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Algorithms and Datastructures
Exercise Sheet 13

Exercise 1: (Binary) Heaps and Heapsort (12 Bonus Points)

(a) Implement a *binary heap* using the *array implementation* from the lecture. The heap should support the following functions: `create`, `insert` (eines key-value pairs), `get_min` and `delete_min`. You may use the template *heap.py*. *(5 Points)*

Hint: To implement `delete_min` efficiently one overwrites the root with the last element of the heap and then deletes the last element. Afterwards one has to repair the min-heap property.

(b) Implement the heapsort algorithm by using your implementation from the previous task.[1] Explain the $O(n \log n)$ runtime of heapsort.

Argue why there can't be a heap implementation where `insert`, `get_min` and `delete_min` have all constant runtime. *(3 Points)*

(c) In this task we consider *ternary* heaps. They are similar to binary heaps with the difference that each parent node may have 3 children. We also have that the underlying tree is filled up with nodes from 'top to bottom' and 'left to right'.

Give the minimal and maximal number of nodes of a ternary heap of depth d. *(1 Point)*

Assume we use an array implementation for ternary heaps[2], starting with index 1 (not 0). Let i be the index of a node v that is neither the root nor a leaf. What are the indices of v's parent and its three children? *(3 Points)*

[1] If you did not solve the previous task, you may use `heapq`. In `heapq`, `heappush` equals the `insert` and `heappop` the `delete-min` operation from the lecture. `heappush` and `heappop` can be applied on Python-lists (for more detail see here).

[2] Similar to the array implementation of binary heaps on slide 26 in lecture 9.

Exercise 2: Hashing *(8 Bonus Points)*

(a) Let $h(s,j) := h_1(s) - 2j \bmod m$ and $h_1(x) := x + 2 \bmod m$. Insert the keys 51, 13, 21, 30, 23, 72 (in the given order) into a hash table of size $m = 7$ by using the hash function h and *linear probing* for collision resolution. (The following table should show the final state after inserting all keys.) *(1 Point)*

0	1	2	3	4	5	6

(b) Assume we would like to insert the sequence of numbers from part a) in a table of size $m = 7$ by using *quadratic probing*. Which of the following hash functions would be the better choice? Explain your answer.

- $h_1(x,i) := x + 6i + 2i^2 \bmod m$
- $h_2(x,i) := x + i + 4i^2 \bmod m$

Insert the keys by using the better hash function into the following table. *(2 Points)*

0	1	2	3	4	5	6

(c) Let $h(s,j) := h_1(s) + j \cdot h_2(s) \bmod m$ with $h_1(x) = x \bmod m$ and $h_2(x) = 1 + \big(x \bmod (m-1)\big)$. Insert the keys 28, 59, 47, 13, 39, 69, 12 in a hash table of size $m = 11$ by using *double-hashing* for collision resolution. *(2 Points)*

0	1	2	3	4	5	6	7	8	9	10

(d) Given the hash functions $h_1(x) := x + 2 \bmod m$ and $h_2(x) := 3x \bmod m$ with $m = 7$, find three pairwise distinct keys $u, v, w \in \mathbb{N}$ such that $h_1(u) = h_1(v) = h_1(w) \neq h_2(u) = h_2(v) = h_2(w)$. Insert u and v into the following table by using *Cuckoo Hashing*.

0	1	2	3	4	5	6

If we also insert w, we obtain a cycle. To avoid this, we apply a rehash by increasing the table's size to $m' = 11$ and use two new hash functions h'_1 and h'_2. Give two distinct functions h'_1 and h'_2 of the form $(ax \bmod m')$ with $a \not\equiv 0$ such that u, v and w can be inserted into the new table (i.e., that no cycle is created). *(3 Points)*