CSC373 Worksheet 5 Solution

August 9, 2020

1. *Proof.* Assume that a flow network $G = (V, E)$ violates the assumption that the network contains a path $s \rightsquigarrow v \rightsquigarrow t$ for all vertices $v \in V$. Let u be a vertex for which there is no path $s \rightsquigarrow u \rightsquigarrow t$.

   I must show such that there is no flow at vertex u. That is, there exists a maximum flow f in G such that $f(u, v) = f(v, u) = 0$ for all vertices $v \in V$.

   Assume for the sake of contradiction that there is some vertex u with flow f. That is, there exists some vertices $v \in V$ such that $f(u, v) > 0$ or $f(v, u) > 0$.

   I see that three cases follows, and I will prove each separately.

   1. **Cases 1:** $f(u, v) = 0$ and $f(v, u) > 0$

      Here, assume that $f(u, v) = 0$ for all $v \in V$ and $f(v, u) > 0$ for some $v \in V$.

      Then, we can write $\sum\limits_{v \in V} f(u, v) = 0$ and $\sum\limits_{v \in V} f(v, u) > 0$

      But this violates the flow conservation property (i.e $\sum\limits_{v \in V} f(u, v) = \sum\limits_{v \in V} f(v, u)$)

      Thus, by proof by contradiction, $f(u, v) = 0$ and $f(v, u) = 0$ for all $v \in V$ and all $u \in V$ with no path $s \rightsquigarrow u \rightsquigarrow t$.

   2. **Cases 2:** $f(u, v) > 0$ and $f(v, u) = 0$

      Here, assume that $f(u, v) > 0$ for some $v \in V$ and $f(v, u) = 0$ for all $v \in V$.

      Then, by similar work as case 1, the same result follows.

3. **Cases 3:** $f(u, v) > 0$ and $f(v, u) > 0$

   Here, assume that $f(u, v) > 0$ and $f(v, u) > 0$ for some $v \in V$.

   Since $s \rightsquigarrow v \rightsquigarrow t$ and u is connected by some vertices v, we can write $s \rightsquigarrow u \rightsquigarrow t$.

   Then, this violates the fact in header that the vertex u has no path $s \rightsquigarrow u \rightsquigarrow t$.

   Thus, by proof by contradiction, $f(u, v) = 0$ and $f(v, u) = 0$ for all $v \in V$ and all $u \in V$ with no path $s \rightsquigarrow u \rightsquigarrow t$.

   □

Notes
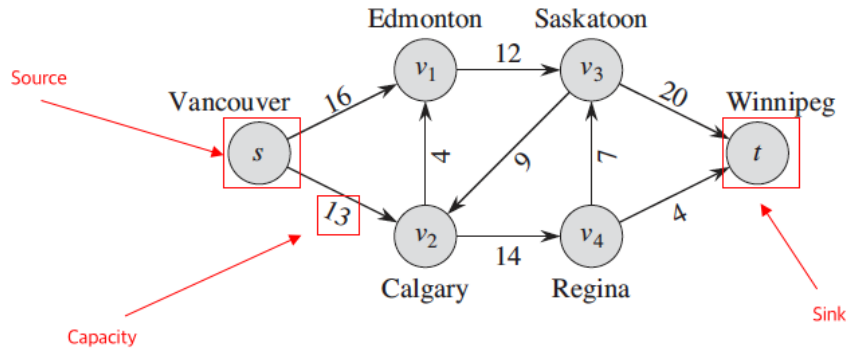
- **Maximum Flow:**
  - Finds a flow of maximum value [1]

    Example

    Here, the maximum flow is $10 + 5 + 13 = 28$

- **Flow Network:**
  - $G = (V, E)$ is a directed graph in which each edge $(u, v) \in E$ has a nonnegative capacity $c(u, v) \geq 0$.
  - Two vertices must exist: **source** s and **sink** t
  - **path** from source s to vertax v to sink t is represented by $s \rightsquigarrow v \rightsquigarrow t$

- **Capacity:**

  - Is a non-negative function $f : V \times V \to \mathbb{R}_{\geq 0}$
  - Has **capacity constraint** where for all $u, v \in V$ $0 \leq f(u,v) \leq c(u,v)$
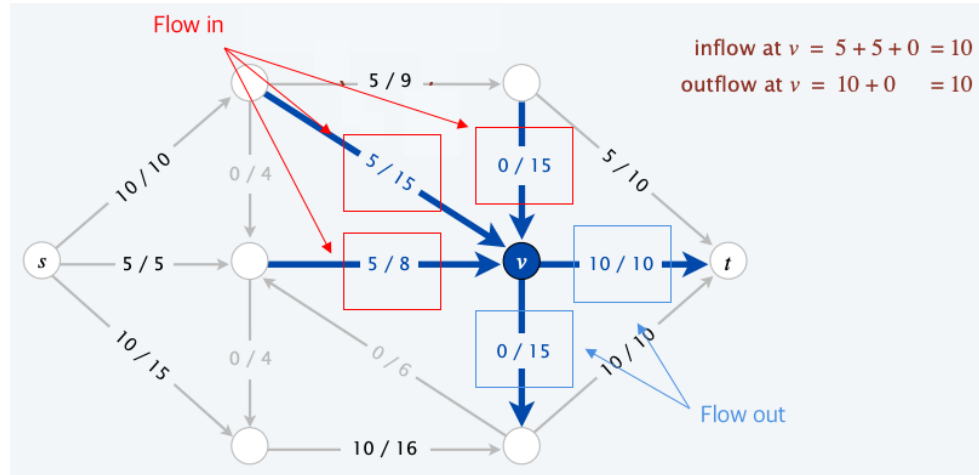   * Means flow cannot be above capacity constraint

- **Flow:**

  - Is a real valued function $f : V \times V \to \mathbb{R}$ in G
  - Satisfies **capacity constraint** (i.e for all $u, v \in V$, $0 \leq f(u,v) \leq c(u,v)$)
  - Satisfies **flow conservation**

  For all $u \in V - \{s, t\}$, we require

  $$\sum_{v \in V} f(v, u) = \sum_{v \in V} f(u, v) \tag{1}$$

  Means flow into vertex u is the same as flow going out of vertex u. [1]
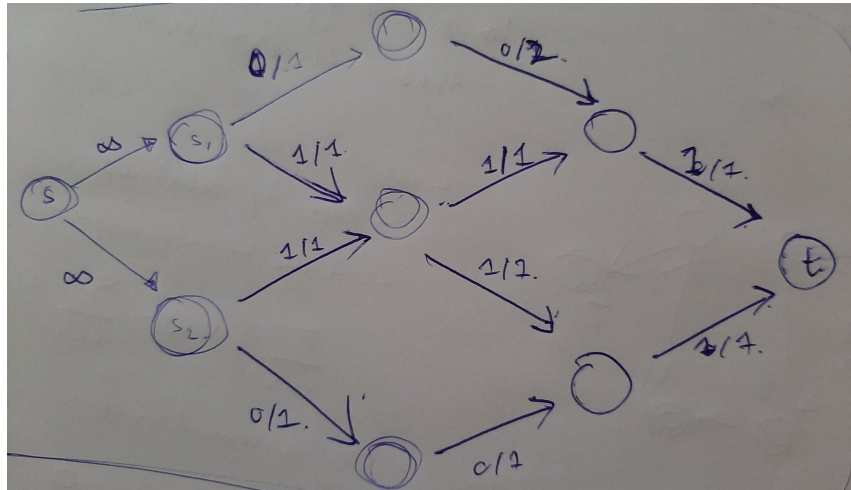
  Example:

References

1) Princeton University, Network Flow 1, link

2. I need to formulate the problem of determining whether both of professor Adam's two children can go to the same school as maximum-flow problem.

The problem statement tells us the following:

1. There is 1 supersource (location of home)
2. There is 1 sink (location of school)
3. There are two sources (s_1 as child 1, s_2 as child 2)
4. Edge (u, v) has capacity of 0 or more (0 representing unavailable sidewalk, 1 for sidewalk with capacity of 1, 2 for street with capacity of 2 and so on)
5. Each vertex represents corner of intersection, and two children can have their paths crossing here.
6. Has flow of 2, 1 or 0 (1 is where one of the two children walking on the road. 0 is none.)

Here we are to find whether children must go on to a vertex and out to the same edge with the flow of 2, or determine whether there is only edge to school with capacity of 1 or less.
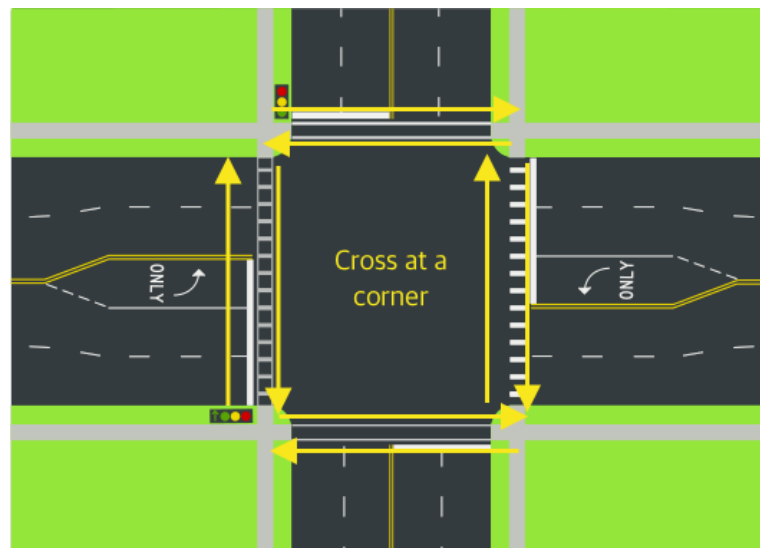
If none, then both children can safely go to school.

Notes:

- **Cross at a Corner**
  - Means to walk across the street at a corner of the intersection.

- **Multiple Sources and Sinks**
  - Has edges (s, s_i) where $i = 1...n$ and (t_j, t) where $j = 1...n$ with capacity of ∞

Example:

Lucky Puck Company having a set of m factories $\{s_1, s_2, ..., s_m\}$, and a set of n warehourses and n warehouses $\{t_1, t_2, ..., t_n\}$

Sources (factories)

Supersource (factory location)

Sinks (warehouses)

Supersink (warhouse location)

These two are the same

3. I need to show how to transform a flow network $G = (V, E)$ with vertex capacities into an equivalent flow network $G' = (V', E')$ without vertex capacities.

For each vertex capacities, change as follows.

After transformation, there will be m more edges and verticies, where m represents the number of vertex capacities in G.

Notes:

- **Vertex Capacities**
  - Each vertex v has limit $l(v)$ on how much flow can pass through v

4. <u>**Notes:**</u>

- **Ford-Fulkerson Method**
  - Is a greedy algorithm that solves the maximum-flow problem
    * Detects maximum flow from start vertex to sink vertex in a graph
  - Called method (not algorithm) because several different implementations with different running time is used

FORD-FULKERSON-METHOD (G, s, t)

1 initialize flow f to 0
2 **while** there exists an augmenting path p in the residual network G_f
3   augment flow f along p
4 **return** f

- **Residual Graph**
  1) **Flow = Capacity:** Opposite arrow