#### **Algorithm 6** highest-label(*G*, *s*, *t*)

1: initialize preflow

2: foreach 
$$u \in V \setminus \{s, t\}$$
 do

- 3: *u.current-neighbour* ← *u.neighbour-list-head*
- 4: while  $\exists$  active node u do
- 5: select active node *u* with highest label
- 6: discharge(u)



#### Lemma 1

When using highest label the number of non-saturating pushes is only  $\mathcal{O}(n^3)$ .

A push from a node on level  $\ell$  can only "activate" nodes on levels strictly less than  $\ell.$ 

This means, after a non-saturating push from u a relabel is required to make u active again.

Hence, after n non-saturating pushes without an intermediate relabel there are no active nodes left.

Therefore, the number of non-saturating pushes is at most  $n(\#relabels + 1) = O(n^3)$ .

Since a discharge-operation is terminated by a non-saturating push this gives an upper bound of  $\mathcal{O}(n^3)$  on the number of discharge-operations.

The cost for relabels and saturating pushes can be estimated in exactly the same way as in the case of the generic push-relabel algorithm.

#### Question:

How do we find the next node for a discharge operation?



Maintain lists  $L_i$ ,  $i \in \{0, ..., 2n\}$ , where list  $L_i$  contains active nodes with label i (maintaining these lists induces only constant additional cost for every push-operation and for every relabel-operation).

After a discharge operation terminated for a node u with label k, traverse the lists  $L_k, L_{k-1}, \ldots, L_0$ , (in that order) until you find a non-empty list.

Unless the last (non-saturating) push was to s or t the list k - 1 must be non-empty (i.e., the search takes constant time).



Hence, the total time required for searching for active nodes is at most

 $\mathcal{O}(n^3) + n(\#non-saturating-pushes-to-s-or-t)$ 

#### Lemma 2

The number of non-saturating pushes to s or t is at most  $O(n^2)$ .

With this lemma we get

# **Theorem 3** The push-relabel algorithm with the rule highest-label takes time $O(n^3)$ .



13.3 Highest Label

#### Proof of the Lemma.

- ► We only show that the number of pushes to the source is at most O(n<sup>2</sup>). A similar argument holds for the target.
- After a node v (which must have ℓ(v) = n + 1) made a non-saturating push to the source there needs to be another node whose label is increased from ≤ n + 1 to n + 2 before v can become active again.
- This happens for every push that v makes to the source. Since, every node can pass the threshold n + 2 at most once, v can make at most n pushes to the source.
- As this holds for every node the total number of pushes to the source is at most  $\mathcal{O}(n^2)$ .

