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Unidirectional Flow: A Survey on Networks, Applications, and Characteristic Attributes

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Abstract

Studies and applications related to unidirectional flow are gaining attention from researchers across disciplines in the recent years. Flow can be viewed as a concept, where the material, fluid, people, air, and electricity are moving from one node to another over a transportation network, water network, or through electricity distribution systems. Unlike other networks such as computer networks, most of the flow networks are visible and have strong material existence and are responsible for the flow of materials with definite shape and volume. The flow of electricity is also unidirectional, and also share similar features as of flow of materials such as liquids and air. Generally, in a flow network, every node in the network participates and contributes to the efficiency of the network. In this survey paper, we would like to evaluate and analyze the depth and application of the acyclic nature of unidirectional flow in several domains such as industry, biology, medicine, and electricity. This survey also provides, how the unidirectional flow and flow networks play an important role in multiple disciplines. The study includes all the major developments in the past years describing the key attributes of unidirectional flow networks, including their applications, scope, and routing methods.

Keywords

Acyclic, Algorithms, Attributes, Flow, Routing, Unidirectional

1. Introduction

The term network is very ubiquitous today, especially since the introduction of computer networks, and the Internet. Generally, the term network synonymously referred to as the interconnection of nodes to transfer messages or information in the form of digital signals or bitstream. However, it is rarely viewed as an interconnection of nodes to transfer physical entities such as people, fluids, air, or electricity. When we think about flow; generally the flow of information, water, fluids, blood, and materials comes to our minds. Moreover, the flow of water, fluid, blood, and materials can be easily visualized and easy to grasp. However, the flow of electricity, data, signal, and the information is hard to visualize and need specialized skills to implement algorithms related to them. The word unidirectional in this paper refers to single directional flow, where an entity is flowing from source to destination or destination to source, but not both ways simultaneously.

The flow of information is not a novel idea today considering the recent developments such as messaging systems, and social networks. There are several algorithms and strategies for implementing

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effective communication between two devices or between two interconnected nodes. Contrary to these developments, there are few studies, which highlight the interconnectedness between nodes, where physical entities such as water, fluid, air or current are exchanged. In this scenario, the term flow network is widely used in applications involving both physical as well as non-physical entities with limitation on flow capacity. Similarly, as flow networks can be unidirectional or bidirectional. Unidirectional flow networks gained significant attention in the recent years involving several engineering and scientific applications.

To visualize a flow network mathematically, we represent a sample flow network as $G(V,E)$, which represent a directed graph. In a directed graph, each edge is has direction linked with it, and vertices are connected by edges. In this kind of directed graph, every edge is represented by (u, v), where $(u, v) \in E$. In flow networks, these edges have non-negative $c(u, v)$, where c represent the flow capacity. As flow is a dynamic mechanism, where some physical entities or electricity move from one node to another, two special vertices are identified. They are source (s) and sink (t). Sometimes, sink node is also called as a destination node. A flow in a network G is represented as a function: $f: V \times V \rightarrow R$. There are three criteria to recognize a network as flow network. Firstly, for all $u, v \in V, f(u, v) \leq c(u, v)$, secondly, for all $u, v \in V, (u, v) = -f(v, u)$, and finally, for all $u \in V - \{s, t\}, \sum f(u, w) = 0$, where $u \in V$, unless $u=s$ or $w=t$. Considering a single node in a flow network other than the source node, the net flow is equal to zero. The source node produces the flow, whereas the sink or destination node deplete the flow [1,2].

The main contribution of this work is to explore the applications, domain, and scope of unidirectional flow considering recent developments in this discipline. This eventually help researchers to develop new algorithms related to unidirectional transmission, flow, traffic, and routing methods. For example, considering the example of a transportation network, there are flow of vehicles as primary flow items, as well as people, food, luggage, information and materials as secondary flow items. However, there are not many algorithms to evaluate the impact, nature, and influence of secondary flow entities along with primary flow items. In such circumstances, one need to study the role of different parameters such as vehicle capacity, maximum flow of vehicles in an unidirectional road, maximum capacity in each vehicles and nature an behavior of physical entities. So, one need to look for implementation of suitable traffic, highway, communication, and routing schemes to develop energy saving, and cost-efficient paths. To develop new mathematical models one need to start with simple edges, and flow of entities in one direction rather than multi-directional. The flow of influential and major entities in this kind of applications can be considered as primary or base flow entities, and other entities which are also flowing along with base entities, but share different roles can be considered as secondary flow entities. Considering the combination of these two primary and secondary flow items in one unidirectional path may pose new challenges in emerging research areas. For example, this will encourage researchers to develop new data structures, and faster network flow algorithms which are applicable to both tangible and intangible items; and help to deal with computational issues, flow constraints and barriers.

In this survey paper, we would like to highlight the past literature work which specifically emphasizes on the characteristics of unidirectional attribute related to flow, flow networks, and routing schemes. We aim to provide the comparative details of networks which carry digital bitstream or signals to networks which carry physical as well as non-physical entities. Section 2 describes the scope and attributes of unidirectional entity in multiple domains. Section 3 presents domains and applications of unidirectional flow. Section 4, presents a general introduction to acyclic unidirectional flow networks and details about

matrix-based algorithms for routing strategies. Section 5 discusses the future challenges and suggests few recommendations. The concluding remarks regarding this survey is presented in Section 6.

2. "Unidirectional" Entity in Multiple Domains

The term unidirectional is discussed in number of studies in the past decades, where it represents a behavior involving single direction, and implied flow of entities (both tangible and intangible) in one direction, and direction of flow is remain unchanged, as opposed to bidirectional. In a bidirectional flow, the entities can move in two opposite directions facing each other. A good example is human aging process, and genealogy maps. In most of the genealogy maps, the knowledge is spread from ancestors to descendants in single direction. In this section, we would like to summarize the scope of our study after surveying over hundred peer-reviewed publications. To carry out this survey work, we have first identified the past research, which have applied the concept of *unidirectional* entity. However, as there are several thousand publications, we narrowed the survey based on the relevance to engineering and industrial applications. We have analyzed the entire research papers to identify the application domain where the features associated with *unidirectional* are consistently used. Then, we have summarized the attributes of unidirectional entity as shown in Fig. 1, and identified the application domains which are closely related to the attributes. Table 1 shows the list of references which summarizes the attributes of unidirectional entity and their application domain. The first column in Table 1 shows the name of attributes which are linked to the term unidirectional. The second column lists the industrial, and engineering fields, where the respective attribute is relevant to the term unidirectional. The third column lists the reference list of publications. As shown in the Table 1, it is evident that the features of unidirectional attribute can be seen in most of the domains. Moreover, Fig. 2 shows the word cloud to represent the application domains which are significantly applied the unidirectional attributes. The results shows that, the application domains such as power grid, electric power systems, smart grids, Network-on-Chip (NoC), wireless sensor networks, and guided vehicles are the major disciplines related unidirectional attributes. Moreover, attributes such as flow, network, power, and link are commonly used along with term unidirectional, as shown in Table 1 as compared to other terms such as distribution, routing, loop, etc.
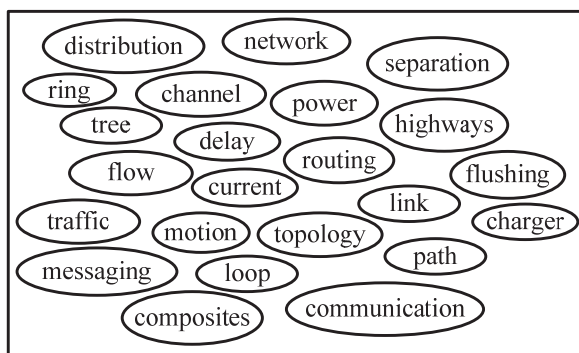

Fig. 1. The identified attributes of unidirectional entity.

Table 1. Unidirectional characteristics in multiple disciplines

Attribute	Application domain	References
Flow	Power grid, energy distribution networks, electric power systems, solar air heaters, smart grids	[2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [25], [66], [91]
	Fractured rock masses, flow dynamic in porous surfaces, vascular networks, molecular dynamics	
	Vehicles and delivery stations, guided vehicles, traffic data applications, pedestrian flow simulations	
	Medical imaging, remote sensing	
	Machine learning, ANN, genetic algorithms, ant colony optimizations	
	Communications, NoC, network simulations, Internet and websites, physical-layer network coding, wireless networks, campus networks	
Network	Electric vehicles, electric grid stations	[10], [14], [17], [23], [27], [28], [29], [31], [32], [33], [34], [66]
	Vehicles and delivery stations, road networks, automated guided vehicles	
	Social networks, ant colony optimization, genetic algorithms	
	Large-scale clusters, cloud computing, cloud data security, optical networks	
Distribution	Power distribution systems	[89]
Routing	High-density metal layer manufacturing	[36]
Charger	Electric vehicles	[30]
Channel	Smart grids	[37], [38]
	Bandwidth utilization	
Power	Photovoltaic cells, solar photovoltaic inverters, solar energy management, electric vehicle chargers, wind turbines allocation, plug-in electric vehicles	[27], [28], [30], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51] , [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [89], [93]
	Electric power distribution system, wind energy conversion systems,	
	Renewable energy resources, renewable energy generators, sinusoidal circuits	
	Distributed energy resources, renewable energy sources, spot networks, smart grids	
	Electrical distribution networks, distributed generators	
Separation	Bayesian networks	[69]
Tree	WSN, Internet, online video conferencing	[24], [70]
Delay	Wireless networks	[15]
Highways	Road networks	[73], [103]
Current	Electric converters, distribution networks	[59], [71], [72]
	Power grids	
Link	Smart grids,	[37], [75], [76], [26], [33], [77]
	Wireless mesh networks, data transmission, WSN, satellite communication	
	Security of cloud data	
Traffic	WSN, Internet	[13], [78], [79], [80]
	Inter-vehicle communication	
Motion	Microscopic flow in active gels	[81]
Topology	Large-scale clusters, 5G transport networks	[32], [82]
Ring	5G transport networks, NoC	[82], [83], [84]
Flushing	Water distribution network	[85]
Messaging	Smart grid applications	[37]
Loop	Material transportation	[86]
Composites	Microvascular networks	[87]
Communication	Plug-in electric vehicles, smart energy management, smart grids	[27], [37], [78], [88]
	WSN	

The attributes listed in Fig. 1 is obtained after surveying the targeted papers, which use the property of unidirectional. In this context, we found that there are total 22 attributes listed. They are power (35), flow

(24), network (12), link (6), traffic (4), communication (4), ring (3), current (3), channel (2), tree (2), highway (2), topology (2), delay (1), routing (1), charger (1), separation (1), motion (1), flushing (1), messaging (1), loop (1), distribution (1), and composites (1). The number within the brackets shows the number of publications which use the respective attribute. However, it is also worth noting that some attributes overlap in the same publications more than once.

Fig. 2. Word cloud representing the significant application domains of unidirectional entity.

It is undeniable that, there are few other attributes may exist linking to unidirectional feature. However, as there not many significant attributes, and we have omitted surveying possibility of such existing attributes. As it shown in Table 1, significant number of researchers used the term unidirectional flow, unidirectional power, and unidirectional network. The term unidirectional flow and unidirectional network is highly relevant here as compared to unidirectional power. Because unidirectional power represents the direction of electric power. This is also similar to the unidirectional current, which represents electric current. So, considering this, we found, the concept of unidirectional is significantly popular with the network, and flow attributes.

Considering the application domain, we have identified almost all engineering, biological, computing, communications, and industrial domains. The major application domain where unidirectional entity is applied is in electricity, and power distribution networks. This include smart grids, power grids, distribution networks, solar air heaters, electric vehicles, energy resources, etc. Comparing to other physical systems, the unidirectional application can also be seen in water distribution networks, microvascular networks, material transportation, road networks, etc. Considering the networks related computing and Internet, there are several application domains such as network simulations, wireless networks, wireless sensor networks, social networks, cloud computing, mesh networks, satellite communication, etc. Some applications related to unidirectional feature can also be seen in 5G transport networks, NoC, Bayesian networks, machine learning, ant colony optimization, genetic algorithms, and artificial neural networks (ANN). With this it is evident that the characteristics of unidirectional feature can be seen in several domains, and they play a significant role in applications ranging from physical networks to communication networks. As this paper is focusing on unidirectional flow, we are targeting our discussion only to unidirectional flow in the subsequent sections.

3. Domains and Applications of Unidirectional Flow

As described in Sections 1 and 2, the unidirectional flow can be considered as one major property of flow networks. In this section, we summarize the different engineering and industrial domains, where unidirectional flow is applied. There are several variations of flow networks, such as unidirectional and bidirectional. Fig. 3(a), and (b) shows the general representations of one directional flow between two nodes, *source,* and *sink.* Fig. 3(c), and (d) shows the representations of bidirectional flows. Fig. 3(e) shows an example of conversion of a bidirectional flow into unidirectional by inserting an intermediate node. This is technique is widely used to simplify the flow network and make the flow unambiguous. Fig. 3(f) shows an example of unidirectional flow network with cycles. These kinds of networks are very common in many theoretical studies related to graph theory. Here the cycle is formed with interdependence between nodes. Moreover, one can form more than one cycles in such networks. Fig. 3(g) shows an example acyclic unidirectional flow network, where there are no cycles. These kinds of networks are very common in many real-life examples, such as road networks, water flow networks, and gravity based networks.
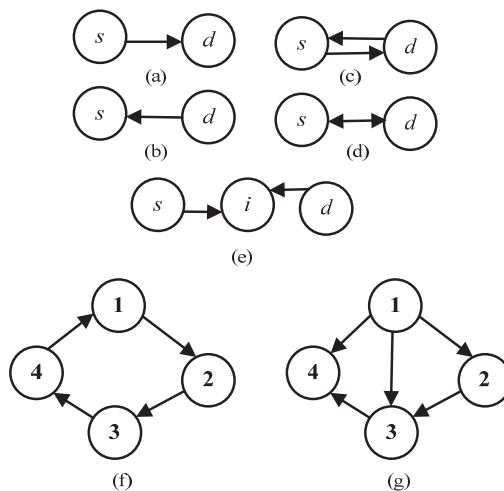
Fig. 3. Several variations of flow networks: (a) unidirectional flow, (b) unidirectional flow, (c) bidirectional flow, (d) bidirectional flow, (e) conversion of bidirectional flow into two unidirectional flows by introducing an intermediate node, (f) cyclic unidirectional flow, and (g) acyclic unidirectional flow.
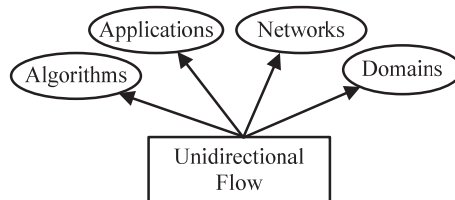
Fig. 4. The scope and attributes of unidirectional flow entity.

Previous studies show the applications related unidirectional flow in multiple disciplines ranging from botany, biology, medicine, engines, pedestrian walking, transportation, social networks, ad-hoc networks,

and wireless sensor networks. After surveying several publications related to unidirectional flow, we found that the general scope and attributes of unidirectional flow are related to algorithms, applications, networks, and domains as shown in Fig. 4. As predicted earlier, most of the works related unidirectional attribute are predominantly related to power and current distribution applications. The overall role of unidirectional flow in multiple contexts can be understood by studying its applications, domains, networks, and algorithms. The general applications can be summarized in four major domains: electrical systems, communication systems, transportation networks, and biological systems. Here, the transportation systems assumed as systems which carry vehicles, people, water, etc.

3.1 Electrical Systems

Most of the unidirectional flow applications are related to electrical engineering applications. Here the flow of current and power are the main flow items. In The concept of unidirectional flow is very common to electric power distribution networks or in distribution networks and it is also argued that power flow in photovoltaic fuel cell is unidirectional [3]. There are several studies which support the claims that the flow of power as well as current as unidirectional, and this feature is widely cited by researchers within electrical engineering and power distribution network specialists. It is widely known since the 1880s that power flows unidirectionally in distribution networks [39,89]. There several related studies on flow of power in unidirectional path. In [40], researchers discussed the power flow mechanism from power plants to customers in urban cities, where the flow of power is unidirectional in distribution networks. The similar details about consumption of electricity by consumers is also provided in [90], where the power is supplied to users over distribution networks in unidirectional mode. The flow of current and power is discussed in electric converters and electric vehicles, respectively in [30,72]. The application of flow of power and current is unidirectional in distribution networks, and this is widely discussed in [43-47,74,89,91,92]. The flow of power in voltage regulators, grid applications, and voltage networks is discussed in [35,59]. The power flow in smart grids, spot networks, and energy resources are mentioned in [41,42]. The role of unidirectional power flow in photovoltaic panels, and photovoltaic mentioned in [48,58]. The unidirectional flow of power in wind turbines, smart grids, solar power grids, and power grids are mentioned in [50,93].

3.2 Communications Systems

Even though it is common understanding that most of the flow networks are physical, the term unidirectional flow is widely used in information and communications discipline. The general properties of a unidirectional flow network is presented in [12], where the term flow is used for sending Internet packets. Here the authors also described the various parameters to define a unidirectional flow including the size of packets, duration of packet flow, total number of packets, etc. The flow item in a communication network is either information, traffic data, security information, information packets, data signals, etc. Most of the applications of unidirectional flow is related to wireless sensor networks, wireless networks, computer networks, routing schemes, Internet, machine learning, cloud computing, social networks, NoC, secure communication, network equipments, and parallel computing. In studies presented in [16,79,94] discuss the flow of traffic data in computer and communication networks.

The works mentioned in [2,15,70,78,95] provides details about the flow of traffic data, signals, and data packets in wireless sensors networks, and wireless networks. Considering the Internet, cloud

computing and machine learning applications, the unidirectional flow of information is discussed in [12,21,80]. The unidirectional flow of security information in cloud systems is discussed in [33]. The role of unidirectional flow of information in social networks is mentioned in [96,97]. There are also few domains where the unidirectional flow is applicable, for example in [7], flow from buffered router to buffer-less router in heterogeneous NoC is discussed. In [13], comparison between, unidirectional, and bidirectional traffic using various performance measures and simulation analysis is experimented involving multi-path routing. In [98] the unidirectional flow is discussed in relation to parallel applications. In [23], the researchers studied the flow of traffic data in vehicle networks. In [82], the studies on information packets and queuing delays considering unidirectional topologies is mentioned. In [99], the importance of unidirectional process while managing risks and uncertainty in financial sector is discussed. In addition, these days the term unidirectional data flow is used while developing applications related to Android, and data flow between view, presenter and model is discussed as unidirectional.

3.3 Transportation Networks

In this subsection, the summary of unidirectional flow related transportation network is provided. Here we have considered water, fluid, air, people vehicles, and materials as entities which use transportation networks. In [85,100], the researchers studied the unidirectional flow and its significance in water distribution networks. The water transportation in unidirectional and bidirectional pipes is mentioned in [100]. In [9], the groundwater flow lines along with hydraulic properties are discussed. This also shows the relevance of unidirectional flow in hydrodynamics and related applications [81]. The study on molecular dynamics and water flow is studied in [11]. The studies on liquid flow in porous maximums are studied in [6]. The flow of fluid in microvascular networks, composites and tubes are discussed in [8,87]. The unidirectional flow of air and heated air is mentioned in [5,101]. Simulation of unidirectional fluids mentioned in [102]. Considering applications related to roads, vehicles, and passengers, several applications can be listed. The studies on people traveling in unidirectional road is mentioned in [18], and flow of materials during transportation is studied in [86]. The studies such as [10,29,73,103,104], all consider the relevance of unidirectional flow in highways, road networks, delivery stations, etc. The communication between multiple vehicles, causes of delay during the unidirectional and bidirectional traffic is studied in [79,94]. In the recent years, the electric vehicles are widely used for transportation, where using batteries, charging stations and electric grids for supplying power to electric vehicles is common practice. Considering this there are several studies discussed the concept of unidirectional flow together with electric vehicles and power related studies [19,27,30,56,57]. These studies mainly focused on charging stations, electric grids, charging methods, and integration of them to electric vehicles. In [14,17], the path design problems, along with genetic algorithms, ant colony optimization methods to solve the problems related to flow paths are discussed.

3.4 Biological Systems

In recent years, researchers have focused their attention to the role of unidirectional flow in biological systems. There are strong evidence to prove that, unidirectional flow exist in plant cells. For example, plasmodesmata exhibiting unidirectional flow is described in [105]. The plasmodesmata are the miniature channels within the plant cells. In [106], the unidirectional flow of oxygen in lungs of birds are studied. Here researchers proved that, while the birds are flying, they need the supply of oxygen in unidirectional

path. The similar behavior of airflow is also studied in American alligators [107]. The alligators also need the airflow to lungs in unidirectional path. In [108], the role of unidirectional airflow in surgical applications is studied.

4. Acyclic Unidirectional Flow Networks and Algorithms

In this paper, the aspect of unidirectional flow is emphasized. In Fig. 5(a), the start node or source node is at the top, and the sink node is at the down, to reflect the gravity based flows in a network, and to depict the downward flow of entities such as water, fluid or liquid. Previous research also shown that, in wireless networks, a source node can send information to sink node, but the reverse may not be true [109]. So, there is no ambiguity regarding the unidirectional nature of flow in several applications, and visibility of flow in all network edges without any interruption or obstacle to flow. Fig. 5(a) shows an example of unidirectional flow network (UFN) without any loops. In this example there are four vertices, A, B, C, and D, and all the edges in this UFN are directed and are unidirectional. Moreover, as there are no cycles in this network, which makes this network acyclic. The applications of acyclic flow networks were discussed by several researchers. Earlier there are also studies to show how these kinds of networks can be used to solve the critical path methods (CPM), program/project evaluation and review technique (PERT) problems, and other applications on managing time, project cost, and deadlines [110,111].

In the past, several simple matrix based algorithms were proposed by the author and his colleagues of this paper [112-114] to find the routing paths in an acyclic unidirectional flow network with several assumptions and preconditions. One precondition is that, the generated network is not generating any cycles, and all the nodes participate in the flow. These algorithms use recursive, induction, and iterative based strategies, and demonstrated their implementations using programs. The algorithms are developed in such a way that, all the paths can be generated using the patterns generated in a two-dimensional (2D) matrix (Fig. 5(d)), which are represented as a 2D array in a program. Here the visualized patterns of 2D array is part of the solution to the problem, making these algorithms as "out-of-box" solutions. If there is a path between A to B, then the current flow and capacity are placed in that matrix location, otherwise it is designated as zero, which represents no flow as shown in Fig. 5(c).

The algorithms proposed assume that the different nodes of UFN are located physically in different geographic locations. So, each node in the network has some role to play especially in cases where the flow of fluid, water, liquid, material or people are involved. However, all these flows assume to maintain unidirectional flow behavior in all situations. The algorithms presented in [112-114] has several limitations. Firstly, they are costly and time-consuming in terms of the complexity involved. For example, if there are 15 nodes in a flow network, the initial matrix size grows exponentially. This can be proved by a simple induction example. As shown in Fig. 5(d), the matrix shows four paths starting from destination. If there are only three nodes, then, there will be only two paths. In general, the numbers of paths from source to destination covering all intermediate nodes in an acyclic network with n nodes (as shown in Fig. 5(a)) is 2^{n-2}. So, assuming that, there are only 15 nodes in a network, the total number of paths would be 8,192. As the size of the matrix grows larger the program generates memory full error or array out of bounds exception. So, testing the algorithm for node size greater than 15 is constrained by programming limitations. With this, we can judge that, as the number of nodes increases, the matrix size grows in the order of n^2 and time to execute the algorithms grows increases exponentially.
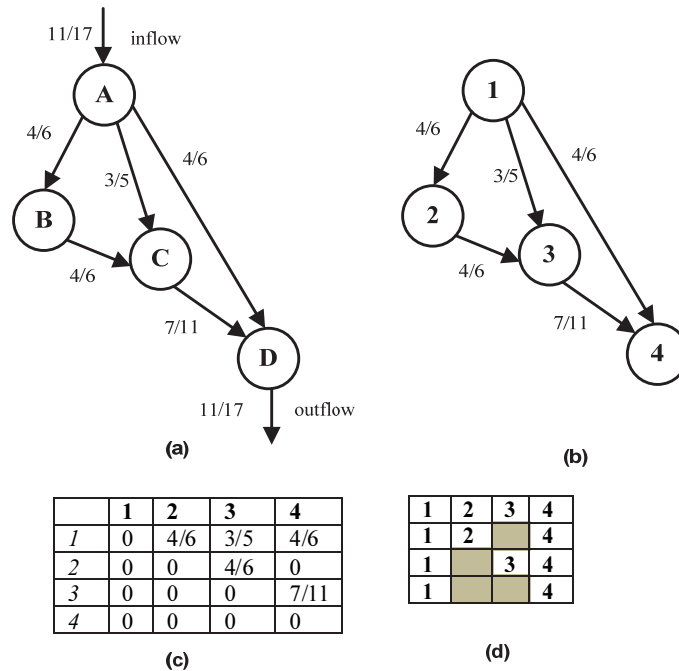
Fig. 5. The aspect of unidirectional flow: (a) A simple example of UFN with inflow, outflow, and flow capacity, (b) The modified UFN, for easy representation in programming, (c) adjacency matrix for representing the flow capacity between unidirectional edges, and (d) the matrix representation of all paths for implementation.

In summary, out of three algorithms proposed, the blanking patterns function [112] is faster than the other two algorithms, and the recursive procedure presented in [114] is efficient during implementation. Even though, the induction algorithm [113] avoids sorting procedure, it is found that, it is not as fast as recursive programs. Moreover, as the node size increases, all programs converge to values with similar time complexity.

5. Discussion, Recommendations and Challenges

The fundamental theory behind a unidirectional flow network is that, each edge has the capacity, direction and the edge is limited by flow. The cumulative flow entering a node is equal to total flow leaving the node. These kinds of unidirectional flow networks helps to model and simulate number of real-life applications where actual physical flow of materials, fluids, water, and gas are involved. Moreover, they also helps to analyze the transmission properties in networks of communication, electrical, transportation, hydraulic, mechanical, and biological systems. In this direction several open research challenges can be considered. For example, considering the transportation in biological systems, there are several studies where the role played by the blood flow mechanism in healing process and bone repair, and their significance in clinical considerations are explored [115,116]. In addition to these, these studies also mentions the evaluation, and importance of maximum, and resting blood flow. As the blood in veins flow unidirectionally [117], there are plenty of scope for analyzing the effects, capacity, contents,

and any bottlenecks exist for maintaining healthy condition. This also helps to evaluate the effects of overall blood distribution, and its impact on regular blood circulation. However, deeper studies related to flow of blood in arteries to veins of living organisms and their influencing unidirectional feature is not yet explored.

The most common challenge related to unidirectional flow network is to evaluate the maximum, minimum flow, and to find the shortest, and longest flow paths. In other words, it is important to evaluate which edges contribute to the minimum flow, and which edges contribute to the maximum flow. In the previous studies conducted by the author and co-researchers [112-114], it is demonstrated that it is possible to implement matrix-based algorithms to evaluate these parameters.

Considering the future works, there are several pointers to further work can be identified. For example, in recent years, there are several studies related to development of mathematical and simulation models for traffic flow on unidirectional roads, highway traffic networks, commodity flow in production networks [118-120]. The digital representation of flow network in hydraulic application is given in [121]. The relationship between biophysical, and transport optimization, biological flow network, and bacterial flow mechanisms are discussed in [122]. The physical flow between parts, raw materials, suppliers, manufacturers, distributors, and flow of people in manufacturing network is presented in [123]. These all areas of research present new directions to expand the applications and scope of UFNs. However, one limitation is of this work presented here is that, the unidirectional flow involving only one source and one sink nodes is considered. However, several applications may have several source and destination nodes, and this pose challenging problems. Moreover visually representing the tangible, and intangible flows using digital maps, and analyzing the information spread, and influence of social and communication networks with physical networks also present new research challenges.

6. Conclusion

We have summarized the importance of problems associated with unidirectional feature into industrial, biological, engineering and management applications. We have surveyed the literature starting from the most recent publications and found that the unidirectional feature is more related to areas such as power distribution networks, smart grids, wireless networks, and water distribution networks. The attributes of unidirectional feature is further investigated, and results demonstrate that, flow, network, power and link features are extensively used in unidirectional systems. Based on these findings, we have further surveyed the features of unidirectional flow, and unidirectional flow networks. In addition, other than entities such as gravity, electricity, fluid, water or data there may be other applications which use this feature.

The main goal of this paper is to introduce the concept of unidirectional flow in multiple disciplines and provide the survey of such works where the concept of unidirectional flow becomes relevant. In summary, it is evident that there is a higher scope for investigating further on features of unidirectional flow, and networks. In addition, as this survey is multidisciplinary, there are opportunities to implement algorithms to solve problems related to flow in several engineering, industrial, biological, and commercial applications. From this extensive survey, we found that, the unidirectional nature is influential in many disciplines, and there is a broad scope to develop efficient and user friendly algorithms in this direction.

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