

# Appendix A

## Proofs of Theorems

### A.1 Proof of Theorems in section 7.2

*Proof.* (Theorem 7.1) Consider a connected network of  $n$  nodes. If every node is connected to all remaining nodes, then any node will connect  $(n - 1)$  other nodes. For best case, if network is divided into  $n$  communities, all connections will be external connection to community. Thus, there will be  $(n - 1)$  external connections for each community. For any pair of communities Unifiability will be  $\frac{1}{(n-1)+(n-1)-1} = \frac{1}{2n-3}$ . Since, each node represents a community so there will be  $(n - 1)$  pair of communities which can unify with any community. Hence, total Unifiability for any community will be  $(n - 1) \times \frac{1}{2n-3}$ . Total Unifiability of the community structure will be  $n \times \frac{n-1}{2n-3}$ . Since, network contains  $n$  communities so AVU will be  $\frac{1}{n} \times n \times \frac{n-1}{2n-3} = \frac{n-1}{2n-3}$ .

Since, Unifiability is the measure of ability of a community to unify with other communities, there has to be at least two communities. Therefore, in AVU measure  $\frac{n-1}{2n-3}$  the value of  $n - 1 \geq 1$  since  $n \geq 2$ . Again for  $n \geq 2$ ,  $(n - 1) \geq 1 \Rightarrow (2n - 3) \geq 1$  and

$(2n - 3) \geq (n + 1)$ . For all  $n \geq 2$ ,  $(n + 1) > (n - 1)$  so  $(2n - 3) \geq (n - 1)$ . Now, by property of ratio  $\frac{n-1}{2n-3} \leq 1$ .

Worst case for AVU can only happen in community structure of any connected network, when there is no direct connection between two communities. This can happen only when communities are connected either in the form of star graph or circular graph. Since, in Unifiability there has no role of internal connections of the community so we can assume each community as nodes. Since, the graph is connected, even though there is no direct connection with any community it will be connected via some other communities. That means in worst-case scenario also any community will have at least one external connection, with which it maintains connectivity with rest of the network. Hence, Unifiability of such community pair  $(A, B)$  will be  $\frac{0}{1+1+0} = 0$ . Let,  $C$  be the community via whom community  $A$  and  $B$  are connected. Unifiability of  $A$  and  $C$  will be at least  $\frac{1}{1+2-1} = 1/2 > 0$ . Hence, in worst case also  $A$ 's Unifiability with all communities will be greater than 0. This implies AVU will always be greater than 0 for with at least two communities.

It is clear with the definition of Unifiability that at least two communities are required to measure AVU of community structure. However, sometimes algorithm identifies single community for entire network. In that case, there is nothing left for the community to unify since the community itself has included entire network into it. Thus, it is quite intuitive to acknowledge that Unifiability of the community would be zero. Therefore, even though by definition Unifiability cannot be measured we suggest to use the value 0 for AVU when there is only one community in the community structure.  $\square$

*Proof.* (Theorem 7.2) Consider a connected network of  $n$  nodes. If every node is connected to all remaining nodes in the network, then maximum  $\frac{n \times (n-1)}{2}$  numbers of connections are possible (Excluding self-loops and multiple connections between two nodes).

For worst case,  $n$  communities will form i.e. each node represents a community. Isolability of each community will be 0 and AVI will also have value 0. For the best case, entire network will be in a single community. Since, every node is connected to all remaining nodes, total internal connection will be  $\frac{n \times (n-1)}{2}$  and external connection will be 0. Therefore, Isolability of community will be  $\frac{\frac{n \times (n-1)}{2}}{\frac{n \times (n-1)}{2} + 0} = \frac{n-1}{n-1} = 1$ . If network contains  $x$  self-loops and  $y$  parallel connections between two nodes, then Isolability of community will be  $\frac{\frac{n \times (n-1)}{2} + x + y}{\frac{n \times (n-1)}{2} + x + y + 0} = 1$ . Since, network contains only one community so AVI will also be 1. Hence, for a connected network AVI will always lie in between 0 and 1.  $\square$

*Proof.* (Theorem 7.3) In connected network, AVU can attain value 1 when only two communities are there. In that case, AVI will always less than 1 because the network is connected. There has to be at least one connection between nodes of two communities so numerator will always less than denominator in Isolability. Again, AVI can attain value 1 when there is only one community. In that case, AVU cannot be measured since to measure Unifiability requires at least two community. For single community, entire network is included into one community so there is nothing left to unify with the community. Thus, logically measuring AVU does not arises for single community, instead assign value 0 as explained above. Thus, both AVI and AVU cannot attain value 1 at the same time. Nevertheless, both can attain value 1 in different cases.  $\square$

*Proof.* (Theorem 7.4) In the Equation 7.9, numerator is  $2 \times AVI$  can have value 0, since AVI can attain value 0 as shown in the Theorem 7.2. Thus, AUI can also attain value 0. The numerator can have maximum value 2 when AVI have value 1. When AVI have value we consider value 0 for AVU so denominator will have value 1. Therefore, AUI will have value 2. In all other cases, the value will be less than 2 and greater than 0.  $\square$

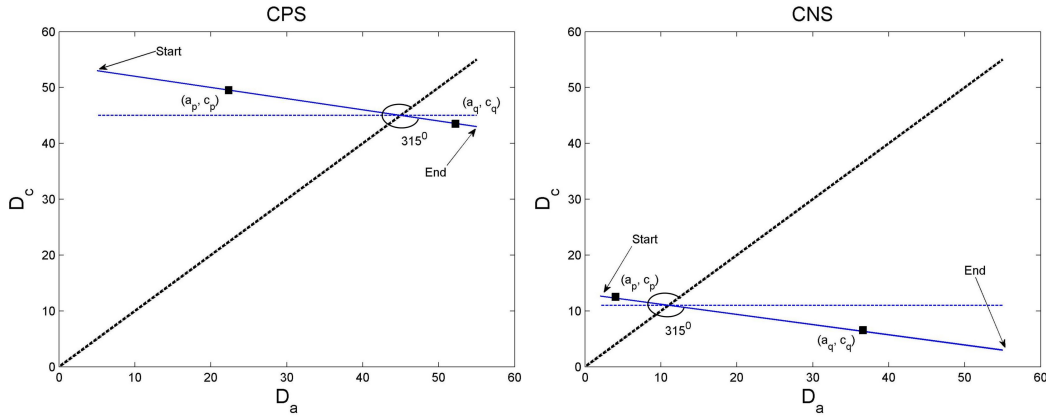


Figure A.1: Angular displacement in CPS and CNS.

The Start and End indicate the starting and ending point of regression line respectively.

Coordinates of points  $p$  and  $q$  are  $(a_p, c_p)$  and  $(a_q, c_q)$  respectively.

## A.2 Proof of Theorems in section 7.4

*Proof.* (Theorem 7.8) Let us consider a RL that has angle less than 315 degree with the NL for the purpose of contradiction. Note that when the angle between RL and NL is 315 degree, at this time RL is parallel to y-axis as shown in Figure A.1. Now, consider two points  $p$  and  $q$  in the RL above and below the intersecting point on NL. It is clear that for these two points, the conditions  $\{a_p < c_p\}$ ,  $\{a_q > c_p\}$ ,  $\{c_p > c_q\}$  and  $\{a_p < a_q\}$  are satisfied. We have plotted  $D_a$  and  $D_c$  which are sorted in increasing order. Therefore, the condition  $c_p > c_q$  contradicts, as in an increasing ordered list  $D_c = c_1, c_2, \dots, c_r$  it is not possible to have an ordered pair  $(c_i, c_j)$  such that  $c_i > c_j$  and  $i < j$ . The RL represents the dominance relationship between  $D_a$  and  $D_c$ . Hence, if any point in the RL has to satisfy  $c_p > c_q$ , it implies that there has to be some points  $(a_i, c_i)$  and  $(a_j, c_j)$  where we have a pair  $(c_i, c_j)$  such that  $c_i > c_j$  and  $i < j$ . Which is a contradiction. Hence, it is proved that for CPS or CNS angle between RL and NL always greater than 315 degree.  $\square$

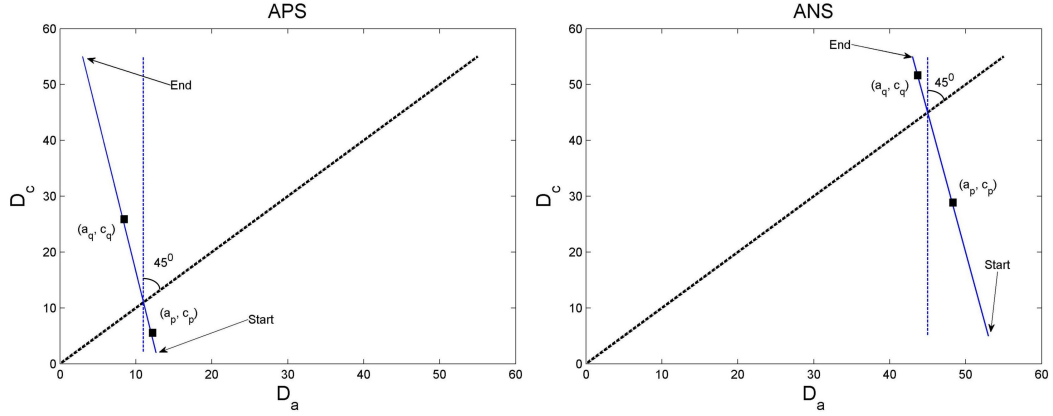


Figure A.2: Angular displacement in APS and ANS.

Start and End indicates starting and ending point of regression line respectively. Coordinates of points  $p$  and  $q$  are  $(a_p, c_p)$  and  $(a_q, c_q)$  respectively.

*Proof.* (Theorem 7.9) Let us consider a RL that has angle greater than 45 degree with NL. Note that when angle between RL and NL is 45 degree, at this time the RL is parallel to x-axis as shown in Figure A.2. Now, consider two point  $p$  and  $q$  in the RL below and above the intersecting point in NL. It is clear that for these two points, the conditions  $\{a_p > c_p\}$ ,  $\{a_q < c_p\}$ ,  $\{c_p < c_q\}$  and  $\{a_p > a_q\}$  are satisfied. Similar to Theorem 7.8, it can be shown that the condition  $a_p > a_q$  contradicts. If any point in the RL has to satisfy  $a_p > a_q$ , it implies that there has to be some points  $(a_i, c_i)$  and  $(a_j, c_j)$  where we have a pair  $(a_i, a_j)$  such that  $a_i > a_j$  and  $i < j$ . Hence, it is proved that for APS or ANS angle between RL and NL angle less than 45 degree.  $\square$

*Proof.* (Theorem 7.10) Using the Theorem 7.8, it is clear that the RL can attain maximum angle of 360 degree up to minimum angle of 315 degree and which takes place in 4<sup>th</sup> quadrant with respect to NL. Thus, maximum possible rotation would be  $360 - 315 = 45$  degree. Similarly from Theorem 7.9, it is also clear that maximum possible rotation would be 45 degree i.e. in 1<sup>st</sup> quadrant, as the RL rotates from 0 degree to 45 degree with respect

to NL. Hence, we have 45 degree in 1<sup>st</sup> and 45 degree in 4<sup>th</sup> quadrant totaling 90 degree shift of RL.  $\square$

### A.3 Proof of Theorems in section 7.5

*Proof.* (Theorem 7.17) For any graph  $G = (V, E)$ , isomorphic graph  $f(G)$  implies  $f(u) = u'$  such that  $u \in V$  and  $u' \in V$ . Thus, any connection  $(u, v) \in E$  will change to  $(u', v')$  such that  $(f^{-1}(u'), f^{-1}(v')) \in E$ . Since connection identity has changed with nodes in  $f(G)$ , not the strength of the connection so  $\delta(u, v) = \delta(u', v')$ . For any community  $C_i \in C$  of  $G$ , if  $u \in C_i$   $v$  then  $u' \in C'_i$   $v'$  for isomorphic graph  $f(G)$  where  $C'_i \in f(C)$ ,  $u \mapsto u'$  and  $v \mapsto v'$ . Thus, associated internal connection  $(u, v)$  remains internal to  $C'_i$  for  $f(G)$ . Hence, total internal connection strength of  $C'_i \in f(C)$  remains same as  $C_i \in C$ . Similarly, it can be shown that total external strength of  $C_i$  also remains same.

Isolability and Unifiability are independent measures for all communities. Both depends on connection strength which remains unaltered with isomorphism. Thus for all isomorphisms of a graph, Isolability and Unifiability remains unaffected. Since individual Isolability and Unifiability of communities are independent measures, mean will also follow the same. Therefore,  $Q_{AVI}(G, C) = Q_{AVI}(f(G), f(C))$  and  $Q_{AVU}(G, C) = Q_{AVU}(f(G), f(C))$  i.e. AVI and AVU are permutation invariant. Since, ANUI is just harmonic mean of AVI and 1/AVU so it will also be permutation invariant.  $\square$

*Proof.* (Theorem 7.18) Consider any two community structures  $C$  and  $D$  of  $G = (V, E)$ . Let, any arbitrary connection  $(u, v) \in E$ . Isolability is a ratio of connection strengths. This particular connection  $(u, v)$  either contributes to numerator or denominator of the ratio. Depending on the contribution of  $\delta(u, v)$  to Isolability for community structures  $C$  and  $D$  arise following possibilities. (i)  $\delta(u, v)$  contributes to denominator for  $C$  and numerator

for  $D$ , (ii)  $\delta(u, v)$  contributes to numerator for  $C$  and denominator for  $D$ , (iii)  $\delta(u, v)$  contributes to denominator for both  $C$  and  $D$ , and (iv)  $\delta(u, v)$  contributes to numerator for both  $C$  and  $D$ .

For case (i),  $\delta(u, v)$  contributes to denominator for  $C$  and numerator for  $D$  means connection  $(u, v)$  is an external connection in  $C$  and an internal to any community  $D_i \in D$ . Suppose,  $Q_{AVI}(G, C) = Q_{AVI}(G, D)$  before addition of  $\delta(u, v)$ . Thus, the contribution of all such  $\delta(u, v)$  will definitely result  $Q_{AVI}(G, C) < Q_{AVI}(G, D)$ . For  $\alpha > 0$ , if all  $\delta(u, v) > \alpha\delta(u, v)$  or all  $\delta(u, v) < \alpha\delta(u, v)$  then  $Q_{AVI}(\alpha G, C) < Q_{AVI}(\alpha G, D)$  when  $Q_{AVI}(\alpha G, C) = Q_{AVI}(\alpha G, D)$  before the contribution of all  $\alpha\delta(u, v)$ . Hence for the case (i),  $\alpha > 0$  will result  $Q_{AVI}(G, C) \leq Q_{AVI}(G, D)$  if and only if  $Q_{AVI}(\alpha G, C) \leq Q_{AVI}(\alpha G, D)$ . Similarly, it can also be shown for the cases (ii), (iii) and (iv).

Any connection  $(u, v) \in E$  will be in one of these four cases for  $C$  and  $D$ . Thus,  $Q_{AVI}(G, C) \leq Q_{AVI}(G, D)$  if and only if  $Q_{AVI}(\alpha G, C) \leq Q_{AVI}(\alpha G, D)$  for all  $\alpha > 0$ . Similarly, it can also be shown for AVU. Thus, ANUI is also scale invariant.  $\square$

*Lemma 1.* Consider a ratio  $\frac{I}{I+E}$ , where  $I, E$  and  $I + E$  are positive and  $E < I$ . If  $I$  is incremented or decremented with amount  $x$  then  $\frac{I}{I+E} < \frac{I+x}{I+E+x}$  or  $\frac{I}{I+E} > \frac{I-x}{I+E-x}$ , and if  $x \ll I$ , then  $\frac{I}{I+E} \cong \frac{I \pm x}{I+E \pm x}$ .

*Proof.* Clearly,  $I < I + E$  since  $I, E, I + E > 0$ . Now, by property of ratio  $\frac{I}{I+E} < \frac{I+x}{I+E+x}$  and  $\frac{I}{I+E} > \frac{I-x}{I+E-x}$ , since  $I < I + E$ .

As  $x \ll I$ , this implies  $\frac{x}{I} \cong 0$ . With this we can write,

$$\frac{I+x}{I+E+x} = \frac{1+\frac{x}{I}}{\frac{I+E}{I}+\frac{x}{I}} \cong \frac{1+0}{\frac{I+E}{I}+0} \cong \frac{1}{\frac{I+E}{I}} \cong \frac{I}{I+E}.$$

Similarly, we can show  $\frac{I-x}{I+E-x} \cong \frac{I}{I+E}$  for  $x \ll I$ .

This means for very small change in  $I$ , the ratio does not change much.  $\square$

*Lemma 2.* Consider a ratio  $\frac{I}{I+E}$ , where  $I, E$  and  $I+E$  are positive and  $E < I$ . If  $E$  is incremented or decremented with amount  $x$  then  $\frac{I}{I+E} > \frac{I}{I+E+x}$  or  $\frac{I}{I+E} < \frac{I}{I+E-x}$ , and if  $x \ll I$ , then  $\frac{I}{I+E} \cong \frac{I}{I+E \pm x}$ .

*Proof.* By property of ratio  $\frac{I}{I+E} > \frac{I}{I+E+x}$  and  $\frac{I}{I+E} < \frac{I}{I+E-x}$ , since  $I, E, I+E > 0$ .

As  $x \ll I$ , this implies  $\frac{x}{I} \cong 0$ . With this we can write,

$$\frac{I}{I+E+x} = \frac{1}{\frac{I+E+x}{I}} \cong \frac{1}{\frac{I+E}{I} + \frac{x}{I}} \cong \frac{1}{\frac{I+E}{I}} \cong \frac{I}{I+E}.$$

Similarly, we can show  $\frac{I}{I+E-x} \cong \frac{I}{I+E}$  for  $x \ll I$ .

This means for very small change in  $E$ , the ratio does not change much.  $\square$

*Proof.* (Theorem 7.19) Since Isolability is a ratio (Equation( 7.6)) of the form  $\frac{I}{I+E}$ , here  $I$  and  $E$  represents total strength of internal and external connections. Consistent improvement can happen either when we strengthen internal connections of the community or weaken external connections of the community. For any graph  $G = (V, E)$ , if additional  $\beta \geq 0$  amount is added to the connection strength  $\delta(u, v)$  such that  $u \in C_i, v$  for any community  $C_i \in C$  then this will be the case as in Lemma 1 where  $I$  is incremented. As shown in Lemma 1, at this situation the ratio increases (by property of ratio) i.e. Isolability increases. Thus,  $Q_{AVI}(G + \beta, C) \geq Q_{AVI}(G, C)$ . Again, if  $\beta \geq 0$  amount is subtracted from the connection strength  $\delta(u, v)$  such that  $u \notin C_i, v$  then this will be the case as in Lemma 2 when  $E$  decreases. As shown in Lemma 2, at this situation also the ratio will also increase (by property of ratio) i.e. Isolability will also increase. Thus,  $Q_{AVI}(G - \beta, C) \geq Q_{AVI}(G, C)$ . Hence, AVI is monotonic. Unifiability does not depend on the internal connections of the community. Hence, strengthening of internal connections will have no impact on Unifiability i.e.  $Q_{AVU}(G + \beta, C) = Q_{AVU}(G, C)$ . Weakening of external connections will result in decrease of Unifiability. Unifiability has to be minimum for good communities. Hence, degradation of Unifiability implies improvement in

quality. Since, both AVI and  $1/AVU$  are non decreasing for consistent improvements so ANUI will reflect the same i.e.  $Q_{ANUI}(G \pm \beta, C) \geq Q_{ANUI}(G, C)$ .  $\square$

*Proof.* (Theorem 7.20) AVI is a measure of individual Isolability contribution of all communities. Isolability of a community depends only on the nodes within the community and neighbor nodes. Isolability of each individual community is independent of other community. Thus, for any graph  $G = (V, E)$  and community structure  $C$ , contribution of any community  $C_i \in C$  is separated as follows. Suppose, community structure  $C$  consists  $k$  communities. Now, quality metric AVI is expressed as:

$$\begin{aligned} Q_{AVI}(G, C) &= \frac{Isolability(C_i)}{k} + \frac{\sum_{j=1, j \neq i}^k Isolability(C_j)}{k} \\ &= \frac{Isolability(C_i)}{k} + \frac{Isolability(C \setminus C_i)}{k} \\ &= Q_{AVI}(C_i, C) + Q_{AVI}(C \setminus C_i, C) \end{aligned}$$

All kind of changes  $G^*$  associated with  $C_i$  will affect AVI. Resulting changed AVI is expressed as follows:

$$\begin{aligned} Q_{AVI}(G^*, C) &= \frac{Isolability(C_i^*)}{k} + \frac{Isolability(C \setminus C_i^*)}{k} \\ &= Q_{AVI}(C_i^*, C) + \frac{Isolability(C \setminus C_i)}{k} \\ &\text{(all changes } C_i^* \text{ is local to } C_i) \\ &= Q_{AVI}(C_i^*, C) + Q_{AVI}(C \setminus C_i, C) \end{aligned}$$

Hence, AVI satisfies locality. Quality metrics is local if it is a sum over number of communities and each summand depends only on nodes and connections associated with single community[196]. AVI is simply a sum over individual Isolability of communities. Thus, looking into the designing itself one can say, AVI is local. Similarly, AVU is also a sum over Unifiability of each community to other communities. Hence, AVU is also local. Harmonic mean of AVI and  $1/AVU$  implies local so ANUI also satisfies locality.  $\square$

*Proof.* (Theorem 7.21) As shown in Theorem 7.19, Isolability and Unifiability are the ratios and can be represented in the form as in Lemma 1 and Lemma 2. Also, it is shown that consistent improvement is possible with both AVI and AVU. This implies that with addition of connection strengths within the community or removal of connection strengths between communities will improve AVI, AVU and ANUI values. With significant amount of such changes, any community structure can be changed to optimal quality. Hence, AVI, AVU and ANUI are rich.  $\square$

*Proof.* (Theorem 7.22) As Isolability is a ratio of the form  $\frac{I}{I+E}$ , with Lemma 1 and Lemma 2 we can show that small change in  $I$  or  $E$  i.e. change in Isolability is negligible. Since AVI satisfies locality (shown in Theorem 7.20), this negligible affection will not spread over entire graph quality. This implies that small change in any connection within or outside community will have small impact on AVI. Consider a graph  $G = (V, E)$ ,  $\delta(u, v) = x$  for all  $(u, v) \in E$ . Since AVI is local so we can separate contribution of any community  $C_i \in C$  of graph  $G$ , i.e.  $Q_{AVI}(G, C) = Q_{AVI}(C_i, C) + Q_{AVI}(C \setminus C_i, C)$ .

Contribution of any community  $C_i \in C$  to AVI is

$$Q_{AVI}(C_i, C) = \frac{1}{k} \times \frac{ax}{ax + bx},$$

where,  $a$ =number of internal connections.

$b$ =number of external connections.

$x$ =weight of each connection in  $G$ .

$k$ =number of communities in the community structure  $C$ .

Let,  $G = (V, E')$ ,  $\delta'(u, v) = y$  for all  $(u, v) \in E'$  be another graph such that  $m$  external connections of community  $C_i \in C$  that associated only to  $C_i$  satisfy  $\delta(u, v) - \beta < \delta'(u, v) < \delta(u, v) + \beta$  for  $\beta > 0$ . Remaining  $|E| - m$  connections have same weights as in  $G$ , i.e.  $y = x$ . Now, for  $m$  connections  $\delta'(u, v) < \delta(u, v) + \beta \Rightarrow y < x + \beta$ .

Contribution of  $C_i \in C$  to AVI with respect to  $G'$  is separately written as,  $Q_{AVI}(G', C) = Q'_{AVI}(C_i, C) + Q_{AVI}(C \setminus C_i, C)$ .

Contribution of community  $C_i \in C$  to AVI with respect to  $G'$  is

$$\begin{aligned} Q'_{AVI}(C_i, C) &= \frac{1}{k} \times \frac{ay}{ay + by} \\ &= \frac{1}{k} \times \frac{ax}{ax + (b - m)x + my} \\ &\text{(for } m \text{ external connections } x \neq y) \\ &= \frac{1}{k} \times \frac{ax}{ax + (b - m)x + m(x + \beta)} \\ &\text{(replacing } y \text{ with } x + \beta) \\ &= \frac{1}{k} \times \frac{ax}{ax + bx + m\beta} \\ &< Q_{AVI}(C_i, C) \end{aligned}$$

Thus,  $Q_{AVI}(G', C) = Q'_{AVI}(C_i, C) + Q_{AVI}(C \setminus C_i, C) < Q_{AVI}(G, C)$

Suppose,  $Q_{AVI}(G', C) = Q_{AVI}(G, C) - z, z > 0$ . Now, addition of any  $\gamma > z$  to  $Q_{AVI}(G', C)$  implies  $Q_{AVI}(G, C) < Q_{AVI}(G', C) + \gamma$ . Similarly, we can show there exist  $\gamma > 0$  such that  $Q_{AVI}(G', C) - \gamma < Q_{AVI}(G, C)$ . Therefore, AVI is continuous. Unifiability can also be represented as a ratio of the form  $\frac{I}{I+E}$  by considering  $I$  as number of common connections and  $E$  as combined external connections of two communities. Hence, we can show AVU as well as ANUI are also continuous.  $\square$

# Appendix B

## List of Publications

### Journals

1. **Anupam Biswas** and Bhaskar Biswas, “Investigating Community Structure in Perspective of Ego Network”, in Expert Systems with Applications, Elsevier, vol. 42, no. 20, pp. 6913-6934, 2015. (**SCI, IF 2.981**)
2. **Anupam Biswas** and Bhaskar Biswas, “Defining Quality Metrics for Graph Clustering Evaluation”, in Expert Systems with Applications (ESWA), Elsevier, vol. 71, pp. 1-17, 2017. (**SCI, IF 2.981**)
3. **Anupam Biswas** and Bhaskar Biswas, “Regression Line Shifting Mechanism for Analyzing Evolutionary Optimization Algorithms”, in Soft Computing (SOCO), Springer, 2016. (**SCI, IF 1.63, Accepted**)
4. **Anupam Biswas** and Bhaskar Biswas, “Community-based Link Prediction”, in Multimedia Tools and Applications, Springer, 2016. (**SCI, IF 1.333, Accepted**)

5. **Anupam Biswas**, Bhaskar Biswas, A. Kumar and K. K. Mishra, “Particle Swarm Optimization with Time Varying Cognitive Avoidance Component”, in International Journal of Computational Science and Engineering, Special Issue on Swarm and Artificial Intelligence, InderScience Publishers, Switzerland, 2014.  
(ESCI, SCOPUS, Accepted)
6. **Anupam Biswas** and Bhaskar Biswas, “FuzAg: Fuzzy Agglomerative Community Detection”, in IEEE Transactions on Fuzzy Systems (TFUZZ). (SCI, IF 6.701, Under Revision)
7. **Anupam Biswas** and Bhaskar Biswas, “Analyzing Evolutionary Optimization and Community Detection Algorithms using Regression Line Dominance Mechanism”, in Information Sciences (IS), Elsevier. (SCI, IF 3.364, Under Revision)

## **Book Chapters**

1. **Anupam Biswas** and Bhaskar Biswas, “Swarm Intelligence Techniques and Their Adaptive Nature with Applications” , in “Complex system modeling and control through intelligent soft computations” vol 219, ch. 9, pp. 253-271, 2015, Springer-Verlag, Germany.
2. **Anupam Biswas**, Gourav Arora, Gaurav Tiwari, Srijan Khare, Vyankatesh Agrawal and Bhaskar Biswas “Agglomerative Approaches for Partitioning of Networks in Big Data Scenarios” in “Data Science and Big Data Computing: Frameworks and Methodologies”, ch. 3, pp. 57-78, 2016, Springer-Verlag, Germany.
3. Abhishek Garg, **Anupam Biswas** and Bhaskar Biswas, “Evolutionary Computation Techniques for Community Detection in Social Network Analysis”, in “Advanced

Methods for Complex Network Analysis”, ch. 11, pp. 271-289, 2016, IGI Global, United States.

## Conferences

1. **Anupam Biswas**, Pawan Gupta, Mradul Modi and Bhaskar Biswas, “Community Detection in Multiple Featured Social Network using Swarm Intelligence”, in International Conference on Communication and Computing (ICC-2014), 12-14 June 2014, Bangalore, India. (**Best Paper Award**)
2. **Anupam Biswas**, Pawan Gupta, Mradul Modi and Bhaskar Biswas, “An Empirical Study of Some Particle Swarm Optimizer Variants for Community Detection”, in Third International Symposium on Intelligent Informatics (ISI’14), 24-27 September 2014, Delhi, India.
3. **Anupam Biswas** and Bhaskar Biswas, “Visual Analysis of Evolutionary Optimization Algorithms”, in ISCBI 2014 II International Symposium on Computational and Business Intelligence, 7-8 Dec. 2014, New Delhi.
4. **Anupam Biswas**, Bhaskar Biswas and K. K. Mishra, “An Atomic Model Based Optimization Algorithm”, in 2nd International Conference on Computational Intelligence & Networks (CINE 2016), 11 Jan. 2016, Bhubaneswar.
5. **Anupam Biswas** and Bhaskar Biswas, “A Framework for Analyzing Community Detection Algorithms”, in 2016 IEEE Students’ Technology Symposium (TechSym 2016), 30 Sep.-2 Oct. 2016, Kharagpur, India.