**Hash Tables Benchmarks**

The goal of this project was to study the performance of the hash table data structure in terms of time and space efficiency based on the chaining and open addressing algorithms of collision resolution.

* [Hash Tables Benchmarks](https://github.com/kevin-funderburg/hashtable-benchmark#hash-tables-benchmarks)
  + [Method](https://github.com/kevin-funderburg/hashtable-benchmark#method)
    - [Chaining versus Addressing](https://github.com/kevin-funderburg/hashtable-benchmark#chaining-versus-addressing)
      * [Open Addressing](https://github.com/kevin-funderburg/hashtable-benchmark#open-addressing)
      * [Chaining](https://github.com/kevin-funderburg/hashtable-benchmark#chaining)
      * [Operation Comparison Summary](https://github.com/kevin-funderburg/hashtable-benchmark#operation-comparison-summary)
    - [Calculating Size](https://github.com/kevin-funderburg/hashtable-benchmark#calculating-size)
  + [Configuration](https://github.com/kevin-funderburg/hashtable-benchmark#configuration)
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    - [Insertion](https://github.com/kevin-funderburg/hashtable-benchmark#insertion)
    - [Deletion](https://github.com/kevin-funderburg/hashtable-benchmark#deletion)
    - [Search](https://github.com/kevin-funderburg/hashtable-benchmark#search)
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  + [Interpretations](https://github.com/kevin-funderburg/hashtable-benchmark#interpretations)
  + [Licensing & thanks](https://github.com/kevin-funderburg/hashtable-benchmark#licensing--thanks)
  + [Changelog](https://github.com/kevin-funderburg/hashtable-benchmark#changelog)
  + [Appendix (Tables)](https://github.com/kevin-funderburg/hashtable-benchmark#appendix-tables)

**Method**

The project itself was executed in Python, and to perform the tests, two classes of hash tables were created, labeled HashTableChaining and HashTableAddressing. Both classes have similar methods in concept but the fundamental differences between them become more prominent upon closer inspection.

Each hash table class contains the following methods:

def set\_table\_with\_load\_factor(self, lf):

def get\_index(self, key: str):

def insert(self, key: str):

def lookup(self, key: str):

def remove(self, key: str):

def get\_random\_val(self):

def print\_table(self):

def get\_mem\_size(self):

def is\_empty(self):

The testing process consists of creating an array of hash tables with load factors ranging from 0 to 1 in 0.05 increments and hash table sizes ranging from 100 to 1000000. After creation of all the hash tables, each table was tested for:

* Average time to insert one key
* Average time to search for one key
* Average time to delete one key
* Overall memory size.

**Chaining versus Addressing**

**Open Addressing**

Collision resolution via open-addressing is implemented using the quadratic probing method to obtain the index of a key in this project.

Quadratic-probing function used:

def quadratic\_probe(self, key, collisions):

return (hash(key) + collisions + 3\*(collisions\*\*2)) % self.ARR\_LENGTH

* hash(key) is a python function to return a integer for a given key
* collisions is the number of times an index was full but did not contain the key
* ARR\_LENGTH is the size of the hash table

**Chaining**

The chaining method of collision resolution inserts creates a linked list at each index of the table. The index is retrieved using the python hash(key) function and, in this project, a new linked list node is inserted at the head of the list to ensure a constant insertion time.

**Operation Comparison Summary**

|  |  |  |
| --- | --- | --- |
| **Operation** | **Chaining** | **Open-Addressing** |
| **Insertion** | Hashes the key to obtain the index and inserts a new node at the beginning of the list to ensure constant insertion time.  *O(1)* | Probes quadratically until an empty index is found or the whole table has been traversed.  *O(n)* |
| **Deletion** | Hashes the key to obtain the index then travels the linked list at the found index until it has found the key or the end of the list.  *O(n)* | Probes quadratically until the key is found or the whole table has been traversed.  *O(n)* |
| **Search** | Search operates identically to deletion except returns whether the key is found or not.  *O(n)* | Identical to deletion except returns whether the key is found or not.  *O(n)* |

**Calculating Size**

One challenge faced, due to the nature of Python, was the ability to calculate the size of the hash table upon completion.

Per python documentation regarding the sys.getsizeof(object) call:

Return the size of an object in bytes.

The object can be any type of object.

The documentation goes on to say:

Only the memory consumption directly attributed to the object is

accounted for, not the memory consumption of objects it refers to.

This behavior led to hash tables of size 100 and 1000000 with all indices filled having the same size in memory (48 bytes). So in order to find the actual size of these data structures, I used the sys.getsizeof(object) call to define the following constants:

SIZE\_LIST\_NODE = 1064 # size of ListNode class

SIZE\_EMPTY\_HASH\_TABLE = 48 # size of hash table with no insertions

SIZE\_ARR\_NONE = 8 # size of an array index with a None value

SIZE\_ARR\_STR = 8 # size of an array index with a 8 character string

Once these constants were defined, I used a simple loop to traverse the entire data structure and calculate the actual size in memory.

**Configuration**

Execution of the program is performed in one of three ways:

python3 hash\_benchmark.py -o # open addressing

python3 hash\_benchmark.py -c # chaining

python3 hash\_benchmark.py -b # both open-addressing and chaining

**Note:** This project uses the matplotlib Python library to create the graphs, I had some issues getting this to execute on the zeus server.

**Results**

**Insertion**

**Chart, line chart

Description automatically generated**Chart, line chart

Description automatically generated

* Open-addressing is faster when the load factor is low, but far slower when the load factor is high.
* Another note of interest was how erratic the chaining method's graph is compared to the smooth and consistent graph of open-addressing.

**Deletion**

Chart, line chart

Description automatically generated

Chart, line chart

Description automatically generated

Open-addressing is faster when the load factor is low, but far slower when the load factor is high.

**Search**

Chart, line chart

Description automatically generated

Chart, line chart

Description automatically generated

Open-addressing is faster when the load factor is low, but far slower when the load factor is high.

**Space**

Chart, line chart

Description automatically generatedA picture containing chart

Description automatically generated

* Chaining uses far more memory than open-addressing, particularly as the size of the table increases and the load factor increases (more insertions).
* Open addressing has a static memory size based on the size the table itself.

The tables containing the results for these tests are in [Appendix (Tables)](https://github.com/kevin-funderburg/hashtable-benchmark#appendix-tables).

**Interpretations**

After comparison of all of the tests, the data proves shows a common pattern, open-addressing is a faster algorithm for insertion, searching and deletion when the tables are small; but as the table sizes and load factors increase, the chaining algorithm becomes much faster. However, the size overhead accumulated from continuous insertions of a linked list node proves to create a dramatically larger data structure as opposed to the open-addressing method.

The data gathered proves neither algorithm is explicitly better than the other, and what defines the usefulness of an algorithm (or data-structure) is the situation in which the said algorithm is utilized. When considering chaining and open-addressing, if an application only requires a small table, then the open-addressing method is a better choice, but if the table is large, speed is desired and space is not a factor, then chaining is the preferred method.

**Licensing & thanks**

This project is released under the [MIT License](https://github.com/kevin-funderburg/hashtable-benchmark/blob/main/LICENSE.txt).

**Changelog**

* v1.0.0

**Appendix (Tables)**

INSERTION (Chaining)

------------------------------------------------------------

LENGTH LF START\_INSERTIONS TIME

------------------------------------------------------------

100 0.0 0 1.2803077697753907e-06

100 0.05 5 1.1658668518066405e-06

100 0.1 10 1.2302398681640625e-06

100 0.15 15 1.1467933654785155e-06

100 0.2 20 1.3589859008789063e-06

100 0.25 25 1.3041496276855468e-06

100 0.3 30 1.2803077697753907e-06

100 0.35 35 1.2660026550292968e-06

100 0.4 40 1.2516975402832031e-06

100 0.45 45 1.25885009765625e-06

100 0.5 50 1.2612342834472656e-06

100 0.55 55 1.2755393981933593e-06

100 0.6 60 1.2874603271484376e-06

100 0.65 65 1.2111663818359375e-06

100 0.7 70 1.2946128845214843e-06

100 0.75 75 1.208782196044922e-06

100 0.8 80 1.3232231140136718e-06

100 0.85 85 1.3184547424316407e-06

100 0.9 90 1.3208389282226563e-06

100 0.95 95 1.3136863708496093e-06

1000 0.0 0 1.175403594970703e-06

1000 0.05 50 1.194477081298828e-06

1000 0.1 100 1.163482666015625e-06

1000 0.15 150 1.1730194091796875e-06

1000 0.2 200 1.2183189392089845e-06

1000 0.25 250 1.2516975402832031e-06

1000 0.3 300 1.25885009765625e-06

1000 0.35 350 1.354217529296875e-06

1000 0.4 400 1.316070556640625e-06

1000 0.45 450 1.354217529296875e-06

1000 0.5 500 1.3518333435058594e-06

1000 0.55 550 1.33514404296875e-06

1000 0.6 600 1.3399124145507813e-06

1000 0.65 650 1.3804435729980469e-06

1000 0.7 700 1.3661384582519532e-06

1000 0.75 750 1.3136863708496093e-06

1000 0.8 800 1.3065338134765626e-06

1000 0.85 850 1.3780593872070313e-06

1000 0.9 900 1.3327598571777343e-06

1000 0.95 950 1.3589859008789063e-06

10000 0.0 0 1.2183189392089845e-06

10000 0.05 500 1.208782196044922e-06

10000 0.1 1000 1.3589859008789063e-06

10000 0.15 1500 1.2564659118652343e-06

10000 0.2 2000 1.3589859008789063e-06

10000 0.25 2500 1.316070556640625e-06

10000 0.3 3000 1.3470649719238282e-06

10000 0.35 3500 1.2826919555664062e-06

10000 0.4 4000 1.3041496276855468e-06

10000 0.45 4500 1.3613700866699219e-06

10000 0.5 5000 1.461505889892578e-06

10000 0.55 5500 1.3685226440429688e-06

10000 0.6 6000 1.4448165893554687e-06

10000 0.65 6500 1.2493133544921876e-06

10000 0.7 7000 1.418590545654297e-06

10000 0.75 7500 1.373291015625e-06

10000 0.8 8000 1.4066696166992188e-06

10000 0.85 8500 1.3232231140136718e-06

10000 0.9 9000 1.41143798828125e-06

10000 0.95 9500 1.3589859008789063e-06

100000 0.0 0 1.25885009765625e-06

100000 0.05 5000 1.2159347534179687e-06

100000 0.1 10000 1.3399124145507813e-06

100000 0.15 15000 1.4829635620117187e-06

100000 0.2 20000 1.4090538024902344e-06

100000 0.25 25000 1.3637542724609374e-06

100000 0.3 30000 1.2660026550292968e-06

100000 0.35 35000 1.3613700866699219e-06

100000 0.4 40000 1.373291015625e-06

100000 0.45 45000 1.3971328735351563e-06

100000 0.5 50000 1.4281272888183594e-06

100000 0.55 55000 1.4162063598632813e-06

100000 0.6 60000 1.4209747314453125e-06

100000 0.65 65000 1.4829635620117187e-06

100000 0.7 70000 1.4781951904296875e-06

100000 0.75 75000 1.4519691467285156e-06

100000 0.8 80000 1.5115737915039062e-06

100000 0.85 85000 1.5568733215332032e-06

100000 0.9 90000 1.5354156494140626e-06

100000 0.95 95000 1.6069412231445313e-06

1000000 0.0 0 1.2660026550292968e-06

1000000 0.05 50000 1.3947486877441405e-06

1000000 0.1 100000 1.3065338134765626e-06

1000000 0.15 150000 1.2874603271484376e-06

1000000 0.2 200000 1.385211944580078e-06

1000000 0.25 250000 1.4066696166992188e-06

1000000 0.3 300000 1.4257431030273439e-06

1000000 0.35 350000 1.3709068298339844e-06

1000000 0.4 400000 1.4138221740722656e-06

1000000 0.45 450000 1.4400482177734375e-06

1000000 0.5 500000 1.423358917236328e-06

1000000 0.55 550000 1.5163421630859376e-06

1000000 0.6 600000 1.4066696166992188e-06

1000000 0.65 650000 1.5354156494140626e-06

1000000 0.7 700000 1.5163421630859376e-06

1000000 0.75 750000 1.5497207641601562e-06

1000000 0.8 800000 1.5568733215332032e-06

1000000 0.85 850000 1.5926361083984374e-06

1000000 0.9 900000 1.506805419921875e-06

1000000 0.95 950000 1.5354156494140626e-06

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SEARCH (Chaining)

------------------------------------------------------------

LENGTH LF TIME

------------------------------------------------------------

100 0.05 5.841255187988282e-07

100 0.1 7.343292236328125e-07

100 0.15 6.461143493652344e-07

100 0.2 6.651878356933594e-07

100 0.25 6.842613220214844e-07

100 0.3 6.198883056640625e-07

100 0.35 6.437301635742188e-07

100 0.4 6.628036499023437e-07

100 0.45 6.151199340820313e-07

100 0.5 5.865097045898437e-07

100 0.55 6.604194641113281e-07

100 0.6 7.009506225585937e-07

100 0.65 6.318092346191406e-07

100 0.7 6.055831909179688e-07

100 0.75 7.224082946777343e-07

100 0.8 6.723403930664062e-07

100 0.85 7.462501525878906e-07

100 0.9 7.43865966796875e-07

100 0.95 7.605552673339844e-07

1000 0.05 7.43865966796875e-07

1000 0.1 6.651878356933594e-07

1000 0.15 7.43865966796875e-07

1000 0.2 6.4849853515625e-07

1000 0.25 7.796287536621094e-07

1000 0.3 7.414817810058593e-07

1000 0.35 7.081031799316407e-07

1000 0.4 7.367134094238281e-07

1000 0.45 6.723403930664062e-07

1000 0.5 7.796287536621094e-07

1000 0.55 7.462501525878906e-07

1000 0.6 8.320808410644532e-07

1000 0.65 8.463859558105468e-07

1000 0.7 8.559226989746093e-07

1000 0.75 8.058547973632812e-07

1000 0.8 8.630752563476563e-07

1000 0.85 8.392333984375e-07

1000 0.9 9.250640869140625e-07

1000 0.95 9.298324584960937e-07

10000 0.05 7.128715515136719e-07

10000 0.1 7.200241088867188e-07

10000 0.15 6.985664367675782e-07

10000 0.2 7.081031799316407e-07

10000 0.25 7.295608520507813e-07

10000 0.3 6.794929504394531e-07

10000 0.35 8.20159912109375e-07

10000 0.4 8.988380432128906e-07

10000 0.45 8.96453857421875e-07

10000 0.5 8.392333984375e-07

10000 0.55 8.535385131835938e-07

10000 0.6 8.678436279296875e-07

10000 0.65 9.226799011230469e-07

10000 0.7 8.678436279296875e-07

10000 0.75 9.34600830078125e-07

10000 0.8 9.5367431640625e-07

10000 0.85 9.703636169433594e-07

10000 0.9 1.0395050048828126e-06

10000 0.95 9.870529174804687e-07

100000 0.05 6.628036499023437e-07

100000 0.1 6.723403930664062e-07

100000 0.15 7.700920104980469e-07

100000 0.2 7.82012939453125e-07

100000 0.25 8.821487426757813e-07

100000 0.3 8.678436279296875e-07

100000 0.35 8.96453857421875e-07

100000 0.4 9.775161743164062e-07

100000 0.45 9.5367431640625e-07

100000 0.5 9.703636169433594e-07

100000 0.55 9.894371032714845e-07

100000 0.6 1.2493133544921876e-06

100000 0.65 1.5473365783691407e-06

100000 0.7 1.2159347534179687e-06

100000 0.75 1.0991096496582032e-06

100000 0.8 1.1444091796875e-06

100000 0.85 1.2159347534179687e-06

100000 0.9 1.10626220703125e-06

100000 0.95 1.170635223388672e-06

1000000 0.05 9.1552734375e-07

1000000 0.1 9.417533874511719e-07

1000000 0.15 9.441375732421875e-07

1000000 0.2 1.0061264038085937e-06

1000000 0.25 1.1444091796875e-06

1000000 0.3 1.0251998901367187e-06

1000000 0.35 9.298324584960937e-07

1000000 0.4 9.965896606445312e-07

1000000 0.45 1.1277198791503907e-06

1000000 0.5 1.1301040649414063e-06

1000000 0.55 1.1229515075683594e-06

1000000 0.6 1.2731552124023437e-06

1000000 0.65 1.1539459228515625e-06

1000000 0.7 1.1777877807617188e-06

1000000 0.75 1.2326240539550781e-06

1000000 0.8 1.3113021850585938e-06

1000000 0.85 1.1920928955078125e-06

1000000 0.9 1.5950202941894532e-06

1000000 0.95 1.8453598022460938e-06

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DELETE (Chaining)

------------------------------------------------------------

LENGTH LF TIME

------------------------------------------------------------

100 0.05 6.628036499023437e-07

100 0.1 7.748603820800781e-07

100 0.15 6.556510925292969e-07

100 0.2 5.984306335449218e-07

100 0.25 7.939338684082031e-07

100 0.3 7.2479248046875e-07

100 0.35 6.4849853515625e-07

100 0.4 7.319450378417968e-07

100 0.45 6.508827209472656e-07

100 0.5 7.724761962890626e-07

100 0.55 8.034706115722657e-07

100 0.6 7.82012939453125e-07

100 0.65 8.177757263183594e-07

100 0.7 8.392333984375e-07

100 0.75 8.177757263183594e-07

100 0.8 7.796287536621094e-07

100 0.85 8.20159912109375e-07

100 0.9 9.131431579589844e-07

100 0.95 8.797645568847656e-07

1000 0.05 7.867813110351562e-07

1000 0.1 6.723403930664062e-07

1000 0.15 7.343292236328125e-07

1000 0.2 7.414817810058593e-07

1000 0.25 8.273124694824219e-07

1000 0.3 8.344650268554688e-07

1000 0.35 9.560585021972656e-07

1000 0.4 8.344650268554688e-07

1000 0.45 8.58306884765625e-07

1000 0.5 8.869171142578125e-07

1000 0.55 9.107589721679687e-07

1000 0.6 9.202957153320312e-07

1000 0.65 8.416175842285156e-07

1000 0.7 8.511543273925781e-07

1000 0.75 9.393692016601562e-07

1000 0.8 9.441375732421875e-07

1000 0.85 9.441375732421875e-07

1000 0.9 1.0037422180175781e-06

1000 0.95 1.02996826171875e-06

10000 0.05 6.771087646484375e-07

10000 0.1 7.43865966796875e-07

10000 0.15 7.200241088867188e-07

10000 0.2 8.249282836914062e-07

10000 0.25 8.726119995117188e-07

10000 0.3 8.106231689453125e-07

10000 0.35 8.654594421386718e-07

10000 0.4 8.916854858398438e-07

10000 0.45 8.96453857421875e-07

10000 0.5 8.797645568847656e-07

10000 0.55 9.79900360107422e-07

10000 0.6 1.0395050048828126e-06

10000 0.65 1.0085105895996095e-06

10000 0.7 1.0132789611816406e-06

10000 0.75 1.1467933654785155e-06

10000 0.8 1.1014938354492188e-06

10000 0.85 1.2540817260742187e-06

10000 0.9 1.3422966003417968e-06

10000 0.95 1.3375282287597657e-06

100000 0.05 8.7738037109375e-07

100000 0.1 8.726119995117188e-07

100000 0.15 8.416175842285156e-07

100000 0.2 9.226799011230469e-07

100000 0.25 8.749961853027344e-07

100000 0.3 9.179115295410156e-07

100000 0.35 9.84668731689453e-07

100000 0.4 1.0466575622558593e-06

100000 0.45 1.0800361633300782e-06

100000 0.5 1.3399124145507813e-06

100000 0.55 1.156330108642578e-06

100000 0.6 1.1324882507324219e-06

100000 0.65 1.2564659118652343e-06

100000 0.7 1.2111663818359375e-06

100000 0.75 1.2922286987304687e-06

100000 0.8 1.6880035400390625e-06

100000 0.85 1.9550323486328123e-06

100000 0.9 1.9550323486328123e-06

100000 0.95 2.0003318786621095e-06

1000000 0.05 8.96453857421875e-07

1000000 0.1 7.62939453125e-07

1000000 0.15 9.1552734375e-07

1000000 0.2 1.0323524475097656e-06

1000000 0.25 8.797645568847656e-07

1000000 0.3 8.893013000488281e-07

1000000 0.35 1.02996826171875e-06

1000000 0.4 1.0514259338378907e-06

1000000 0.45 1.0013580322265625e-06

1000000 0.5 1.0943412780761718e-06

1000000 0.55 1.0609626770019532e-06

1000000 0.6 1.175403594970703e-06

1000000 0.65 1.227855682373047e-06

1000000 0.7 1.0561943054199218e-06

1000000 0.75 1.2254714965820312e-06

1000000 0.8 1.2660026550292968e-06

1000000 0.85 1.2612342834472656e-06

1000000 0.9 1.3375282287597657e-06

1000000 0.95 1.5091896057128906e-06

------------------------------------------------------------

MEMORY (Chaining)

------------------------------------------------------------

LENGTH LF MEMORY

------------------------------------------------------------

100 0.0 848

100 0.05 6128

100 0.1 11408

100 0.15 16688

100 0.2 21968

100 0.25 27248

100 0.3 32528

100 0.35 37808

100 0.4 42032

100 0.45 48368

100 0.5 53648

100 0.55 58928

100 0.6 64208

100 0.65 67376

100 0.7 74768

100 0.75 78992

100 0.8 83216

100 0.85 90608

100 0.9 93776

100 0.95 101168

1000 0.0 8048

1000 0.05 60848

1000 0.1 113648

1000 0.15 166448

1000 0.2 219248

1000 0.25 272048

1000 0.3 323792

1000 0.35 377648

1000 0.4 430448

1000 0.45 483248

1000 0.5 536048

1000 0.55 588848

1000 0.6 640592

1000 0.65 694448

1000 0.7 747248

1000 0.75 800048

1000 0.8 852848

1000 0.85 905648

1000 0.9 958448

1000 0.95 1011248

10000 0.0 80048

10000 0.05 608048

10000 0.1 1136048

10000 0.15 1664048

10000 0.2 2192048

10000 0.25 2720048

10000 0.3 3248048

10000 0.35 3776048

10000 0.4 4304048

10000 0.45 4832048

10000 0.5 5360048

10000 0.55 5888048

10000 0.6 6416048

10000 0.65 6944048

10000 0.7 7472048

10000 0.75 8000048

10000 0.8 8528048

10000 0.85 9056048

10000 0.9 9584048

10000 0.95 10112048

100000 0.0 800048

100000 0.05 6080048

100000 0.1 11360048

100000 0.15 16640048

100000 0.2 21920048

100000 0.25 27200048

100000 0.3 32480048

100000 0.35 37760048

100000 0.4 43040048

100000 0.45 48320048

100000 0.5 53600048

100000 0.55 58880048

100000 0.6 64160048

100000 0.65 69440048

100000 0.7 74720048

100000 0.75 80000048

100000 0.8 85280048

100000 0.85 90560048

100000 0.9 95840048

100000 0.95 101120048

1000000 0.0 8000048

1000000 0.05 60800048

1000000 0.1 113600048

1000000 0.15 166400048

1000000 0.2 219200048

1000000 0.25 272000048

1000000 0.3 324800048

1000000 0.35 377600048

1000000 0.4 430400048

1000000 0.45 483200048

1000000 0.5 536000048

1000000 0.55 588800048

1000000 0.6 641600048

1000000 0.65 694400048

1000000 0.7 747200048

1000000 0.75 800000048

1000000 0.8 852800048

1000000 0.85 905600048

1000000 0.9 958400048

1000000 0.95 1011200048

------------------------------------------------------------

INSERTION (Open-Addressing)

------------------------------------------------------------

LENGTH LF START\_INSERTIONS TIME

------------------------------------------------------------

100 0.0 0 2.167224884033203e-06

100 0.05 5 2.491474151611328e-06

100 0.1 10 2.651214599609375e-06

100 0.15 15 2.610683441162109e-06

100 0.2 20 2.510547637939453e-06

100 0.25 25 3.3259391784667967e-06

100 0.3 30 3.5238265991210936e-06

100 0.35 35 3.371238708496094e-06

100 0.4 40 4.072189331054687e-06

100 0.45 45 4.727840423583984e-06

100 0.5 50 4.999637603759765e-06

100 0.55 55 5.457401275634766e-06

100 0.6 60 5.364418029785156e-06

100 0.65 65 6.625652313232422e-06

100 0.7 70 6.08205795288086e-06

100 0.75 75 6.2537193298339845e-06

100 0.8 80 6.825923919677734e-06

100 0.85 85 6.740093231201172e-06

100 0.9 90 6.999969482421875e-06

100 0.95 95 7.998943328857421e-06

1000 0.0 0 2.25067138671875e-06

1000 0.05 50 2.331733703613281e-06

1000 0.1 100 2.6297569274902342e-06

1000 0.15 150 3.528594970703125e-06

1000 0.2 200 3.7598609924316405e-06

1000 0.25 250 5.09023666381836e-06

1000 0.3 300 5.543231964111328e-06

1000 0.35 350 6.945133209228515e-06

1000 0.4 400 8.683204650878907e-06

1000 0.45 450 9.78708267211914e-06

1000 0.5 500 1.1146068572998047e-05

1000 0.55 550 1.21307373046875e-05

1000 0.6 600 1.446247100830078e-05

1000 0.65 650 2.167940139770508e-05

1000 0.7 700 1.6498565673828126e-05

1000 0.75 750 1.7125606536865234e-05

1000 0.8 800 1.8351078033447265e-05

1000 0.85 850 1.9001960754394532e-05

1000 0.9 900 2.2194385528564454e-05

1000 0.95 950 3.244638442993164e-05

10000 0.0 0 2.379417419433594e-06

10000 0.05 500 3.7980079650878906e-06

10000 0.1 1000 3.972053527832031e-06

10000 0.15 1500 4.4894218444824215e-06

10000 0.2 2000 6.268024444580078e-06

10000 0.25 2500 1.024007797241211e-05

10000 0.3 3000 1.3763904571533202e-05

10000 0.35 3500 1.3685226440429687e-05

10000 0.4 4000 1.8775463104248047e-05

10000 0.45 4500 2.012491226196289e-05

10000 0.5 5000 2.42161750793457e-05

10000 0.55 5500 2.8524398803710938e-05

10000 0.6 6000 3.443241119384765e-05

10000 0.65 6500 3.187417984008789e-05

10000 0.7 7000 4.624605178833008e-05

10000 0.75 7500 4.178285598754883e-05

10000 0.8 8000 4.6143531799316404e-05

10000 0.85 8500 5.0647258758544924e-05

10000 0.9 9000 5.7315826416015626e-05

10000 0.95 9500 5.970478057861328e-05

100000 0.0 0 2.2530555725097655e-06

100000 0.05 5000 5.567073822021485e-06

100000 0.1 10000 1.1701583862304687e-05

100000 0.15 15000 1.1816024780273438e-05

100000 0.2 20000 2.1119117736816406e-05

100000 0.25 25000 3.0739307403564455e-05

100000 0.3 30000 3.188610076904297e-05

100000 0.35 35000 3.521442413330078e-05

100000 0.4 40000 6.224870681762695e-05

100000 0.45 45000 5.7697296142578125e-05

100000 0.5 50000 6.572961807250977e-05

100000 0.55 55000 7.150888442993164e-05

100000 0.6 60000 0.00010644435882568359

100000 0.65 65000 0.00011627674102783203

100000 0.7 70000 0.00011710643768310547

100000 0.75 75000 0.0001436758041381836

100000 0.8 80000 0.0001497483253479004

100000 0.85 85000 0.00017334938049316407

100000 0.9 90000 0.0002018594741821289

100000 0.95 95000 0.00020658254623413087

1000000 0.0 0 2.262592315673828e-06

1000000 0.05 50000 8.707046508789063e-06

1000000 0.1 100000 3.541469573974609e-05

1000000 0.15 150000 2.4330615997314452e-05

1000000 0.2 200000 3.537416458129883e-05

1000000 0.25 250000 7.76839256286621e-05

1000000 0.3 300000 0.00013521909713745117

1000000 0.35 350000 9.412527084350586e-05

1000000 0.4 400000 0.0001767873764038086

1000000 0.45 450000 0.00017335891723632813

1000000 0.5 500000 0.00024774789810180667

1000000 0.55 550000 0.00029632568359375

1000000 0.6 600000 0.00031252145767211913

1000000 0.65 650000 0.0003596949577331543

1000000 0.7 700000 0.00033381223678588865

1000000 0.75 750000 0.0004416179656982422

1000000 0.8 800000 0.0004789495468139648

1000000 0.85 850000 0.000578005313873291

1000000 0.9 900000 0.0005841326713562012

1000000 0.95 950000 0.0006232786178588867

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SEARCH (Open-Addressing)

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LENGTH LF TIME

------------------------------------------------------------

100 0.05 1.10626220703125e-06

100 0.1 1.3756752014160155e-06

100 0.15 1.0061264038085937e-06

100 0.2 1.4138221740722656e-06

100 0.25 1.4901161193847656e-06

100 0.3 1.5902519226074219e-06

100 0.35 1.7714500427246093e-06

100 0.4 1.7547607421875e-06

100 0.45 2.224445343017578e-06

100 0.5 2.2554397583007815e-06

100 0.55 2.4437904357910156e-06

100 0.6 2.875328063964844e-06

100 0.65 3.1900405883789064e-06

100 0.7 4.265308380126953e-06

100 0.75 2.951622009277344e-06

100 0.8 3.173351287841797e-06

100 0.85 3.087520599365234e-06

100 0.9 2.55584716796875e-06

100 0.95 3.24249267578125e-06

1000 0.05 1.2636184692382812e-06

1000 0.1 1.4925003051757812e-06

1000 0.15 1.3875961303710938e-06

1000 0.2 2.17437744140625e-06

1000 0.25 2.593994140625e-06

1000 0.3 2.8443336486816406e-06

1000 0.35 3.0660629272460936e-06

1000 0.4 4.270076751708984e-06

1000 0.45 4.4941902160644535e-06

1000 0.5 5.173683166503906e-06

1000 0.55 6.072521209716797e-06

1000 0.6 6.239414215087891e-06

1000 0.65 5.640983581542969e-06

1000 0.7 6.814002990722656e-06

1000 0.75 8.542537689208984e-06

1000 0.8 8.540153503417969e-06

1000 0.85 8.695125579833984e-06

1000 0.9 1.0442733764648437e-05

1000 0.95 1.678943634033203e-05

10000 0.05 1.5401840209960937e-06

10000 0.1 2.1266937255859375e-06

10000 0.15 2.8347969055175783e-06

10000 0.2 3.087520599365234e-06

10000 0.25 6.4730644226074215e-06

10000 0.3 7.698535919189453e-06

10000 0.35 8.852481842041016e-06

10000 0.4 1.039743423461914e-05

10000 0.45 1.039266586303711e-05

10000 0.5 1.1687278747558594e-05

10000 0.55 1.648902893066406e-05

10000 0.6 2.073049545288086e-05

10000 0.65 2.3543834686279297e-05

10000 0.7 2.552032470703125e-05

10000 0.75 2.8443336486816406e-05

10000 0.8 3.6292076110839843e-05

10000 0.85 3.4880638122558596e-05

10000 0.9 3.3314228057861326e-05

10000 0.95 3.470659255981445e-05

100000 0.05 2.467632293701172e-06

100000 0.1 5.626678466796875e-06

100000 0.15 1.068115234375e-05

100000 0.2 9.670257568359376e-06

100000 0.25 1.2362003326416016e-05

100000 0.3 2.4650096893310547e-05

100000 0.35 2.5420188903808595e-05

100000 0.4 3.860950469970703e-05

100000 0.45 4.564523696899414e-05

100000 0.5 5.530595779418945e-05

100000 0.55 5.527257919311524e-05

100000 0.6 5.199193954467773e-05

100000 0.65 6.030559539794922e-05

100000 0.7 7.044553756713868e-05

100000 0.75 7.416009902954102e-05

100000 0.8 9.057998657226563e-05

100000 0.85 9.179353713989258e-05

100000 0.9 9.605169296264649e-05

100000 0.95 0.00010422945022583008

1000000 0.05 4.546642303466797e-06

1000000 0.1 2.2006034851074218e-05

1000000 0.15 2.060651779174805e-05

1000000 0.2 2.643108367919922e-05

1000000 0.25 3.7572383880615235e-05

1000000 0.3 5.3260326385498044e-05

1000000 0.35 9.169578552246094e-05

1000000 0.4 9.081602096557618e-05

1000000 0.45 0.0001190638542175293

1000000 0.5 0.00011915445327758789

1000000 0.55 0.00015690088272094727

1000000 0.6 0.00017487287521362305

1000000 0.65 0.00017169952392578124

1000000 0.7 0.00025520801544189455

1000000 0.75 0.00023440122604370117

1000000 0.8 0.0002936840057373047

1000000 0.85 0.0003442215919494629

1000000 0.9 0.0003423380851745605

1000000 0.95 0.0003786802291870117

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DELETE (Open-Addressing)

------------------------------------------------------------

LENGTH LF TIME

------------------------------------------------------------

100 0.05 1.1920928955078125e-06

100 0.1 1.4638900756835937e-06

100 0.15 1.1539459228515625e-06

100 0.2 1.506805419921875e-06

100 0.25 1.5687942504882813e-06

100 0.3 1.5544891357421874e-06

100 0.35 2.1457672119140625e-06

100 0.4 2.0194053649902345e-06

100 0.45 2.1696090698242187e-06

100 0.5 2.17437744140625e-06

100 0.55 2.446174621582031e-06

100 0.6 3.070831298828125e-06

100 0.65 2.932548522949219e-06

100 0.7 3.3831596374511718e-06

100 0.75 3.2901763916015627e-06

100 0.8 3.2019615173339843e-06

100 0.85 2.7632713317871093e-06

100 0.9 2.720355987548828e-06

100 0.95 3.4570693969726562e-06

1000 0.05 1.3041496276855468e-06

1000 0.1 1.94549560546875e-06

1000 0.15 1.690387725830078e-06

1000 0.2 1.7523765563964843e-06

1000 0.25 2.8252601623535155e-06

1000 0.3 2.875328063964844e-06

1000 0.35 3.464221954345703e-06

1000 0.4 3.6668777465820314e-06

1000 0.45 3.821849822998047e-06

1000 0.5 5.104541778564453e-06

1000 0.55 5.91278076171875e-06

1000 0.6 6.7138671875e-06

1000 0.65 7.083415985107422e-06

1000 0.7 6.971359252929687e-06

1000 0.75 6.52313232421875e-06

1000 0.8 9.87529754638672e-06

1000 0.85 9.65118408203125e-06

1000 0.9 1.1343955993652343e-05

1000 0.95 1.6024112701416014e-05

10000 0.05 1.3828277587890625e-06

10000 0.1 2.9277801513671873e-06

10000 0.15 3.731250762939453e-06

10000 0.2 4.0936470031738285e-06

10000 0.25 7.462501525878906e-06

10000 0.3 8.428096771240235e-06

10000 0.35 9.722709655761719e-06

10000 0.4 1.3551712036132813e-05

10000 0.45 1.1548995971679687e-05

10000 0.5 1.41143798828125e-05

10000 0.55 1.8596649169921875e-05

10000 0.6 2.126932144165039e-05

10000 0.65 2.4938583374023436e-05

10000 0.7 2.557516098022461e-05

10000 0.75 2.6311874389648437e-05

10000 0.8 2.7909278869628907e-05

10000 0.85 3.0448436737060545e-05

10000 0.9 3.111839294433594e-05

10000 0.95 3.542423248291016e-05

100000 0.05 2.903938293457031e-06

100000 0.1 3.950595855712891e-06

100000 0.15 5.772113800048828e-06

100000 0.2 1.4898777008056641e-05

100000 0.25 1.760244369506836e-05

100000 0.3 2.6905536651611327e-05

100000 0.35 2.849578857421875e-05

100000 0.4 3.490924835205078e-05

100000 0.45 3.890037536621094e-05

100000 0.5 5.148649215698242e-05

100000 0.55 6.070852279663086e-05

100000 0.6 6.130218505859375e-05

100000 0.65 6.885528564453125e-05

100000 0.7 7.21287727355957e-05

100000 0.75 0.00010318517684936524

100000 0.8 9.439468383789063e-05

100000 0.85 0.00011126518249511719

100000 0.9 0.0001018977165222168

100000 0.95 0.00011851310729980468

1000000 0.05 5.180835723876953e-06

1000000 0.1 5.104541778564453e-06

1000000 0.15 4.749298095703125e-06

1000000 0.2 3.2923221588134766e-05

1000000 0.25 6.508350372314454e-05

1000000 0.3 7.170677185058594e-05

1000000 0.35 6.974935531616211e-05

1000000 0.4 7.916450500488282e-05

1000000 0.45 0.00013160228729248047

1000000 0.5 0.00016855001449584962

1000000 0.55 0.00018468141555786133

1000000 0.6 0.00017623186111450194

1000000 0.65 0.00018252134323120116

1000000 0.7 0.0002575516700744629

1000000 0.75 0.0002857184410095215

1000000 0.8 0.00028034925460815427

1000000 0.85 0.0003724479675292969

1000000 0.9 0.0003305196762084961

1000000 0.95 0.00038273096084594726

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MEMORY (Open-Addressing)

------------------------------------------------------------

LENGTH LF MEMORY

------------------------------------------------------------

100 0.0 848

100 0.05 848

100 0.1 848

100 0.15 848

100 0.2 848

100 0.25 848

100 0.3 848

100 0.35 848

100 0.4 848

100 0.45 848

100 0.5 848

100 0.55 848

100 0.6 848

100 0.65 848

100 0.7 848

100 0.75 848

100 0.8 848

100 0.85 848

100 0.9 848

100 0.95 848

1000 0.0 8048

1000 0.05 8048

1000 0.1 8048

1000 0.15 8048

1000 0.2 8048

1000 0.25 8048

1000 0.3 8048

1000 0.35 8048

1000 0.4 8048

1000 0.45 8048

1000 0.5 8048

1000 0.55 8048

1000 0.6 8048

1000 0.65 8048

1000 0.7 8048

1000 0.75 8048

1000 0.8 8048

1000 0.85 8048

1000 0.9 8048

1000 0.95 8048

10000 0.0 80048

10000 0.05 80048

10000 0.1 80048

10000 0.15 80048

10000 0.2 80048

10000 0.25 80048

10000 0.3 80048

10000 0.35 80048

10000 0.4 80048

10000 0.45 80048

10000 0.5 80048

10000 0.55 80048

10000 0.6 80048

10000 0.65 80048

10000 0.7 80048

10000 0.75 80048

10000 0.8 80048

10000 0.85 80048

10000 0.9 80048

10000 0.95 80048

100000 0.0 800048

100000 0.05 800048

100000 0.1 800048

100000 0.15 800048

100000 0.2 800048

100000 0.25 800048

100000 0.3 800048

100000 0.35 800048

100000 0.4 800048

100000 0.45 800048

100000 0.5 800048

100000 0.55 800048

100000 0.6 800048

100000 0.65 800048

100000 0.7 800048

100000 0.75 800048

100000 0.8 800048

100000 0.85 800048

100000 0.9 800048

100000 0.95 800048

1000000 0.0 8000048

1000000 0.05 8000048

1000000 0.1 8000048

1000000 0.15 8000048

1000000 0.2 8000048

1000000 0.25 8000048

1000000 0.3 8000048

1000000 0.35 8000048

1000000 0.4 8000048

1000000 0.45 8000048

1000000 0.5 8000048

1000000 0.55 8000048

1000000 0.6 8000048

1000000 0.65 8000048

1000000 0.7 8000048

1000000 0.75 8000048

1000000 0.8 8000048

1000000 0.85 8000048

1000000 0.9 8000048

1000000 0.95 8000048

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