

CS 6820  
HW 2  
Question 4

Given the inputs, we will construct a graph, get the max flow from it, and get the schedule from the max flow, which will always be admissible. We will denote the total number of days in a given problem as  $d$ .

A note: this was discussed in lecture, but we define once again that for a directed edge  $(u, v)$ ,  $u$  is the tail and  $v$  is the head.

## Graph Construction

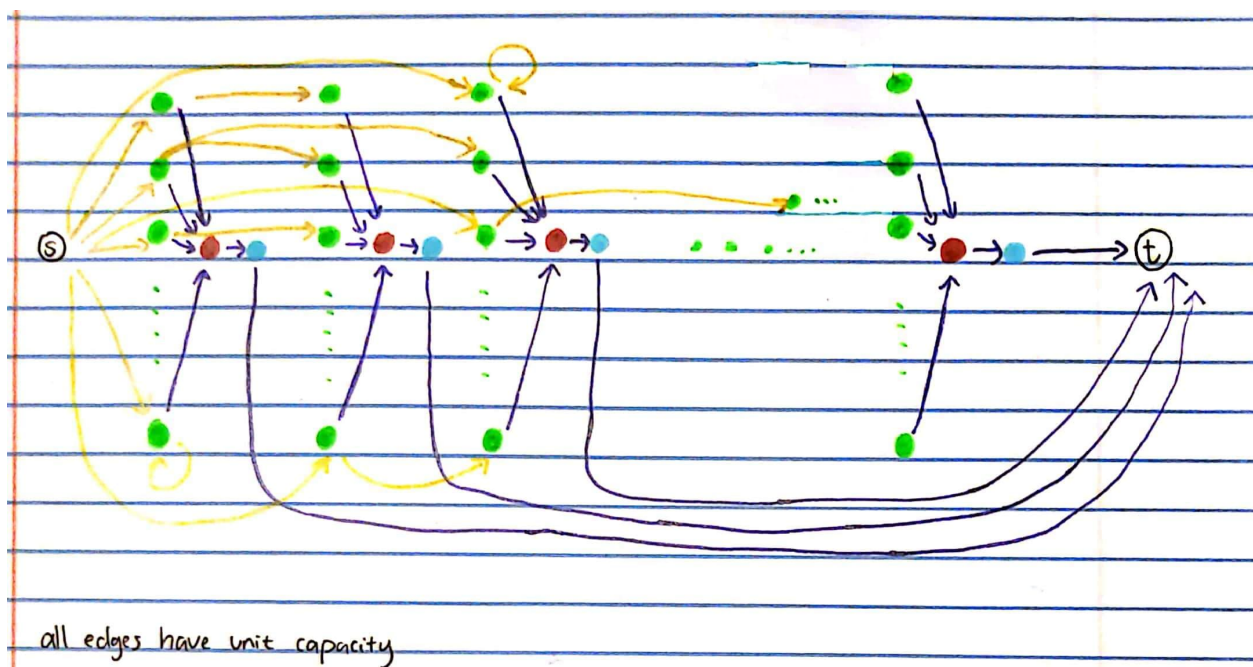


Figure 1: example abbreviated flow network

## Nodes

- Source node  $s$
- Sink node  $t$
- $nd$  "town nodes" (green); every town has a node everyday
- $d$  "day1 nodes" (red); one for each day
- $d$  "day2 nodes" (blue); one for each day

## Edges

- All edges have unit capacity
- For each day, there's an edge from the day1 to the day2 node
- For each day, there's an edge from the day2 node to the sink  $t$
- For each day, there's an edge from every town node for that day to the day1 node
- "town-town" edges, who are generated by the following algorithm
- For each unique tail  $u$  of every "town-town" edge, have a  $(s, u)$  edge (recall  $s$  is the source)

## Town-Town Edges

Before giving the exact algorithm, we discuss the idea behind town-town edges. Each town-town edge goes from an earlier day to a later or same day connecting the same town; town-town edges never connect different towns. A town-town edge only exists if the garbage accumulated between those two days (inclusive) in that town doesn't exceed 1. For every town node  $\tau$  between the endpoints of a town-town edge  $(u, v)$ , we have town-town edge  $(u, \tau)$ . Heads of town-town edges cannot be tails of town-town edges; if we term town-town edges as "intervals", then towns at the middle and ends of intervals cannot also be starts of intervals. Town-town edges that end on the last day (and the shorter edges they span) aren't included. The following is pseudocode for constructing town-town edges.

```
function construct_town-town_edges(n, d, garbage_information) {
  for town t ∈ [1, ..., n]:
    i = 1
    while day i < d:
      add edge (s, (t, i))

      find the latest possible day j that makes the garbage
        between day i and day j (inclusive) in town t not exceed 1

      if j == d:
        skip to next town in outer loop

      add edge ((t, i), (t, j))

      for day k ∈ [i+1, ..., j-1]:
        add edge ((t, i), (t, k))

      i = j+1
}
```

The reason we don't bother including town nodes within intervals that span until the last day is because each interval accumulates  $\leq 1$  units of garbage, so even if we don't collect this last interval, we're still at  $< 2$  if we collected the previous interval, which we will.

## The Algorithm

We run a max flow algorithm on this constructed flow network from  $s$  to  $t$ . To get the garbage collection schedule, we trace each saturated path  $P$  from  $s$  to  $t$ . For the last town node  $(\tau, i)$  on  $P$  (i.e. the node right before going to the day1 node), we collect garbage on day  $i$  in town  $\tau$ .

## Time Complexity

Constructing the graph is polynomial time. There are  $2 + nd + 2d$  nodes and  $nd + 2d$  non town-town edges. The time complexity for the algorithm constructing town-town edges is  $O(nd^2)$ .

The max flow algorithms we've learned are all polynomial time. Dinitz's, for example, is  $O(V^2E) = O(n^3d^4)$ .

Constructing the schedule from the max flow is also polynomial time because finding all saturated paths using DFS is polynomial time,  $O(V + E) = O(nd^2)$ , and finding the last town node on the path is constant time (fourth to last node).

## Proof of Correctness

For each town-town edge (recall we termed them "intervals"), the sequence of nodes is  $s \rightarrow (\text{town}, \text{day } i) \rightarrow (\text{town}, \text{day } j) \rightarrow \text{day1 node} \rightarrow \text{day2 node} \rightarrow t$ , where  $i \leq j < d$ . The max flow is thus exactly  **$\min(\# \text{ of unique interval starts}, d)$** .

Our algorithm procures an admissible schedule because first of all, the truck never visits more than one town per day because each day1 node has unit outgoing capacity (as does every edge in the graph), restricting the truck to only visit one town per day; and second of all, for each town's saturated intervals, the truck visits at the end of the interval, and for each pair of adjacent intervals (i.e. end of interval 1  $<$  start of interval 2

and there's no interval that starts and ends between) in a town, the most extreme case is when the truck visits at the very beginning of the first one and at the very end of the second one, but even in that case, the garbage buildup is  $< 2$  before the second visit because each of the two intervals' garbage buildup is  $\leq 1$ .

For each group of intervals that share an interval start, one of the intervals from the group has unit flow running through it. This is because each day, every town altogether produces no more than 1 unit of garbage, so overall, there is always less than  $d$  unique interval starts because we don't include intervals that *are* or are spanned *by* intervals that end on the last day.

Thus, we always have an admissible schedule.