CS 375 Homework 1 Anchu A. Lee
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I have done this assignment completely on my own. I have not copied it, nor have I given my solution to anyone else. I understand that if I am involved in plagiarism or cheating I will have to sign an official form that I have cheated and that this form will be stored in my official university record. I also understand that I will receive a grade of 0 for the involved assignment for my first offense and that I will receive a grade of F for the course for any additional offense.

1. Use the Master theorem to solve the following recurrences.

   (a) $T(n) = 3T(n/4) + n$
   $a = 3$, $b = 4$, $f(n) = n$
   Case 3: $f(n) = \Theta(n^c)$ if $c = 1$.
   $log_4 3 = 0.79248 < c$
   $T(n) = \Theta(f(n)) = \Theta(n)$

   (b) $T(n) = 2T(n/4) + \sqrt{n}\log(n)$
   $a = 2$, $b = 4$, $f(n) = \sqrt{n}\log(n)$
   Case 2: $f(n) = \Theta(n^c \log^k n)$ if $c = \frac{1}{2}$ and $k = 0$
   $\log_4 2 = 0.5$ so $c = \log_b a$
   $T(n) = \Theta(n^{0.5}\log^1 n = \Theta(\sqrt{n}\log(n))$

   (c) $T(n) = 5T(n/2) + n^2$
   $a = 5$, $b = 2$, $f(n) = n^2$
   Case 1: $f(n) = \Theta(n^c)$ if $c = 2$
   $\log_2 5 = 2.3219... > c$
   $T(n) = \Theta(n^{log_2 5}) = \Theta(n^{2.3218...})$

2. Solve the recurrence

$$T(n) = \begin{cases} \Theta(1) & \text{for } n \leq 1 \\ T(n/4) + T(3n/4) + n & \text{otherwise} \end{cases}$$

   using the recursion tree method. Draw the recursion tree and show the aggregate instruction counts for the following levels (0th, 1st, and last levels), and derive the Θ growth class for $T(n)$ with justifications.

3. Use the substitution method to prove that $T(n) = T(n-1) + n \in O(n^2)$

   Proof. Assume that $T(n) = O(n^2)$. So then $T(n) \leq c \cdot n^2$ for some constant c.
   Assume $T(k) \leq ck^2$ for $k < n$. Prove $T(n) \leq cn^2$ by induction.

$$\begin{aligned} T(n) = T(n-1) + n &\leq c \cdot (n-1)^2 + n \\ &\leq c \cdot (n-1)(n-1) + n \\ &\leq c \cdot (n^2 - 2n + 1) + n \\ &\leq cn^2 - cn + c \leq cn^2 \end{aligned}$$

   Which holds provided $cn + c \geq 0$. Which is $cn \geq -c$. So $T(n)$ is in $O(n^2)$ as long as $c \geq 0$ and $n \geq 0$. □

4. Assume that you are given an array of n ($n \geq 1$) elements sorted in non-descending order. Design a *ternary* search function that searches the array for a given element x by applying the divide and conquer strategy.

   - **Divide:** Grab an array index at 1/3 of the array length (a_1) and at 2/3 of the array length (a_2). That way the indexes split the array into thirds.
   - **Conquer:** If the element x is less than $A[a_1]$ then it must be in the subarray $A[0 \text{ to } a_1]$. Otherwise if x is greater than $A[a_1]$ and less than $A[a_2]$ then it must be in the subarray $A[a_1 \text{ to } a_2]$ Lastly if x is greater than $A[a_2]$ then it must be in the subarray $A[a_2 \text{ to } n]$. Then recusievly search the subarray until x is the value of $A[a_1]$ or $A[a_2]$.
   - **Combine:** The final answer is the index found when the recursive function returns.

```
function ternarySearch(x, A, left, right)
    a_1 = 1/3 * (right-left)  // first index
    a_2 = 2/3 * (right-left)  // second index
    if A[a_1] == x return a_1   // found x
    if A[a_2] == x return a_2

    // check left subarray
    if A[a_1] > x return ternarySearch(x, A, left, a_1-1)

    // check right subarray
    else if A[a_2] < x return ternarySearch(x, A, a_2+1, right)

    // check middle subarray
    else return ternarySearch(x, A, a_1+1, a_2-1)
```

   The recursive time complexity of ternarySearch would be $T(n) = T(n/3) + \Theta(1)$. $n/3$ because the size of the array that needs to be searched is divided by three. Other functions of ternarySearch is trivial so happens over $\Theta(1)$
   Solve $T(n) = T(n/3) + \Theta(1)$ using the master theorem.
   $a = 1$, $b = 3$, $f(n) = \Theta(1)$
   Guess case 2: $f(n) = \Theta(n^c \text{log}^k n)$ is true for $c = 0$ and $k = 0$
   $\text{log}_3 1 = 0 = c$ so case 2 condition satisfied.
   Thus $T(n) = \Theta(n^0 \text{log}^{k+1} n) = \Theta(\text{log} n)$

5. Develop a divide-and-conquer approach to selection (and hence a solution for the finding median problem). Hint: for any number v, imagine splitting list S into three categories: elements smaller than v, those equal to v (there might be duplicates), and those greater than v.

   - **Divide:** For a number v which is an random element of S, split the list into sublists with numbers larger than v, smaller than v, and equal to v.

- **Conquer:** Using the number of elements in each list, we can determine which sublist the kth element must reside in. For example, if $k = 6$ and the number of elements smaller than v is 3, the number of elements the same as v is 1 and the number of elements larger than v is 5, then we know that the desired number is the smallest element in the sublist containing elements larger than v. Repeat this process until k is bounded below by the number of elements less than v and bounded above by the number of elements less than v added with the number of elements equal to v. In that case return v.
- **Combine:** Each time requires the list to be interated (linear).

```
function selection(S, k)
    s_ls, s_gr, s_eq
    v = S[random]
    for each i in S:
        if i < v s_ls.add(v)
        else if i > v s_gr.add(v)
        else s_eq.add(v)
    if s_ls.size >= k return selection(s_ls,k)
    else if s_ls.size + s_eq.size < k return selection(s_gr, k)
    else if s_ls.size < k and k <= s_ls.size + s_eq.size return v
```

Worst case situation for this function would be if it picked the largest or smallest element in the list every time.

$$n + (n-1) + (n-2) + (n-3) + ... + \frac{n}{2} = \Theta(n^2)$$

Best case situation would be if the exact middle was chosen randomly every time. That would mean the solution is found after the first iteration of the list. $O(n)$

6. Use the recursion tree method to solve $T(n) = 2T(n/2) + 1/\log n$ Draw the recursion tree and show the aggregate instruction counts for the following levels (0th, 1st, and last levels), and derive the Θ growth class for $T(n)$ with justifications.