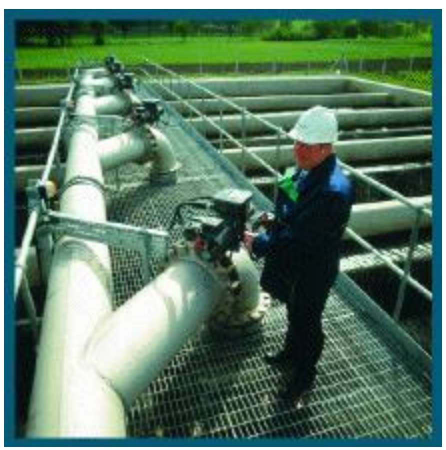
# CSE 417
# Algorithms and Complexity

Lecture 22

Network Flow, Part 1

# Network Flow

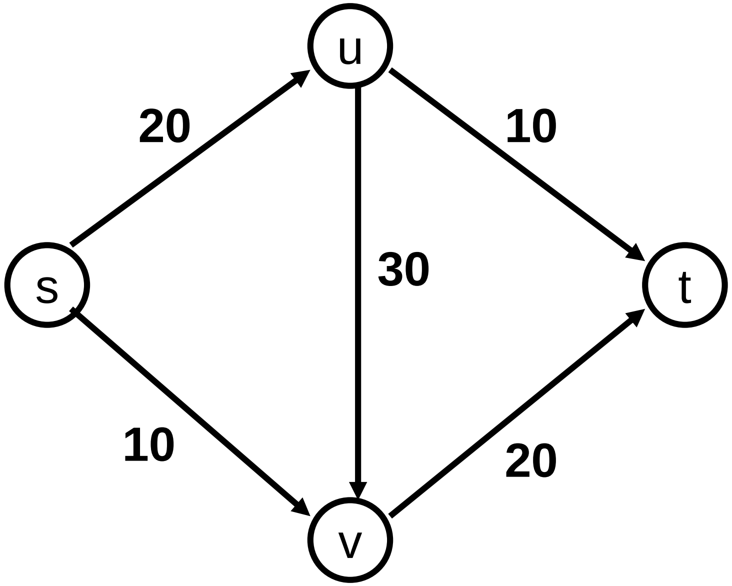
# Outline

- Network flow definitions
- Flow examples
- Augmenting Paths
- Residual Graph
- Ford Fulkerson Algorithm
- Cuts
- Maxflow-MinCut Theorem

# Network Flow Definitions

- Capacity
- Source, Sink
- Capacity Condition
- Conservation Condition
- Value of a flow

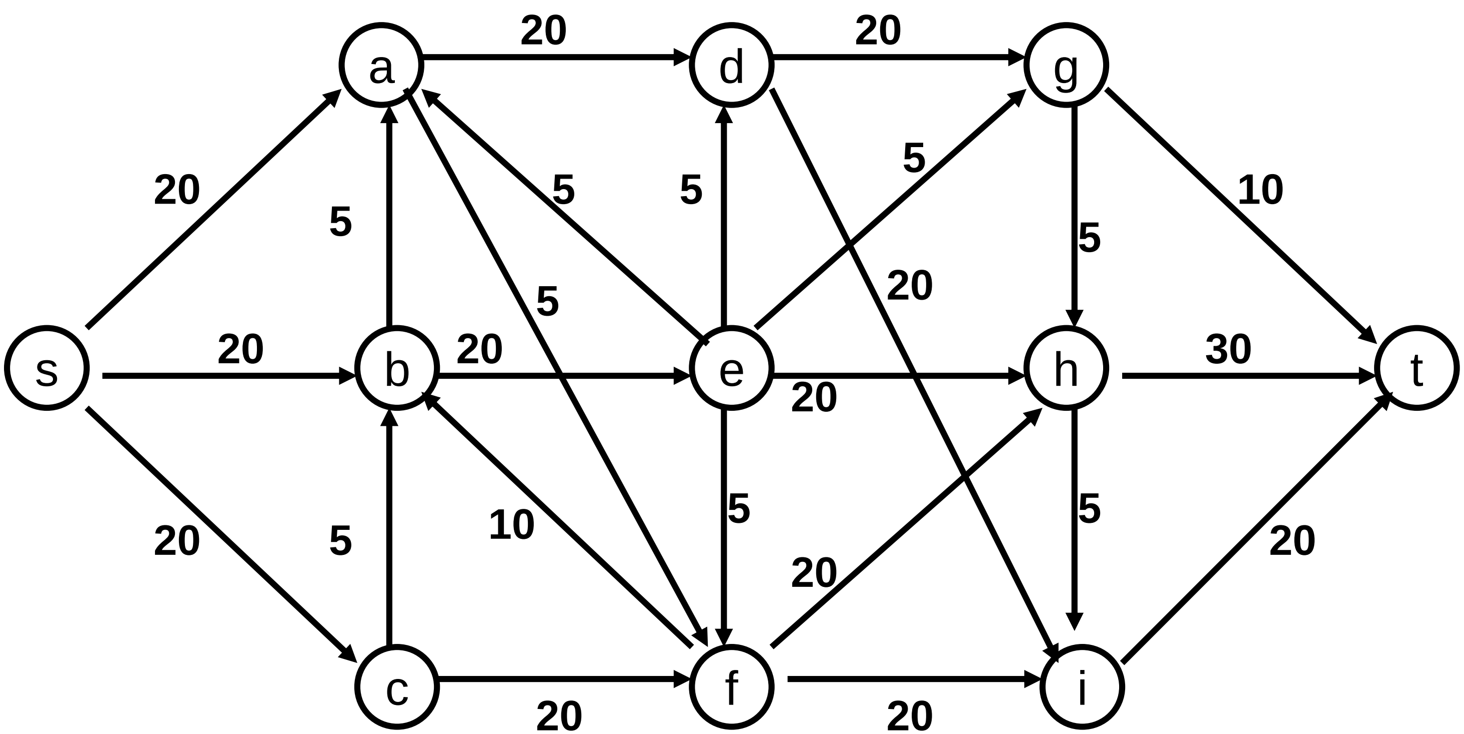
# Flow Example



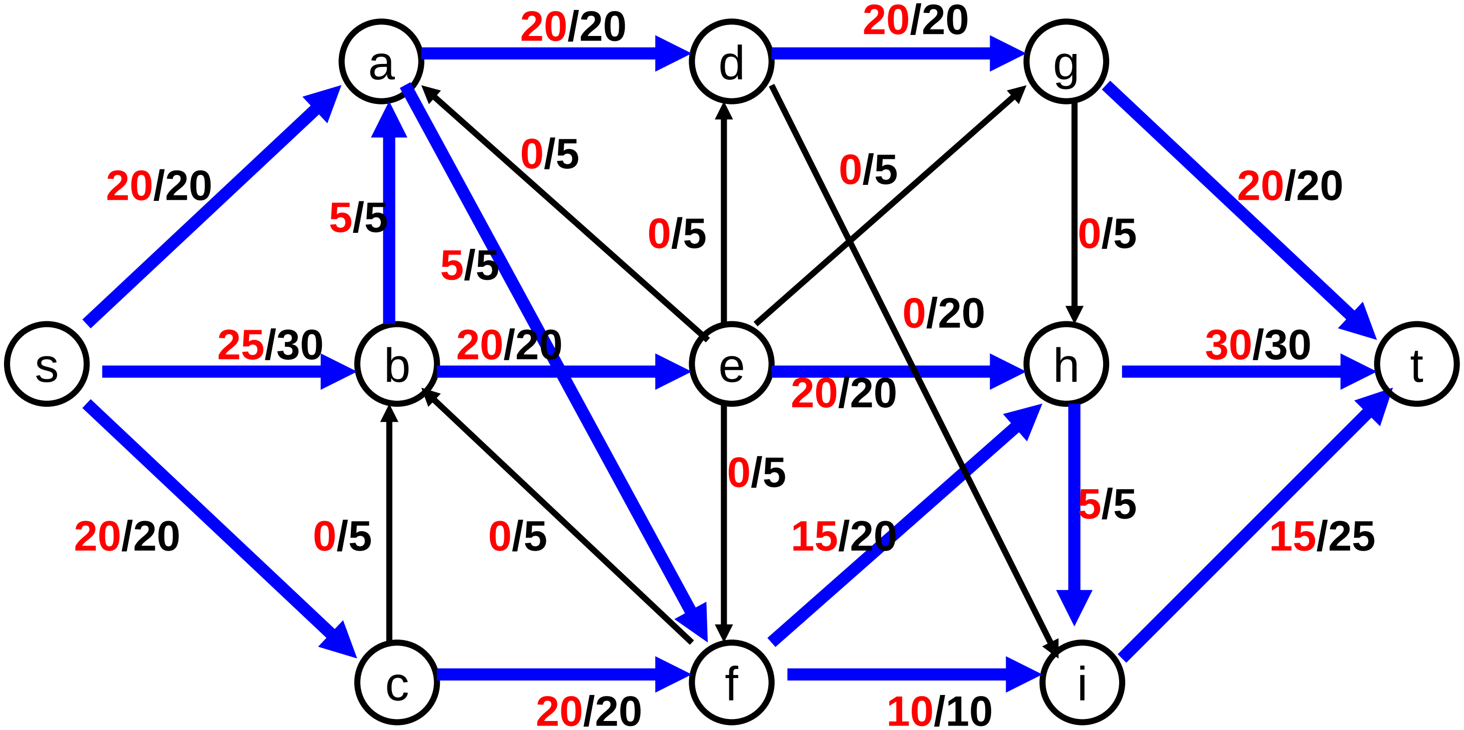
# Network Flow Definitions

- Flowgraph: Directed graph with distinguished vertices s (source) and t (sink)
- Capacities on the edges, c(e) >= 0
- Problem, assign flows f(e) to the edges such that:
  - 0 <= f(e) <= c(e)
  - Flow is conserved at vertices other than s and t
    - Flow conservation: flow going into a vertex equals the flow going out
  - The flow leaving the source is a large as possible

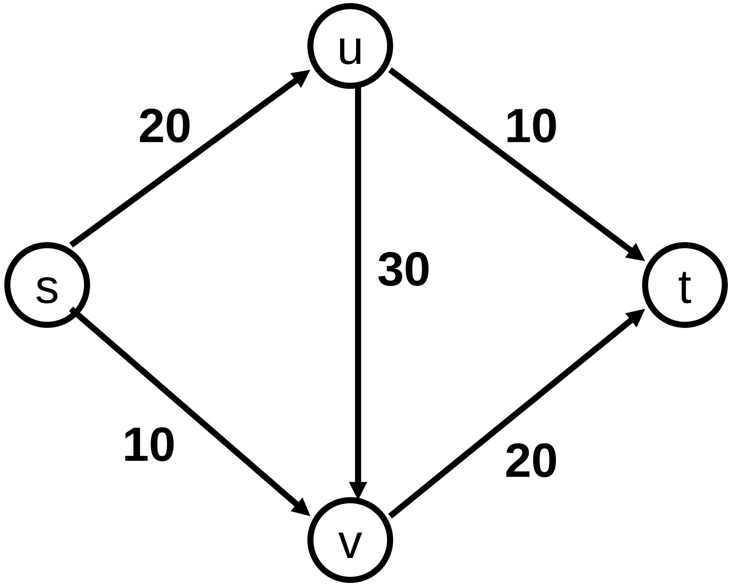
# Flow Example

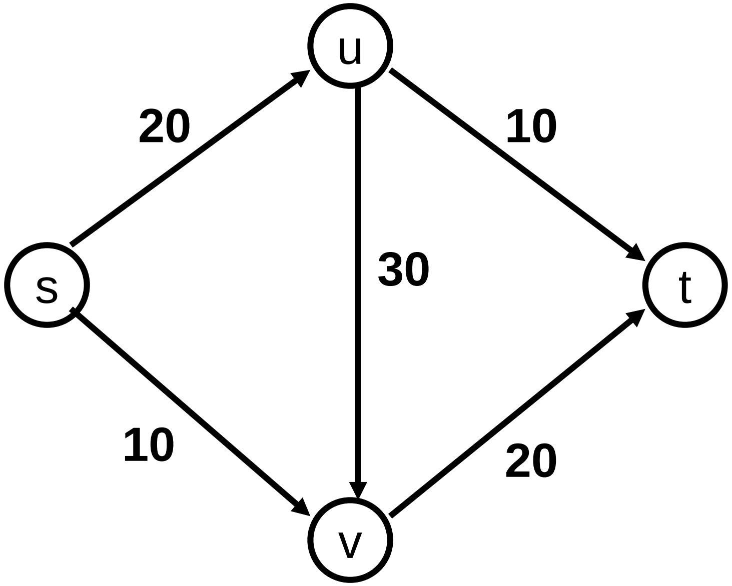


# Find a maximum flow



# Flow Example

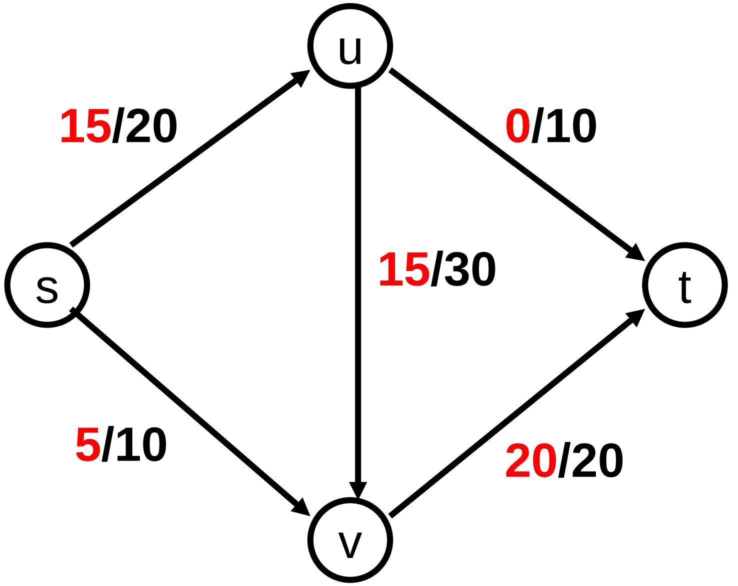


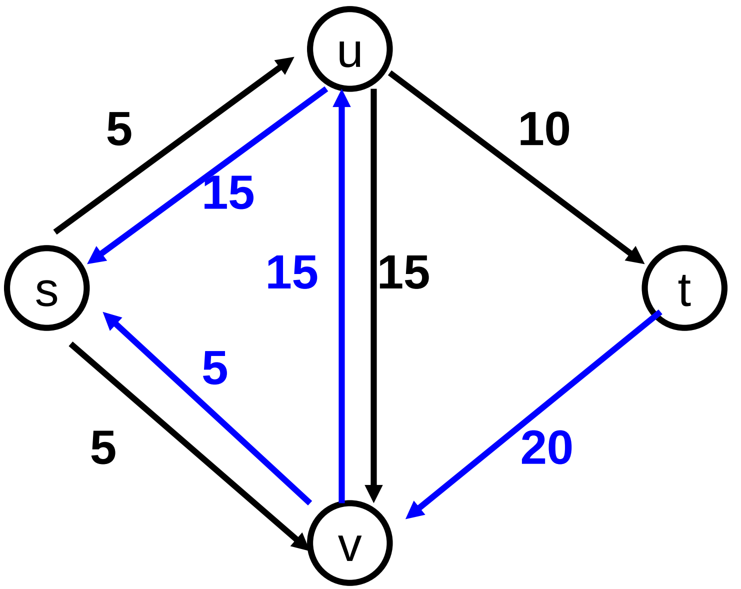



# Residual Graph

- Flow graph showing the remaining capacity
- Flow graph G,  Residual Graph $G_R$
  - G: edge e from u to v with capacity c and flow f
  - $G_R$: edge e’ from u to v with capacity c – f
  - $G_R$: edge e’’ from v to u with capacity f

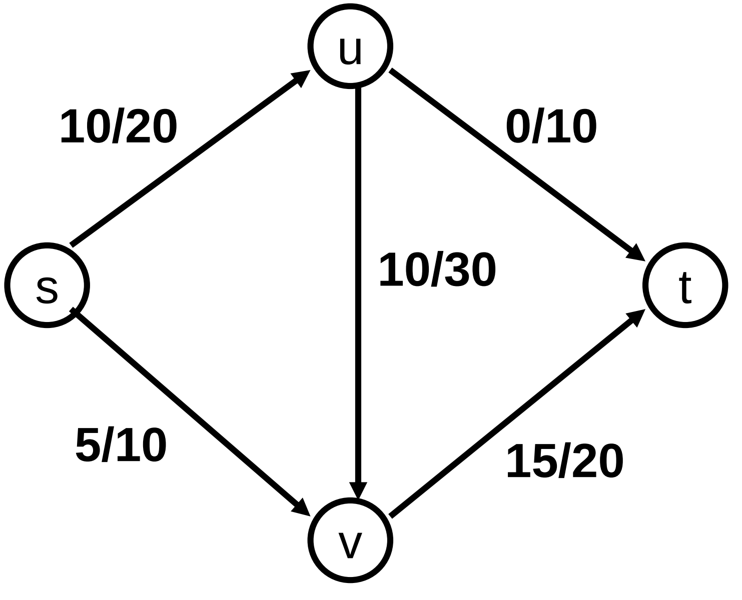
# Flow assignment and the residual graph



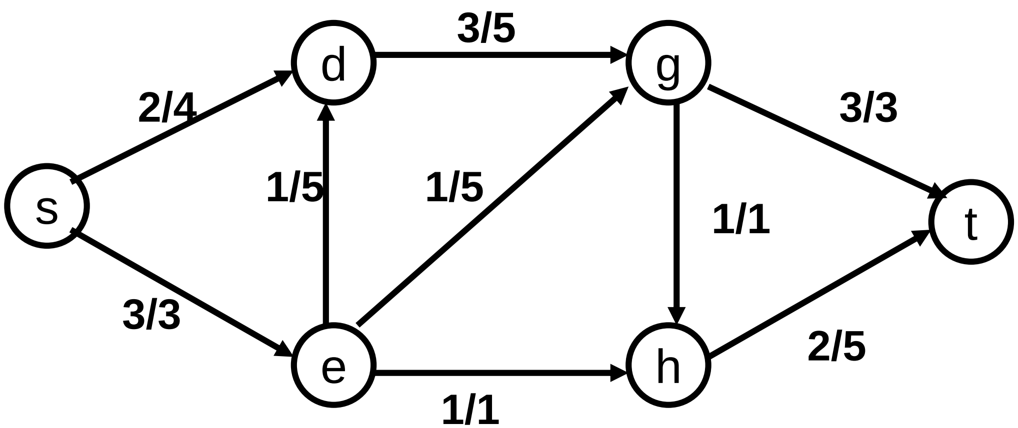



# Augmenting Path Algorithm

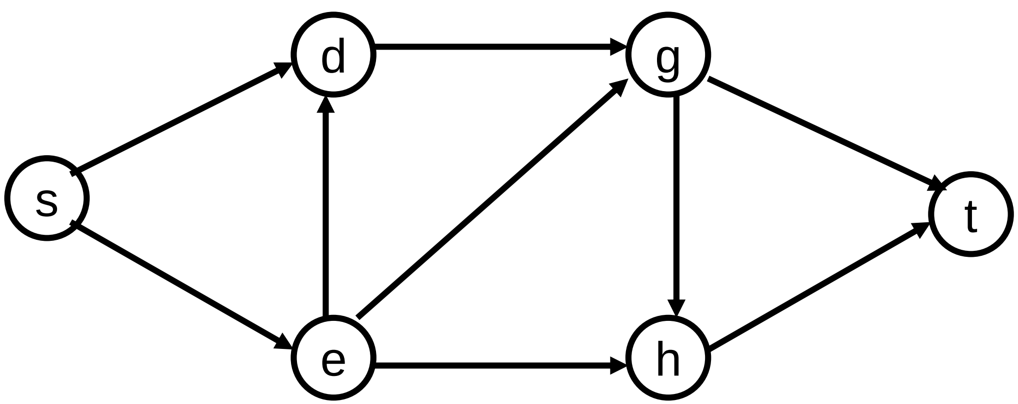
- Augmenting path
  - Vertices $v_1, v_2, \ldots, v_k$
    - $v_1 = s$, $v_k = t$
    - Possible to add b units of flow between $v_j$ and $v_{j+1}$ for j = 1 … k-1



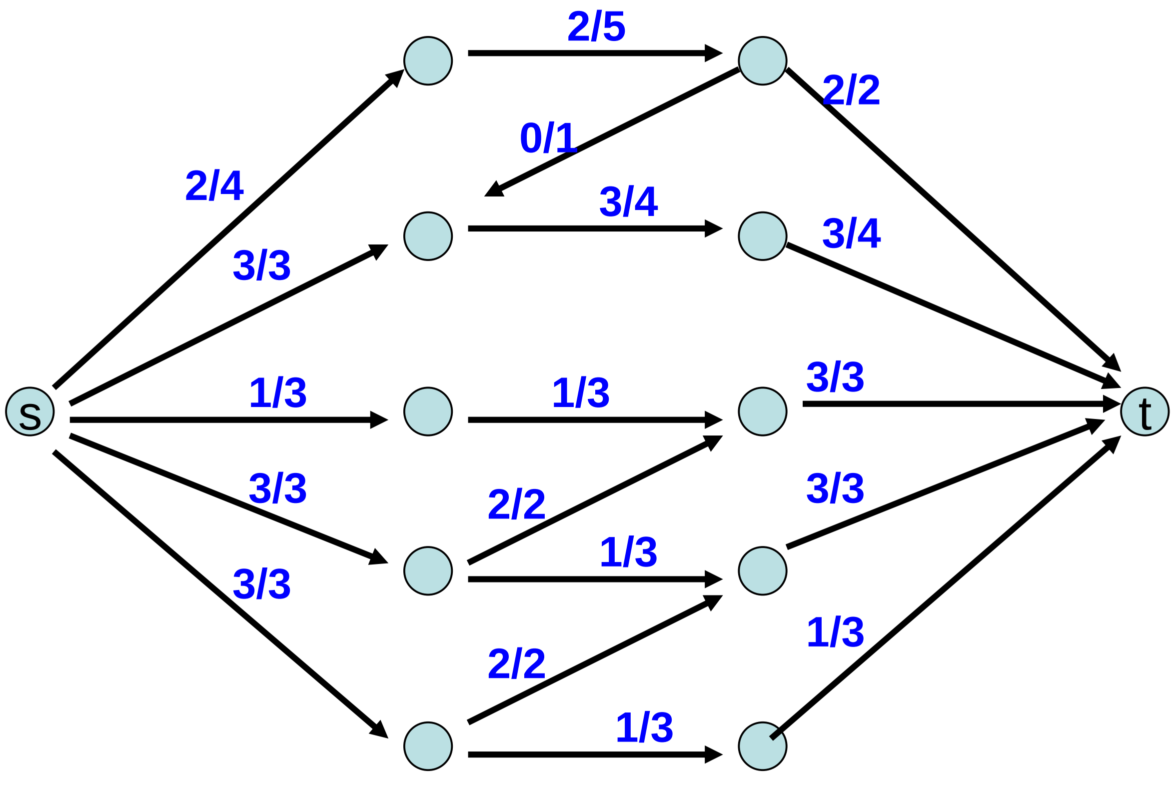
# Build the residual graph




Residual graph:

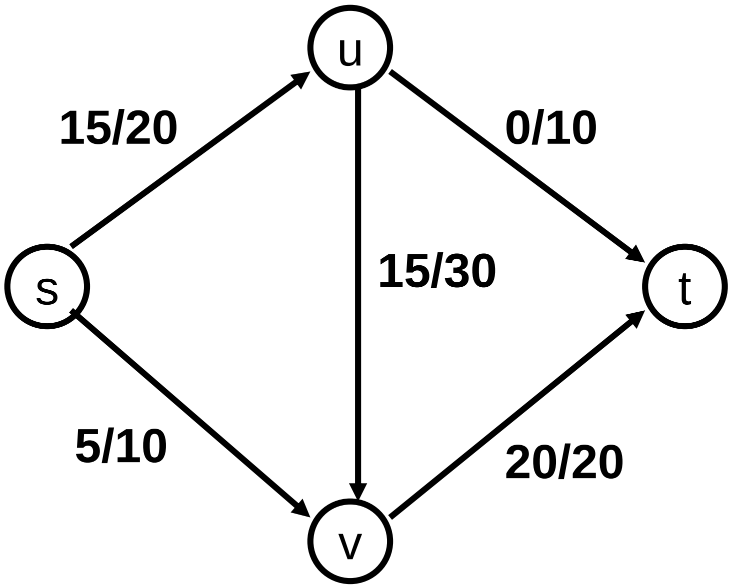


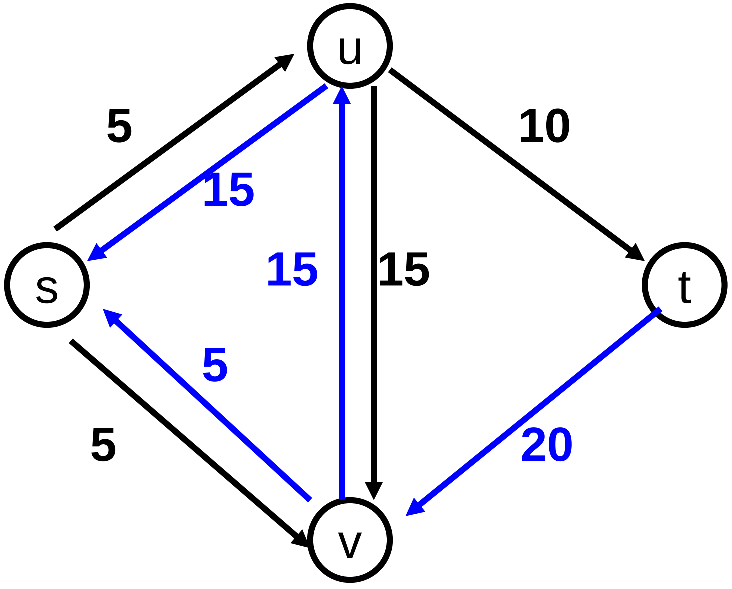
# Find two augmenting paths



# Augmenting Path Lemma

- Let P = $v_1, v_2, \ldots, v_k$ be a path from s to t with minimum capacity b in the residual graph.
- b units of flow can be added along the path P in the flow graph.



# Proof

- Add b units of flow along the path P
- What do we need to verify to show we have a valid flow after we do this?
  - 
  - 

# Ford-Fulkerson Algorithm (1956)

while not done

Construct residual graph $G_R$

Find an s-t path P in $G_R$ with capacity $b > 0$

Add b units along in G

If the sum of the capacities of edges leaving S is at most C, then the algorithm takes at most C iterations