Weekplan: Hashing

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References and Reading

[1] Notes from Aarhus, Peter Bro Miltersen.

[2] Scribe notes from MIT.

[3] Universal Classes of Hash Functions, J. Carter and M. Wegman, J. Comp. Sys. Sci., 1977.

[4] Storing a Sparse Table with O(1) Worst Case Access Time, M. Fredman, J. Komlos and E. Szemeredi, J. ACM., 1984.

We recommend reading [1] and [2] in detail. [3] and [4] provide background on universal and perfect hashing.

Exercises

1 [w] **Streaming Statistics** An IT-security friend of yours wants a high-speed algorithm to count the number of *distinct* incoming IP-addresses in his router to help detect denial of service attacks. Can you help him?

2 Dense Set Hashing A set $S \subseteq U = \{0, \ldots, u-1\}$ is called *dense* if $|S| = \Theta(u)$. Suggest a simple and efficient dictionary data structure for dense sets.

3 Multi-Set Hashing A multi-set is a set M, where each element may occur multiple times. Design an efficient data structure supporting the following operations:

- add(x): Add an(other) occurrence of x to M.
- remove(x): Remove an occurrence of x from M. If x does not occur in M do nothing.
- report(x): Return the number of occurrences of x.

4 Linear Space Hashing The chained hashing solution for the dynamic dictionary problem presented assume that $|S| \leq N$ and we can use $O(N)$ space. Show how to remove this assumption. Specifically, give a solution that achieves that the same time complexities using only $O(|S|)$ space. *Hint:* Think dynamic tables.

5 Basic Probability Theory Refresh Bonus In case your knowledge of probability theory is rusty. Solve the following self-help exercises.

5.1 Prove linearity of expectation.

5.2 Prove that the expectation of the *indicator function* for $h(x) = h(y)$ (1 if $h(x) = h(y)$ and 0 otherwise) is equal to the probability that $h(x) = h(y)$.

5.3 Show that the expected number of trials to get a perfect hashing function using an array of size N^2 is ≤ 2.

6 Lost Integer Puzzles Suppose that you receive a stream of $n-1$ distinct integers from the set $\{1,\ldots,n\}$, i.e., the stream consists of all of $\{1,\ldots,n\}$ except a single missing integer. We want a space-efficient algorithm that efficiently computes this integer during a single pass over the input stream. Solve the following exercises:

6.1 Show how to find the lost integer using $O(n)$ space.

6.2 [$*$] Show how to find the lost integer using $O(1)$ space.

6.3 [$**$] Suppose there are now two lost integers. Show how to find them using $O(1)$ space.

7 Graph Adjacency Let G be a graph with n vertices and m edges. We want to represent G efficiently and support the following operation.

- adjacent(v,w): Return true if nodes v are w are adjacent and false otherwise.

Solve the following exercises:

7.1 Analyse the space and query time in terms of n and m for the classic adjacency matrix and adjacency list representation.

7.2 Design a data structure that improves both the adjacency matrix and adjacency list.