University of Waterloo
CS 466 — Advanced Algorithm
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Problem Set 2
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1. [8 marks: The Need for Paid Exchanges] In discussing Move to Front and other self-organizing heuristics the model was very important. In the model in which swapping the requested element with one immediately in front of it (and perhaps repeating this many times) as a free exchange, bring the question as to whether paid exchanges are necessary to achieve the offline optimal. Clearly they are not necessary to come within a factor of two of optimal under this model.

   a. Show that the offline optimal to service the request a_3, a_2, a_3, a_2 is 8. The list is initially in the order a_1, a_2, a_3.

      Assume we know the procedures to achieve offline optimal. Then, let $\delta_0, \delta_1, \delta_2, \delta_3$ represent the ordering before the before first, second, third and fourth accesses; let c_0, c_1, c_2, c_3 represent the cost for first, second, third and fourth accesses.

      We know that $c_0, c_1, c_2, c_3 \geq 1$. Assuming $c_0 = 1$, then the access cost for a_2 in δ_0 is greater than 1. Since c_1 is at least access cost for a_2 in δ_0, we have $c_1 \geq 2$. Thus,

      $$c_0 + c_1 \geq 3 \tag{1}$$

      Otherwise $c_0 \geq 2$, and $c_1 \geq 1$, we still have equation 1.

      And for the same reason, we have

      $$c_2 + c_3 \geq 3 \tag{2}$$

      Now, looking at the initial ordering a_1, a_2, a_3, if δ_0 is a_1, a_2, a_3, then we have$c_0 = 3$ and $c_1 \geq 2$. Thus, we have

      $$c_0 + c_1 \geq 5 \tag{3}$$

which leads to

$$c_0 + c_1 + c_2 + c_3 \geq 8 \tag{4}$$

Thus, the **total cost is at least 8**.

Otherwise, δ_0 is derivied from a_1, a_2, a_3 after exchanges. However, each paid exchange reduce access cost by one to at most one element. Therefore, we easily have

$$c_0 + c_1 \geq 4 \tag{5}$$

which leads to

$$1 + c_0 + c_1 + c_2 + c_3 \geq 8 \tag{6}$$

Thus, the **total cost is at least 8**.

if δ_0 is derivied from a_1, a_2, a_3 after one paid exchange. And, the **total cost is at least 8**. if δ_0 is derivied from a_1, a_2, a_3 after k paid exchanges where $k \geq 2$, we still have

$$k + c_0 + c_1 + c_2 + c_3 \geq 8 \tag{7}$$

Thus, the **total cost is at least 8**.

From above, we conclude the optimal **total cost is at least 8**. And we actually achieve the total cost of 8 if we have $\delta_0 = a_2, a_3, a_1$ is derivied from a_1, a_2, a_3 after two paid exchanges as well as $\delta_0 = \delta_1 = \delta_2 = \delta_3$. Therefore, the optimal **total cost is 8**.

b. Also show that the optimal offline algorithm without using these paid exchanges is 9.

2. [6 marks] In a splay tree we use double rotations to move an element to the root. It was mentioned that moving the requested element to the root by a sequence can give very bad amortized behavior. Prove that this amortized cost can be $\Theta(n)$ (actually you can get it to n)for an arbitrarily long sequence of requests on a tree with n nodes, with a starting configuration of your choice. (You need not deal with either insertions or deletions.)