

Problem 3: Carpooling (Rephrasing of problem 27 in Chapter 7 of Kleinberg-Tardos, 25 points)

A group of k people p_1, \dots, p_k are carpooling to work for n days and they need to choose drivers for each day. However, only a subset of the people go to work each day. Also, they would like to divide up the driving duties fairly. In particular, no person should drive more than the expected number of times they would drive if the driver was chosen randomly each day (rounded up).

Example 0.1. *Let's say there are 3 people p_1, p_2, p_3 carpooling for 4 days and the people carpooling on each day are as follows:*

1. *On day 1, all 3 people are carpooling.*
2. *On day 2, p_1 and p_3 are carpooling.*
3. *On day 3, p_2 and p_3 are carpooling.*
4. *On day 4, p_2 and p_3 are carpooling again.*

In this case, if the driver was chosen randomly each day, the expected number of times p_1 drives is $\frac{1}{3} + \frac{1}{2} = \frac{5}{6}$. The expected number of times p_2 drives is $\frac{1}{3} + 2 \cdot \frac{1}{2} = \frac{4}{3}$. The expected number of times p_3 drives is $\frac{1}{3} + 3 \cdot \frac{1}{2} = \frac{11}{6}$. Thus, we can have p_1 drive at most 1 time and we can have p_2 and p_3 drive at most 2 times. One way to do this is to have p_1 drive on day 2, have p_2 drive on day 3, and have p_3 drive on days 1 and 4.

We can state this problem more precisely as follows. We are given subsets the subsets of people $\{S_j\}$ who are carpooling each day and we want to choose drivers $\{p_{i_j}\}$ such that

1. $\forall j \in [n], i_j \in S_j$ (the driver for each day is one of the people carpooling for that day)
2. $\forall i \in [k], |j : i_j = i| \leq \lceil \sum_{j \in [n] : i \in S_j} \frac{1}{|S_j|} \rceil$ (no person drives more than the expected number of times they should drive rounded up)

Show that such a driving shedule always exists, give an algorithm whose running time is polynomial in k and n to find such a driving schedule, and prove that your algorithm is correct (hint is available).

Kleinberg Tardos Solutions Chapter 7

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