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Principles of Distributed Computing
Exercise 9

1 Communication Complexity of Set Disjointness

In the lecture we studied the communication complexity of the equality function. Now we consider the disjointness function: Alice and Bob are given subsets $X, Y \subseteq \{1, \ldots, k\}$ and need to determine whether they are disjoint. Each subset can be represented by a string. E.g., we define the i^{th} bit of $x \in \{0,1\}^k$ as $x_i := 1$ if $i \in X$ and $x_i := 0$ if $i \notin X$. Now define disjointness of X and Y as:

$$DISJ(x, y) := \begin{cases} 0 & : \text{there is an index } i \text{ such that } x_i = y_i = 1 \\ 1 & : \text{else} \end{cases}$$

a) Write down M^{DISJ} for the $DISJ$-function when $k = 3$.

b) Use the matrix obtained in a) to provide a fooling set of size 4 for $DISJ$ in case $k = 3$.

c) In general, prove that $CC(DISJ) = \Omega(k)$.

2 Distinguishing Diameter 2 from 4

In the lecture we stated that when the bandwidth of an edge is limited to $O(\log n)$, the diameter of a graph can be computed in $O(n)$. In this problem, we show that we can do faster in case we know that all networks/graphs on which we execute an algorithm have either diameter 2 or diameter 4. We start by partitioning the nodes into sets: Let $s := s(n)$ be a threshold and define the set of high degree nodes $H := \{v \in V \mid d(v) \geq s\}$ and the set of low degree nodes $L := \{v \in V \mid d(v) < s\}$. Next, we define: An H-dominating set $\mathcal{DOM}$ is a subset $\mathcal{DOM} \subseteq V$ of the nodes such that each node in H is either in the set $\mathcal{DOM}$ or adjacent to a node in the set $\mathcal{DOM}$.
Note: We define $N_1(v)$ as the closed neighborhood of vertex v (v and its adjacent nodes).
Assume in the following, that we can compute an H-dominating set $\mathcal{DOM}$ of size $\frac{n \log n}{s}$ in time $O(D)$.

a) What is the distributed runtime of Algorithm 2-vs-4 (stated next page)? In case you believe that the distributed implementation of a step is not known from the lecture, find a distributed implementation for this step! **Hint: The runtime depends on s and n.**

b) Find a function $s := s(n)$ such that the runtime is minimized (in terms of n).

c) Prove that if the diameter is 2, then Algorithm 2-vs-4 always returns 2.

Now assume that the diameter of the network is 4 and that we know vertices u and v with distance 4 to each other.

Algorithm 1 "2-vs-4". Input: G with diameter 2 or 4 Output: diameter of G

if $L \neq \emptyset$ **then**
    choose $v \in L$ ▷ We know: This takes $O(D)$.
    compute a BFS tree from each vertex in $N_1(v)$
else
    compute an H-dominating set $\mathcal{DOM}$ ▷ Use: Assumption
    compute a BFS tree from each vertex in $\mathcal{DOM}$
end if
if all BFS trees have depth 2 or 1 **then**
    return 2
else
    return 4
end if

d) Prove that if the algorithm performs a BFS from at least one node $w \in N_1(u)$ it decides "the diameter is 4".

e) In case $L \neq \emptyset$: Prove that the algorithm performs a BFS of depth at least 3 from some node w. **Hint: use d)**

f) In case $L = \emptyset$: Prove that the algorithm performs a BFS of depth at least 3 from some node w.

g) Give a high level idea, why you think that this does not violate the lower bound of $\Omega(n/\log n)$ presented in the lecture!

h) Assume $s = \frac{n}{2}$. Prove or disprove: If the diameter is 2, then Algorithm 2-vs-4 will always compute some BFS tree of depth exactly 2.