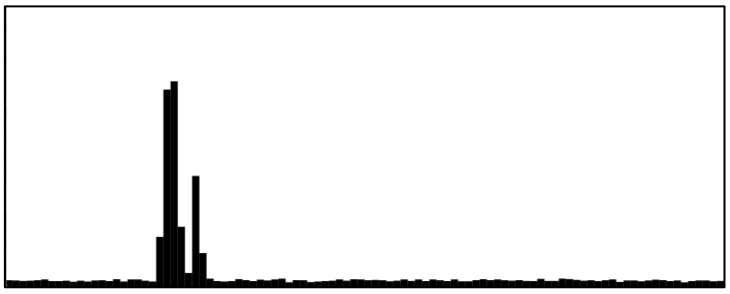
As a result, Q-hash seems to be the best option as it not only distributes the hashes regularly but also ensures no collisions whatsoever in a case where the number of distinct entries is much smaller than 2^31.

Dna3. Txt – case of very large strings composed of repeating characters

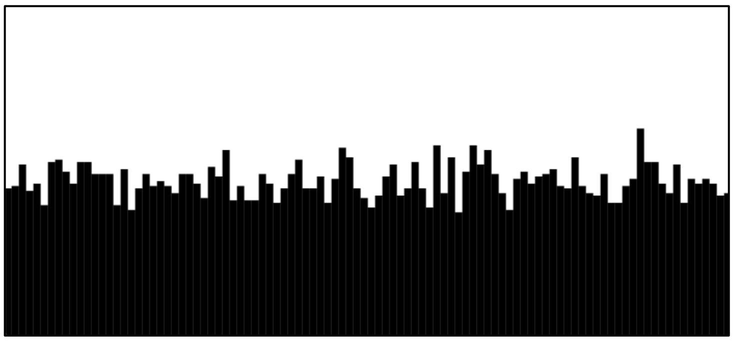
M-Hash

Spread of Hash values (100 bins)

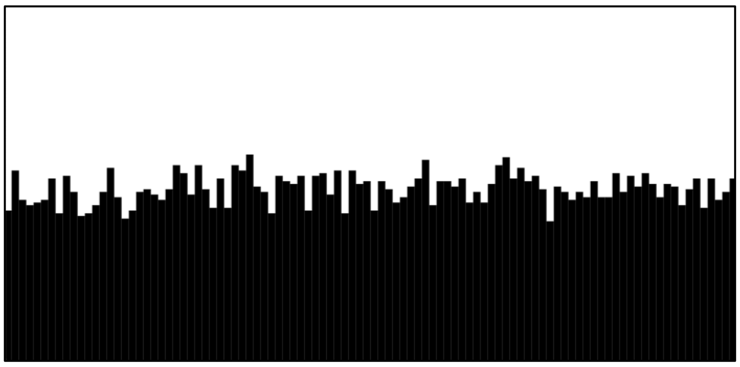
R = 3



R = 31



R = 140



Reviewing the 3 cases above, M-hash seems to work well for R = 31 and R = 140 but very poorly for R = 3, with a large number of majority of hash values within a fairly small range.

<u>"Time to collision" for 100 experiments</u>

R = 3

```
       N        min           mean        stdev           max
--------------------------------------------------------------------
     100    310.000   3056.370   1563.117   8349.000
```

R = 31 (No Collision)

```
       N         min            mean          stdev       max
--------------------------------------------------------------------
     100  13086.000  13086.000      0.000  13086.000
```

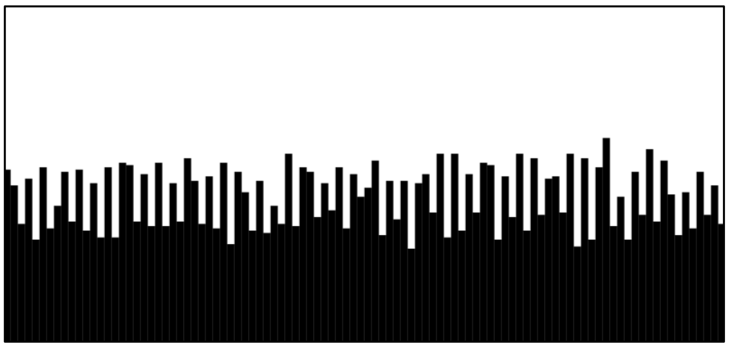
R = 140

```
       N         min         mean          stdev       max
--------------------------------------------------------------------
     100    244.000   2440.960   1274.995   6951.000
```

Reviewing the 3 cases above, M-hash seems to work best for R = 31 as there seems to be a case of no collisions across 100 experiments. Upon verifying with the frequency counter class from Lab 8 & 9 indeed has 13085 distinct DNA sequences present in the text file. Furthermore, R = 3 and R = 140 have similar time to collision values. Given the huge lengths of each DNA sequence, it is possible that the hash values of with R = 140 exceed the range of 2^31 and as a result of the "& 0x7FFFFFFF" operation, we might have skewed results in this situation.

P-Hash

<u>Spread of Hash values (100 bins)</u>



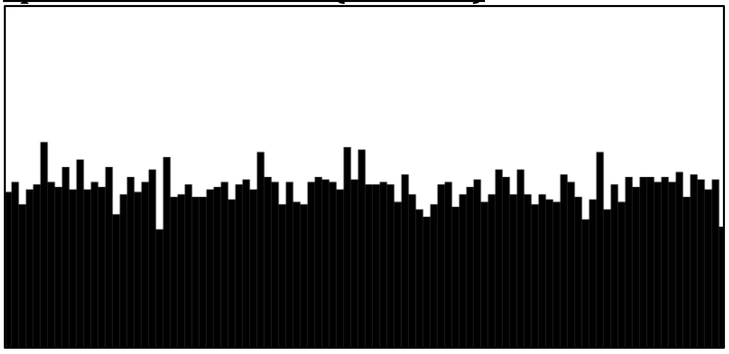
Again, this version of P hash has an uneven distribution of hash values. With a pattern observed of certain equally spaced ranges of hash values occurring more frequently.

<u>“Time to collision” for 100 experiments</u>

```
      N        min       mean      stdev       max
-------------------------------------------------------------------
     100     3.000     19.130     9.056     46.000
```

The time to collision for this hash function is still very small compared to those from M-hash, making it ineffective.

Q-Hash
<u>Spread of Hash values (100 bins)</u>



Like the case for R = 31 in M-Hash, Q-hash has a well distributed graph. However, on closer visual inspection it seems (to me) like the M-Hash function still has a slightly more even distribution.

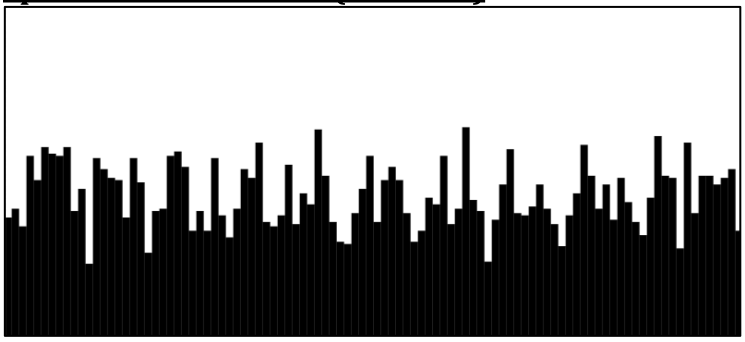
<u>“Time to collision” for 100 experiments</u>

```
      N        min           mean          stdev       max
-------------------------------------------------------------------
     100  13086.000  13086.000     0.000  13086.000
```

Similar to the R=31 case, Q-Hash exhibits no collisions.

J-Hash

Spread of Hash values (100 bins)



Compared to M-Hash and Q-Hash, the distribution of hash values for J-hash is far more uneven, making it less effective than the other two hashes.

"Time to collision" for 100 experiments

```
      N        min        mean        stdev      max
-----------------------------------------------------------------
     100   125.000  1082.840   591.200  2729.000
```

J hash has a much smaller value for time to collision as well, even less so than the M-hash case for R = 3 which had a very uneven distribution in the centre. This suggests it is less effective for this case.

Reviewing all the cases above, both Q-hash and M-Hash for R = 31 seem to work very well, with a good distribution of Hash values as well as no collisions. However, the M-hash seems to have a slightly more even distribution based on a visual comparison and is also less computationally intensive than Q-Hash, performing noticeably faster upon multiple attempts. Therefore for this data set, I would recommend using M-hash with R = 31.