Solar Panel Cleaning Robot Scheduling with Energy Constraints

Introduction

The increasing deployment of solar farms worldwide has made maintaining panel efficiency a critical task. Cleaning solar panels regularly prevents efficiency loss due to dust and dirt accumulation. Autonomous cleaning robots are a sustainable solution, but their operation is constrained by battery capacities and energy management.

In this problem, you are given a solar farm with multiple panels and a fleet of cleaning robots. Each robot's battery is recharged partially by solar energy harvested during the day. The challenge is to schedule the robots' cleaning routes and charging times to maximize the total weighted cleanliness score of the panels cleaned within the limited working hours.

Task

Given a description of solar panels, cleaning robots, and energy constraints, plan the cleaning schedule for each robot — including which panels to clean, in what order, and when — to maximize the total importance score of all cleaned panels within the available working time. The schedule must respect robot battery capacities, energy consumption for travel and cleaning, and allow for energy recharging from solar power during idle or cleaning times.

Problem Description

Solar Panels

There are N solar panels indexed from 0 to N-1. Each panel has an importance score reflecting how critical it is to keep the panel clean to maintain optimal energy production. Cleaning a panel restores its efficiency.

Robots

There are **M** cleaning robots indexed from 0 to M-1. Each robot:

- Has a battery with limited energy capacity.
- Consumes energy both when traveling between panels and when cleaning.
- Can recharge energy through solar power when idle or while cleaning, but the recharge rate is limited.
- Starts at a predefined initial position (e.g., charging station).

Time and Energy Constraints

- The robots operate within a fixed total time **T** (for example, one working day).
- Moving from panel i to panel j takes a known amount of time.
- Cleaning a panel requires a fixed cleaning time.
- Energy consumption rates for moving and cleaning are known for each robot.
- Robots cannot operate if their battery energy is depleted; they must recharge to continue.
- Robots may recharge while idle or cleaning, but the recharge rate is limited and cannot exceed solar energy availability.
- Robots cannot clean the same panel simultaneously.

Cleaning Rules

- Each panel can be cleaned multiple times, but the importance score for that panel is counted only once towards the total score.
- Cleaning of a panel must be completed within the total available time **T**.
- Robots may wait or recharge between tasks but must finish all activities within **T**.

Objective

Schedule routes, cleaning, and charging times for all robots to maximize the total sum of importance scores of all panels cleaned within the working time T.

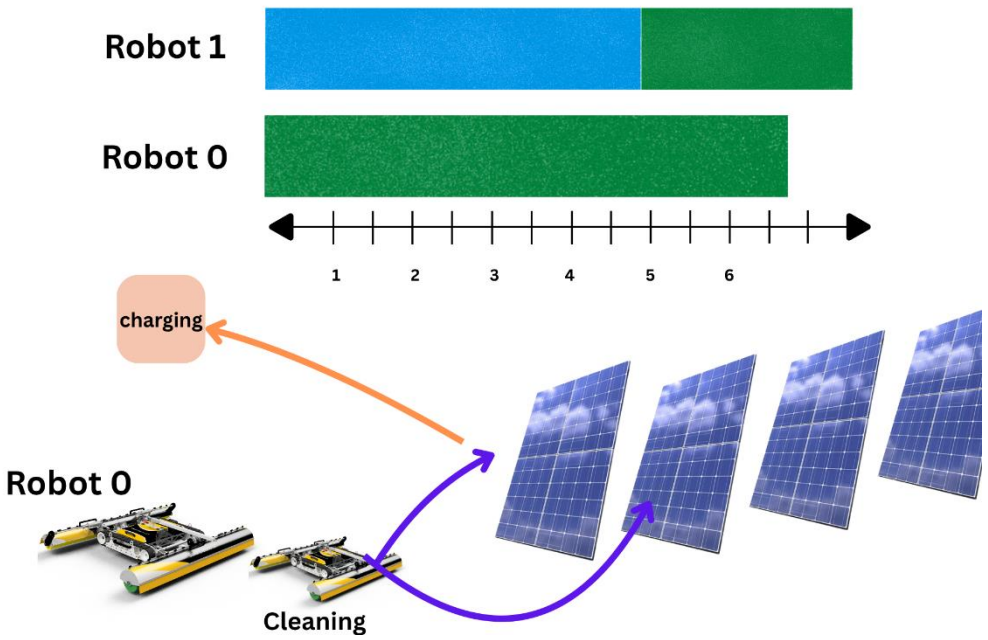
Example

For **example**, if

- Robot 0 requires **2 hours to fully recharge** before starting cleaning,
- Robot 1 requires **3 hours to fully recharge**,
- Robot 1 starts recharging **before** Robot 0,

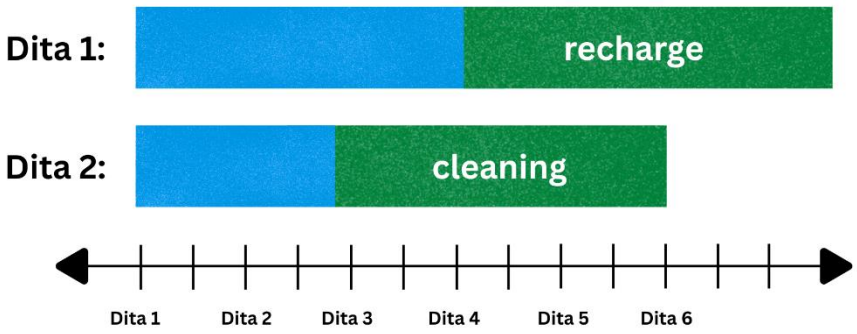
then

- The recharge process of Robot 1 starts on **hour 0**, and finishes on **hour 3** (3 hours total),
- Robot 1 can start cleaning panels beginning at **hour 3** (immediately after recharge completes),
- The recharge of Robot 0 starts on **hour 3** (right after Robot 1 finishes) and finishes on **hour 5** (2 hours total),
- Robot 0 can start cleaning panels beginning at **hour 5**.



While Robot 1 is cleaning, Robot 0 is recharging. After Robot 0 finishes recharging, it begins cleaning. Robots cannot clean the same panel simultaneously, and each cleaning task consumes battery and time.

Solar Panel Cleaning



The process for solar panel cleaning would look like this:

- All panels are cleaned by the robots in the cleaning facility
- The entire process of moving robots to panels, cleaning them, and returning to charging stations happens over a series of days.
- Each robot can clean a specific number of panels per day, and there's a maximum number of panels that can be cleaned per day by each robot.
- Time constraints: The robots must also manage their energy usage by recharging, which can affect the number of panels they can clean each day.

Example for Solar Panel Cleaning:

- Robot 0 needs to clean 5 panels.
- Robot 0 can clean 2 panels per day.
- Robot 0 completes its signup/recharge process on day 1.

Then:

- Day 2: Robot 0 can clean 2 panels.
- Day 3: Robot 0 can clean 2 panels again.
- Day 4: The one remaining panel can be cleaned.

Example for Solar Panel Cleaning

- Robot 0 has 5 panels to clean and can clean 2 panels per day.
- **Day 1**: The robot starts its recharge process
- **Day 2**: Robot 0 can clean 2 panels.
- **Day 3**: Robot 0 can clean 2 more panels.
- **Day 4**: The remaining 1 panel is cleaned.

Input Data Format

File Format

Each input data set is provided in a plain text file with ASCII characters. The file follows the standard UNIX-style line endings (\n). When multiple numbers are given in one line, they are separated by a single space.

Input Format

The first line of the file contains:

- N: The number of solar panels ($1 \leq N \leq 10^5$)
- M: The number of robots ($1 \leq M \leq 10^5$)
- T: The number of total available days ($1 \leq T \leq 10^5$)

This is followed by one line containing N integers: S_0, S_1, ..., S_(N-1), which represent the importance scores for each panel ($0 \leq S_i \leq 1000$).

Following this, there are M sections that describe each robot:

Each section contains:

1. The first line:
    - C: The cleaning capacity of the robot (maximum number of panels cleaned per day)
    - R: The recharge time for the robot (time in hours required to recharge after cleaning)
    - E: The energy capacity of the robot (maximum energy the robot can carry)
2. The second line:

- The initial position of the robot (charging station ID) (0 ≤ position ≤ N-1)

After the robots' descriptions, each panel's cleaning time is provided on a separate line.

6 2 10 **10 5 8 6 4 7** **2 3 10** **0 4** **2 3 12** **1 5** **2 3 1 4 2 3**	N = 6: There are 6 panels. M = 2: There are 2 robots. T = 10: The total available time is 10days. Panels' importance scores are [10, 5, 8, 6, 4, 7].

- Robot 0 has a cleaning capacity of 2 panels per day, recharge time of 3 hours, and energy capacity of 10.
- Robot 1 has a cleaning capacity of 2 panels per day, recharge time of 3 hours, and energy capacity of 12.

Score

Your score is the sum of the scores of all panels that are cleaned within the available time T. Note that if the same panel is cleaned by multiple robots within the allowed time (as panels 2 and 3 are in the example), the solution will be accepted, but the score for that panel will only be awarded once.

Capacity and Energy Considerations:

- **Cleaning Capacity:** Each robot can clean a specific number of panels per day. If a robot’s capacity is exceeded, it will not be able to clean more panels that day.

- **Energy Consumption:** Robots consume energy when traveling between panels and cleaning them. If a robot's energy is depleted, it must recharge before continuing its cleaning tasks. The recharge time is also considered in the total available time T.
- **Recharge Time:** When a robot requires recharge, it will not be able to clean any panels until it has enough energy to continue.
- **Cleaning the Same Panel:** If a robot cleans the same panel multiple times, only the first cleaning counts towards the score, as the panel's score is counted only once.

Example:
Let's consider the following scenario:

- Robot 0:
  - Cleaning capacity: 2 panels per day
  - Energy capacity: 10 (enough for 2 panels)
  - Recharge time: 3 hours
- Robot 1:
  - Cleaning capacity: 2 panels per day
  - Energy capacity: 12 (enough for 3 panels)
  - Recharge time: 2 hours

Detailed Timeline:

- Day 0 to Day 2: Robot 0 completes its recharge process.
- Day 3: Robot 1 starts cleaning panel 0 and panel 4.
- Day 4: Robot 1 continues cleaning panel 1.
- Day 5: Robot 0 begins cleaning panel 2 and panel 3.
- Day 6: Robot 0 completes cleaning panel 5 and panel 6.