

# Overview: Shortest Augmenting Paths

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*The length of the shortest augmenting path never decreases.*

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*After at most  $\mathcal{O}(m)$  augmentations, the length of the shortest augmenting path strictly increases.*

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These two lemmas give the following theorem:

## Theorem 3

*The shortest augmenting path algorithm performs at most  $\mathcal{O}(mn)$  augmentations. This gives a running time of  $\mathcal{O}(m^2n)$ .*

## Proof.

We can find the shortest augmenting paths in time  $\mathcal{O}(m)$ .

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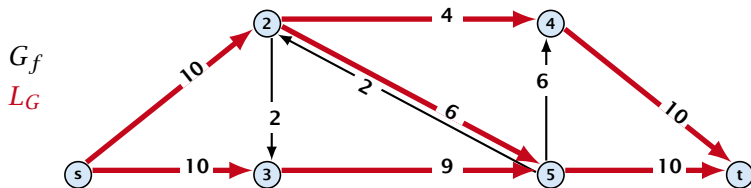
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In the following we assume that the residual graph  $G_f$  does not contain zero capacity edges.

This means, we construct it in the usual sense and then delete edges of zero capacity.

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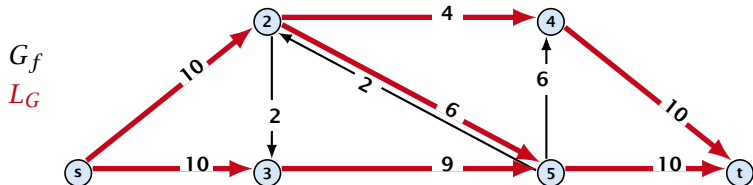
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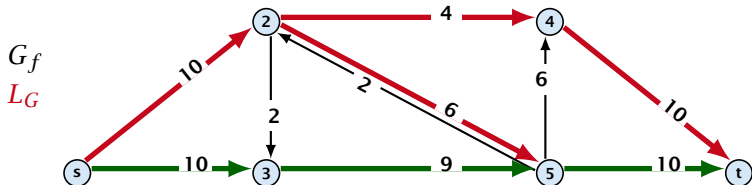
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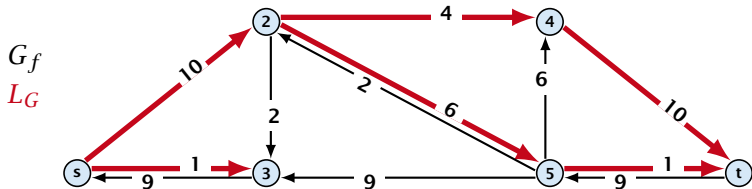
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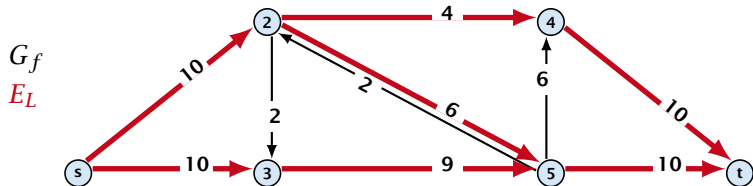
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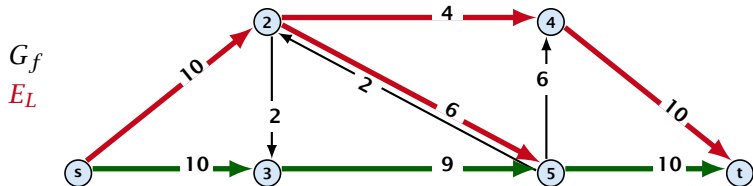
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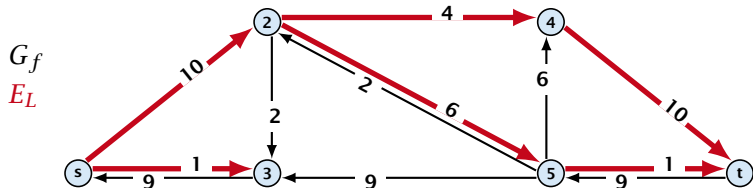
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## Theorem 4

*The shortest augmenting path algorithm performs at most  $\mathcal{O}(mn)$  augmentations. Each augmentation can be performed in time  $\mathcal{O}(m)$ .*

## Theorem 5 (without proof)

*There exist networks with  $m = \Theta(n^2)$  that require  $\mathcal{O}(mn)$  augmentations, when we restrict ourselves to only augment along shortest augmenting paths.*

## Note:

There always exists a set of  $m$  augmentations that gives a maximum flow.

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When sticking to shortest augmenting paths we cannot improve (asymptotically) on the number of augmentations.

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We maintain a subset  $E_L$  of the edges of  $G_f$  with the guarantee that a shortest  $s$ - $t$  path using only edges from  $E_L$  is a shortest augmenting path.

With each augmentation some edges are deleted from  $E_L$ .

When  $E_L$  does not contain an  $s$ - $t$  path anymore the distance between  $s$  and  $t$  strictly increases.

Note that  $E_L$  is not the set of edges of the level graph but a subset of level-graph edges.



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$E_L$  is initialized as the level graph  $L_G$ .

Perform a **DFS search** to find a path from  $s$  to  $t$  using edges from  $E_L$ .

Either you find  $t$  after at most  $n$  steps, or you end at a node  $v$  that does not have any outgoing edges.

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Let a phase of the algorithm be defined by the time between two augmentations during which the distance between  $s$  and  $t$  strictly increases.

Initializing  $E_L$  for the phase takes time  $\mathcal{O}(m)$ .

The total cost for searching for augmenting paths during a phase is at most  $\mathcal{O}(mn)$ , since every search (successful (i.e., reaching  $t$ ) or unsuccessful) decreases the number of edges in  $E_L$  and takes time  $\mathcal{O}(n)$ .

The total cost for performing an augmentation during a phase is only  $\mathcal{O}(n)$ . For every edge in the augmenting path one has to update the residual graph  $G_f$  and has to check whether the edge is still in  $E_L$  for the next search.

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