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Quantifying individual performance in Cricket — A network analysis of batsmen and bowlers

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HIGHLIGHTS

- We construct a network of batsmen as well as bowlers in a team sport — Cricket.
- Social network analysis on the networks.
- Construction of gradient networks.
- PageRank Algorithm to evaluate player performance.
- Captures the consensus opinions on player's performance according to ICC ranking.

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ABSTRACT

Quantifying individual performance in the game of Cricket is critical for team selection in International matches. The number of runs scored by batsmen and wickets taken by bowlers serves as a natural way of quantifying the performance of a cricketer. Traditionally the batsmen and bowlers are rated on their batting or bowling average respectively. However, in a game like Cricket it is always important the manner in which one scores the runs or claims a wicket. Scoring runs against a strong bowling line-up or delivering a brilliant performance against a team with a strong batting line-up deserves more credit. A player's average is not able to capture this aspect of the game. In this paper we present a refined method to quantify the 'quality' of runs scored by a batsman or wickets taken by a bowler. We explore the application of Social Network Analysis (SNA) to rate the players in a team performance. We generate a directed and weighted network of batsmen–bowlers using the player-vs-player information available for Test cricket and ODI cricket. Additionally we generate a network of batsmen and bowlers based on the dismissal record of batsmen in the history of cricket—Test (1877–2011) and ODI (1971–2011). Our results show that *M. Muralitharan* is the most successful bowler in the history of Cricket. Our approach could potentially be applied in domestic matches to judge a player's performance which in turn paves the way for a balanced team selection for International matches.

1. Introduction

Tools of Social Network Analysis (SNA) have been a subject of interest for theoretical as well as empirical studies of social systems [1–3]. A social network is a collection of people or groups interacting with each other and displaying complex features [4]. Tools of SNA provide a quantitative understanding for the human interaction of collective behavior. Considerable research has been done on scientific collaboration networks [5–8], boards of directors, movie–actor collaboration networks [3] and citation networks [9–13]. The use of network analysis not only provides a global view of the

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system, it also shows the complete list of interactions. In the world of sports, individual players interact with each other and also with the players in the opponent team. It is therefore important to study the effect of interactions on performance of a player.

In recent years there has been an increase in studies of quantitative analysis of individual performance involving team sports. Time series analysis has been applied to football [14,15], baseball [16,17], basketball [18–20] and soccer [21,22]. Quantifying the individual performance or 'quality' of a player in any sport is a matter of great importance for the selection of team members in international competitions and is a topic of recent interest [23,24]. A lot of negotiations are involved in the process of team-selection [25]. Studies have focused on non-linear modeling techniques like neural networks to rate an individual's performance. For example, neural network techniques were used to predict the performance of individual cricketer's based on their past performance [25]. Earlier tools of neural networks were used to model performance and rank NCAA college football teams [26], predicting javelin flights [27] and to recognize patterns in Table Tennis and Rowing [28]. Again, a model-free approach was developed to extract the outcome of a soccer match [29]. It was also shown that the statistics of ball touches presents power-law tails and can be described by q-gamma distributions [30]. In recent years, the study of complex networks has attracted a lot of research interest [1]. The tools of complex network analysis have previously been applied to quantify individual brilliance in sports and also to rank the individuals based on their performance. For example, a network approach was developed to quantify the performance of individual players in soccer [31]. Network analysis tools have been applied to football [32] and Brazilian soccer players [33]. Successful and un-successful performances in water polo have been quantified using a network-based approach [34]. Head-to-head matchups between Major League Baseball pitchers and batters was studied as a bipartite network [35]. More recently a network-based approach was developed to rank US college football teams [36], tennis players [37] and cricket teams and captains [38].

The complex features of numerous social systems are embedded in the inherent connectivity among system components [1,34]. Social network analysis (SNA) provides insight about the pattern of interaction among players and how it affects the success of a team [39]. This article points out how topological relations between players help better the understanding of individuals who play for their teams and thus elucidate the individual importance and impact of a player. In this paper we apply the tools of network analysis to batsmen and bowlers in cricket and quantify the 'quality' of an individual player. The advantage of a network based approach is that it provides a different perspective for judging the excellence of a player.

We take the case of individual performance of batsmen and bowlers in International Cricket matches. Cricket is a game played in most of the Commonwealth countries. The International Cricket Council (ICC) is the governing body which controls the cricketing events around the globe. Although the ICC includes 120 member countries, only ten countries with 'Test' status — Australia, England, India, South Africa, New Zealand, West Indies, Bangladesh, Zimbabwe, Pakistan and Sri Lanka — play the game extensively. There are three versions of the game — 'Test', One Day International (ODI) and Twenty20 (T20) formats. Test cricket is the longest format of the game dating back to 1877. Usually it lasts for five days involving 30–35 hours. Shorter formats, lasting almost 8 h like ODI started in 1971 and during late 2000 ICC introduced the shortest format called T20 cricket which lasts approximately 3 h [40].

Batsmen and Bowlers in Cricket are traditionally ranked according to their batting and bowling average respectively. Judged by the batting average, Sir Donald Bradman (with an average of 99.94) is regarded as the greatest batsman of all times. The next best batting average of 60.9 is held by Graeme Pollock. Even though most of the records held by Bradman have been eclipsed by modern day batsmen like Sachin Tendulkar, Brian Lara, Graham Gooch, and Mohammad Yusuf, Bradman's legacy still survives and generates debate among fans about his greatness relative to recent players like Sir Vivian Richards, Brian Lara or Sachin Tendulkar. The question that thus naturally arises is whether the batting average of batsmen (or the bowling average of bowlers) is the best measure for judging the worth of a batsman (or a bowler). It was shown that rankings based on averages suffer from two defects—(i) Consistency of scores across innings and (ii) Value of runs scored by the player [41]. However, one should also consider the quality of bowling as well. For example according to Bradman himself, the greatest innings he ever witnessed was that of McCabe's innings of 187 at Sydney in 1932. The reason being it came against Douglas Jardine's body-line attack, widely regarded as one of the fiercest bowling attacks. Similarly, runs scored against West Indian bowlers like Michael Holding, Joel Garner, Malcolm Marshall and Andy Roberts deserve more credit than runs scored against the low bowling attack of Bangladesh or Zimbabwe. On similar arguments the wicket of top-order batsman is valued more than the wicket of a lower-order batsman. If a bowler claims the wicket of Bradman, Lara, Richards or Tendulkar, he gets more credit than if he dismisses any lower-order batsman. Under the usual ranking scheme based on bowling average, *George Lohmann* of England has the lowest (best) bowling average (10.75) in Test cricket. However, bowlers like *George Lohmann* played under pitch conditions favoring fast bowlers. Hence, batting (or bowling) average does not serve as an efficient gauge for a batsman's (or bowler's) ability [42]. Against this background, we propose a network based approach to quantify the 'quality' of a batsman or bowler. The rest of the paper is presented as follows. In Section 2 we propose the methods of link formation among the batsmen and bowlers. In Section 3 we discuss the results and we conclude in Section 4.

2. Methodology

We obtain data from the cricinfo website [43]. The website contains the information of proceedings of all Test matches played since 1877 and all ODI matches from 1971 onwards. These include the runs scored by batsmen, wickets taken by bowlers, outcome of a game and also the information of the mode of dismissal of a batsman. We collect the data of player-vs-player for Test cricket (2001–2011), and ODI cricket (1999–2011) from the cricinfo website. The data of player-vs-player contain the information of runs scored by a batsman against every bowler he faced and how many times he was dismissed by the bowlers he faced. No information of player-vs-player is available for games played earlier than 2001. We also collect the batting and bowling averages of players from the player's profile available in the cricinfo website. The batting average of a batsman is defined as the total number of runs scored by the batsman divided by the number of times he was dismissed. Thus, a higher batting average reflects a higher 'quality' of a batsman. Similarly, the bowling average is defined as the number of runs given by the bowler divided by the number of wickets claimed by him. Thus, a lower bowling average indicates a higher ability of the bowler. This information is used to generate the network of interaction among bowlers and batsmen in cricket matches.

2.1. Weighted and directed network

Cricket is a bat-and-ball game played between two teams of 11 players each. The team batting first tries to score as many runs as possible, while the other team bowls and fields, trying to dismiss the batsmen. At the end of an innings, the teams switch between batting and fielding. This can be represented as a directed network of interaction of batsmen (B_a) and bowlers (B_o). Every node in B_o has a directed link to all nodes in B_a, provided the batsman and bowler face each other. The performance of a batsman is judged by the 'quality' of runs scored and not the number of runs scored. Hence, runs scored against a bowler with a lower bowling average carry more credit than runs scored against a bowler of less importance. We introduce a performance index of a batsman (PIB) against a bowler given by the following equation

$$\mathrm{PIB} = \frac{A_{Ba}}{C_{Bo}} \tag{1}$$

where A_{Ba} is the batting average of the batsman against the bowler he faced and C_{Bo} refers to the career bowling average of the bowler. Mathematically, the batting average of the batsman (A_{Ba}) is given by the ratio $\frac{R}{d}$ where R is the number of runs scored against a bowler and d is the number of times he was dismissed by the bowler.[1] Hence, if the career bowling average of a bowler is low (indicating a good bowler), PIB increases indicating that the batsman scored runs against quality opposition. We generate a weighted and directed network of bowlers to batsmen where the weight of the link is given by PIB. The network generated is thus based on the directed interaction of B_o and B_a. For the weighted network the in-strength s_i^{in} is defined as

$$s_i^{\mathrm{in}} = \sum_{j \neq i} W_{ji} \tag{2}$$

where W_{ji} is given by the weight of the directed link.

So far, we have concentrated on the performance index of batsmen since 2001. Although the data for player-vs-player are not available for dates earlier than 2001, one could quantify the overall performance of a bowler based on the dismissal record of batsmen. For example, the wicket of a top-order batsman always deserves more credit than the wicket of a tail-ender. Thus, the 'quality' of dismissal serves as a measure for the greatness of a bowler. We define the quality index of bowler (QIB) as

$$\mathrm{QIB} = D\frac{C_{Ba}}{C_{Bo}} \tag{3}$$

where D is defined as the number of times a batsman was dismissed by a particular bowler, C_{Ba} refers to the career batting average of a batsman and C_{Bo} indicates the career bowling average of a bowler. Thus, a greater value of QIB indicates a better rank of a bowler. As before, we construct weighted and directed networks, this time the directed link pointing towards the bowlers. We evaluate the in-strength of the bowlers, which serves as a quantification of the 'quality' of a bowler.

2.2. Projected network

The manner in which the game is played does not allow us to compare the relative dominance of one batsman over another batsman or one bowler over another bowler. Unlike in tennis, where each player has to compete directly with the opponent, in cricket a batsman is pitted against a bowler. Hence, it is very difficult to judge the relative superiority of a batsman (bowler) over another batsman (bowler). The in-strength of a bowler or batsman conveys the 'quality' of dismissal by a bowler or the 'quality' of runs scored by a batsman. However, it does not reflect the relative importance or popularity of one player over other players. To address this issue, in this section we generate a one-mode projected network between batsmen who face the same bowler (or bowlers who dismiss the same batsman) in which the links are generated according to the method of gradient link formation. Traditionally a gradient network is constructed as follows. Consider a substrate

[1] R and d are evaluated for Test matches played between 2001 and 2011 and ODI (1999–2011).

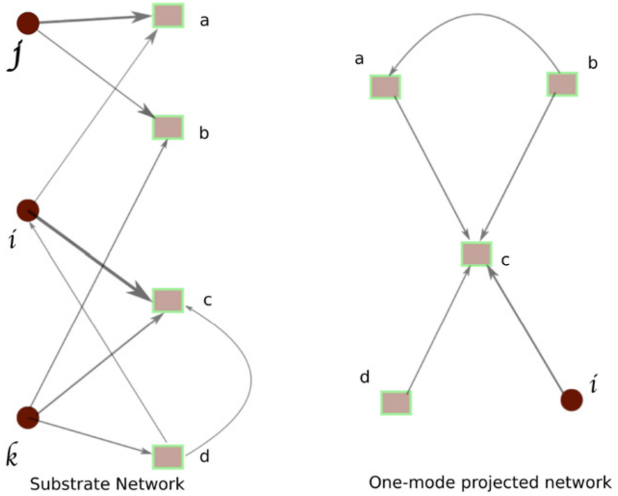

Fig. 1. (Color online) Substrate network of batsmen and bowlers. The thickness of the directed link is proportional to the QIB. The resultant network of bowlers is constructed if the bowlers dismiss the same batsman and they are contemporary players. The direction and weights of the links are applied according to the gradient scheme of link formation.

network S. Each node i in the network is assigned a random number h_i which describes the 'potential' of the node. A gradient network is constructed by directed links that point from each node to the nearest neighbor with highest potential [44,45]. Here we take a slightly different route to construct the projected network.

In Fig. 1 we demonstrate the generation of the one-mode projected network according to the gradient scheme of link formation. First we consider the substrate network of batsmen and bowlers according to the dismissal records. The thickness of the edge is proportional to QIB. Thus, if batsman i is dismissed by bowlers a and c, then bowlers a and c are connected. We evaluate the in-strength s_i^{in} of the nodes a and c. The in-strength acts a 'potential' for each bowler. We construct gradient links between two bowlers along the steepest ascent, where the weight of the directed link is the difference of the in-strength of two nodes. Thus, weighted and directed links are formed between two bowlers if they dismiss the same batsman. We repeat this procedure for all the nodes in the substrate network and a resultant one-mode projected network is formed. Additionally we introduce a constraint, in which two bowlers are linked only if they are contemporary. Thus, b and d are not linked in the gradient scheme since they are not contemporary players. We apply the same method of gradient link formation on batsmen, where the weight of each link in the substrate network is proportional to the PIB. The weight ω_{ij} of a gradient-link is given as

$$\omega_{ij} = |s_i^{\text{in}} - s_j^{\text{in}}| \tag{4}$$

where $s_{i,j}^{\text{in}}$ are the in-strength of two nodes i and j. The projected network thus highlights the relative importance of a player over other. We construct the substrate network of batsmen and bowlers for Test cricket and ODI cricket and construct the projected network of players. Next we apply the PageRank algorithm on the resultant projected network and evaluate the importance of each player. In Fig. 2(A) we show a subgraph of the substrate network of batsmen and bowlers in ODI (1971–2011). The projected network of bowlers is generated if they dismiss the same batsman (*Wasim Akram*) (see Fig. 2(B)). In the same way one can construct a projected network of batsmen who are dismissed by *Wasim Akram*.

2.2.1. PageRank algorithm

We quantify the importance or 'popularity' of a player with the use of a complex network approach and evaluating the PageRank score, originally developed by Brin and Page [46]. Mathematically, the process is described by the system of coupled equations

$$p_i = (1-q)\sum_j p_j \frac{\omega_{ij}}{s_j^{\text{out}}} + \frac{q}{N} + \frac{1-q}{N}\sum_j \delta\left(s_j^{\text{out}}\right), \tag{5}$$

where ω_{ij} is the weight of a link and $s_j^{\text{out}} = \Sigma_i \omega_{ij}$ is the out-strength of a link. p_i is the PageRank score assigned to team i and represents the fraction of the overall "influence" sitting in the steady state of the diffusion process on vertex i [37]. $q \in [0, 1]$ is a control parameter that awards a 'free' popularity to each player and N is the total number of players in the network. The term $(1-q)\sum_j p_j \frac{\omega_{ij}}{s_j^{\text{out}}}$ represents the portion of the score received by node i in the diffusion process obeying the hypothesis that nodes redistribute their entire credit to neighboring nodes. The term $\frac{q}{N}$ stands for a uniform redistribution of credit among all nodes. The term $\frac{1-q}{N}\sum_j p_j\, \delta\left(s_j^{\text{out}}\right)$ serves as a correction in the case of the existence nodes

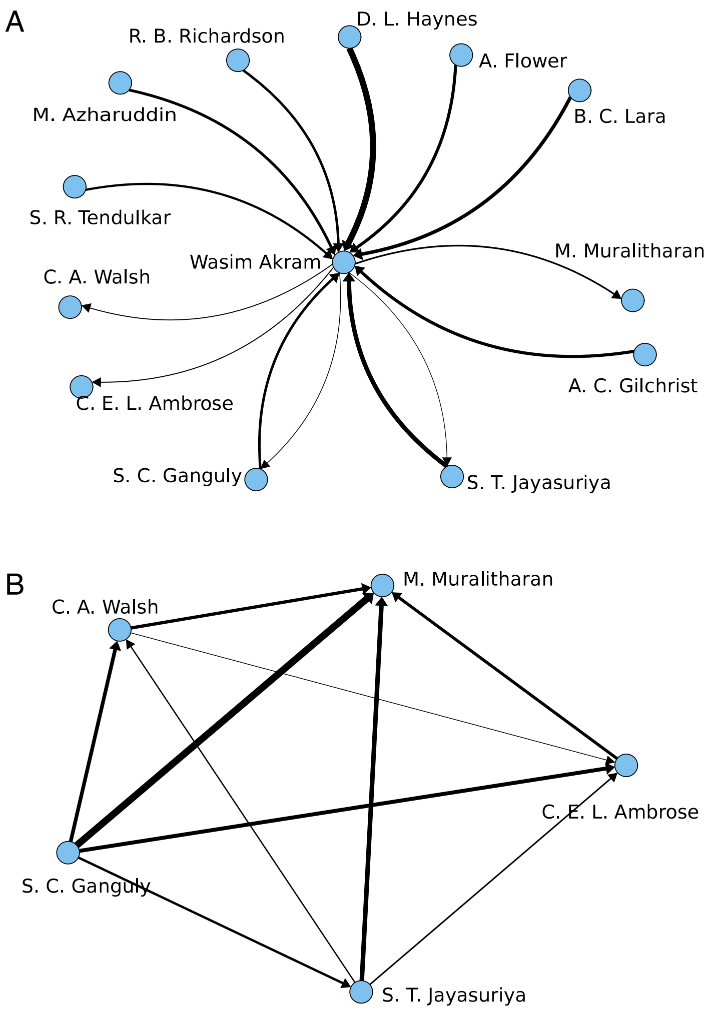

Fig. 2. (Color online) (A) Subgraph of the substrate network of batsmen and bowlers in ODI (1971–2011). The thickness of the directed link is proportional to the QIB. (B) The resultant projected network of bowlers is constructed if the bowlers dismiss the same batsman (here it is *Wasim Akram*).

with null out-degree, which otherwise would behave as sinks in the diffusion process. It is to be noted that the PageRank score of a player depends on the scores of all other players and needs to be evaluated at the same time. To implement the PageRank algorithm in the directed and weighted network, we start with a uniform probability density equal to $\frac{1}{N}$ at each node of the network. Next we iterate through Eq. (5) and obtain a steady-state set of PageRank scores for each node of the network. Finally, the values of the PageRank score are sorted to determine the rank of each player. According to tradition, we use a uniform value of $q = 0.15$. This choice of q ensures a higher value of PageRank scores [37]. In general it is difficult to get analytical solutions for Eq. (5) [37,47]. Although in the simplest case of a single tournament an analytical solution for values of p_i was determined [37], in Cricket such a situation is not possible since it is a team game. The values of p_is are evaluated recursively by setting $p_i = \frac{1}{N}$. Then we iterate Eq. (5) until a steady-state of values is reached.

3. Results

In this section, we explore the in-strength distribution of the weighted and directed networks. The in-strength of a node is an indication of the performance of an individual against the opponent team member. Thus, a greater value of in-strength indicates a better performance of the individual. In Fig. 3 we plot the cumulative in-strength distribution of batsmen and bowlers in Test cricket and ODI cricket. The in-strength distribution reflects the topology of the network and how the players interact with each other. As shown in Fig. 3(A), the in-strength distribution decays slowly for smaller values of in-strength (≈70). For values higher than 70, the in-strength distribution decays at a much faster rate. This is in contrast with the in-strength distribution of bowlers (Fig. 3(B)), where the decay is slow. The reason being that all bowlers have to bat once the top order batsmen have been dismissed, thus establishing more links for the batsmen. However, not all batsmen are specialist bowlers, which leads to low connections for bowlers.

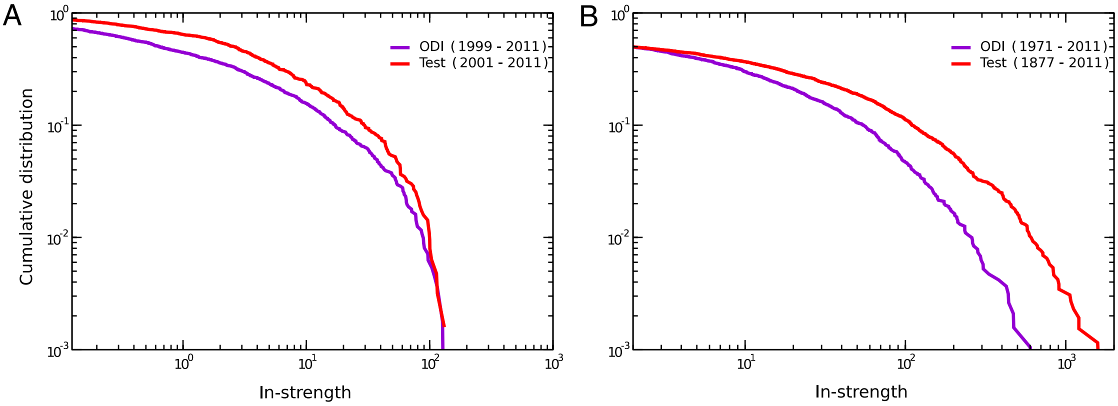

Fig. 3. (Color online) In-strength distribution of the weighted and directed network of (A) batsmen in Test cricket (2001–2011) and ODI cricket (1999–2011) and (B) bowlers network in the history of Test cricket (1877–2011) and ODI (1971–2011).

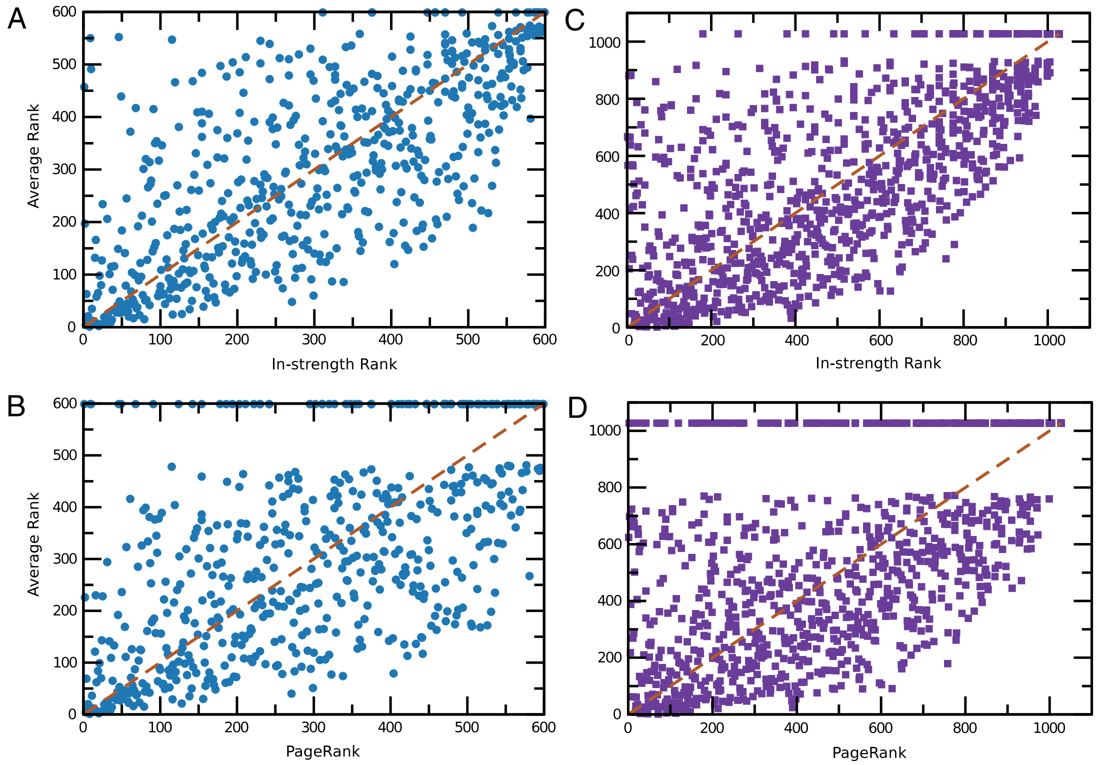

Fig. 4. (Color online) (A) Scatter plot of between the rank positions obtained according to batting average rank and In-strength rank for Test cricket (2001–2011); Spearman correlation $\rho = 0.71$. (B) Scatter plot of between the rank positions obtained according to batting average rank and PageRank score for Test cricket (2001–2011); Spearman correlation $\rho = 0.62$. (C) Scatter plot of between the rank positions obtained according to batting average rank and In-strength rank for ODI cricket (1999–2011); Spearman correlation $\rho = 0.69$. (D) Scatter plot of between the rank positions obtained according to batting average rank and PageRank score in ODI cricket (1999–2011); Spearman correlation $\rho = 0.61$.

As mentioned above the in-strength of a batsman reflects the performance of a batsman in terms of the quality of runs scored. In Table 1 we list the top 50 batsmen in Test cricket between 2001 and 2011. The batsmen are ranked according to their in-strength. We observe that *K. C. Sangakkara* of Sri Lanka occupies the top spot followed by India's *S. R. Tendulkar* with Australia's *R. T. Ponting* and South Africa's *J. H. Kallis* occupying the third and fourth spot respectively. *R. Dravid* of India occupies the fifth position. We compare the in-strength rank with the PageRank score and batting average of batsmen for runs scored between 2001 and 2011. Additionally we list the best ever cricket rating received by a batsman between 2001 and 2011. In Fig. 4(A), (B) we compare the correlation of ranks obtained from in-strength and PageRank algorithm with batting average. We observe that ranks obtained from the batting average are positively correlated with in-strength rank

Table 1
Ranking of the top 50 batsmen in Test cricket (2001–2011). We compare the rank of the batsmen according to their In-strength and compare them with the corresponding PageRank score, Batting average and best ever points according to ICC ratings.

Rank	Batsman	Country	In strength	PageRank score	Batting average	ICC points
1	K. C. Sangakkara	Sri Lanka	131.520	0.189813	59.43	938
2	S. R. Tendulkar	India	115.460	0.065442	55.13	898
3	R. T. Ponting	Australia	113.582	0.049806	59.93	942
4	J. H. Kallis	South Africa	103.545	0.030825	66.66	935
5	R. Dravid	India	100.344	0.023313	54.31	892
6	V. Sehwag	India	100.076	0.022095	51.87	866
7	D. P. M. D. Jayawardene	Sri Lanka	99.131	0.022345	55.41	883
8	V. V. S. Laxman	India	97.555	0.020722	49.58	781
9	S. Chanderpaul	West Indies	96.319	0.019905	56.40	901
10	G. C. Smith	South Africa	88.943	0.014527	50.28	843
11	M. L. Hayden	Australia	85.628	0.012232	56.27	935
12	Younis Khan	Pakistan	83.255	0.011589	57.15	880
13	B. C. Lara	West Indies	82.112	0.009571	60.88	991
14	A. N. Cook	England	80.407	0.008708	48.69	836
15	A. J. Strauss	England	78.447	0.008470	41.60	769
16	K. P. Pietersen	England	77.312	0.007912	50.79	909
17	C. H. Gayle	West Indies	74.070	0.007991	43.27	755
18	A. B. de Villiers	South Africa	73.922	0.007441	51.00	776
19	M. E. K. Hussey	Australia	70.899	0.006557	51.29	921
20	M. P. Vaughan	England	65.216	0.005795	44.28	876
21	T. T. Samaraweera	Sri Lanka	64.221	0.006355	60.08	750
22	J. L. Langer	Australia	62.221	0.005165	50.69	780
23	R. R. Sarwan	West Indies	58.056	0.005216	41.94	767
24	B. B. McCullum	New Zealand	57.958	0.004427	36.90	673
25	D. L. Vettori	New Zealand	57.919	0.006190	35.70	672
26	M. J. Clarke	Australia	57.830	0.004501	50.43	855
27	H. H. Gibbs	South Africa	57.566	0.004485	46.67	825
28	I. R. Bell	England	57.356	0.004460	47.80	822
29	M. E. Trescothick	England	55.499	0.003753	45.83	818
30	T. M. Dilshan	Sri Lanka	54.190	0.005119	44.37	700
31	A. C. Gilchrist	Australia	53.751	0.003999	48.16	874
32	D. R. Martyn	Australia	53.141	0.003723	48.32	848
33	H. M. Amla	South Africa	52.579	0.003863	48.52	842
34	A. Flintoff	England	48.845	0.003620	34.06	645
35	Inzamam ul Haq	Pakistan	46.838	0.003317	57.75	870
36	S. T. Jayasuriya	Sri Lanka	46.401	0.003044	42.66	770
37	S. M. Katich	Australia	45.676	0.003037	46.01	807
38	S. C. Ganguly	India	45.418	0.002945	42.26	713
39	M. V. Boucher	South Africa	44.699	0.004131	31.78	566
40	L. R. P. L. Taylor	New Zealand	44.060	0.002538	45.72	775
41	G. Gambhir	India	43.806	0.002713	47.51	886
42	P. D. Collingwood	England	43.739	0.002763	40.57	730
43	S. P. Fleming	New Zealand	43.374	0.002823	44.15	725
44	M. S. Dhoni	India	43.344	0.002406	37.84	662
45	M. S. Atapattu	Sri Lanka	40.912	0.002540	44.72	670
46	A. G. Prince	South Africa	40.704	0.002530	43.12	756
47	Habibul Bashar	Bangladesh	40.702	0.002456	31.03	656
48	Mohammad Ashraful	Bangladesh	38.937	0.002942	22.62	491
49	M. J. Prior	England	38.594	0.001972	46.75	679
50	Imran Farhat	Pakistan	37.910	0.002399	33.03	575

and PageRank score. Judged by the batting average and the ICC points we observe that *B. C. Lara* of West Indies emerge as the most successful batsman in Test cricket between 2001 and 2011. Similarly Australia's *R. T. Ponting* averages more than *S. R. Tendulkar* and *K. C. Sangakkara*. However, both *K. C. Sangakkara* and *S. R. Tendulkar* accumulated runs against better bowling attack. In Table 2 we list the top 50 batsmen in ODI cricket (1999–2011). As shown in Fig. 4(C), (D) we observe that the ranks obtained from batting average are positively correlated with in-strength rank and PageRank score. The top 5 positions according to in-strength rank or PageRank do not correspond with that of batting average or ICC rankings. Again *K. C. Sangakkara* emerges as the most successful batsman followed by Australia's *R. T. Ponting* and India's *S. R. Tendulkar*. Even though *S. R. Tendulkar* averages more than his predecessors and also received the highest ICC points, both *K. C. Sangakkara* and *R. T. Ponting* scored runs against better bowling attack. Note that this ranking is sensitive to change in information of player-vs-player once the information prior to the year 2000 is available in the cricinfo website.

We rank the performance of all bowlers in Test cricket (1877–2011) in Table 3, and identify the bowlers with the highest influence. We observe that the bowlers ranked by the average are different from those obtained from SNA. In Fig. 5(A),

Table 2
Ranking of the top 50 batsmen in ODI cricket (1999–2011). We compare the rank of the batsmen according to their In-strength and compare them with the corresponding PageRank score, Batting average and best ever points according to ICC ratings.

Rank	Batsman	Country	In strength	PageRank score	Batting average	ICC points
1	K. C. Sangakkara	Sri Lanka	128.075	0.165704	42.59	863
2	R. T. Ponting	Australia	127.058	0.095677	46.94	829
3	S. R. Tendulkar	India	120.251	0.052469	50.90	898
4	D. P. M. D. Jayawardene	Sri Lanka	115.475	0.040357	38.33	738
5	Yuvraj Singh	India	109.620	0.027228	40.48	787
6	V. Sehwag	India	104.183	0.022008	38.51	774
7	J. H. Kallis	South Africa	97.150	0.016652	49.89	817
8	M. S. Dhoni	India	96.639	0.014579	56.44	836
9	Younis Khan	Pakistan	90.578	0.013467	37.19	659
10	S. T. Jayasuriya	Sri Lanka	89.352	0.012719	36.13	838
11	G. C. Smith	South Africa	88.873	0.011473	40.25	784
12	M. J. Clarke	Australia	86.790	0.010249	51.50	750
13	R. Dravid	India	85.407	0.009736	48.95	749
14	A. C. Gilchrist	Australia	79.554	0.007398	36.95	820
15	C. H. Gayle	West Indies	78.427	0.008268	42.50	804
16	S. Chanderpaul	West Indies	77.500	0.008227	48.10	776
17	M. E. K. Hussey	Australia	77.276	0.006517	53.15	857
18	M. L. Hayden	Australia	76.883	0.007100	46.95	850
19	T. M. Dilshan	Sri Lanka	71.624	0.006672	38.74	765
20	H. H. Gibbs	South Africa	71.192	0.006471	40.06	750
21	B. B. McCullum	New Zealand	67.281	0.005514	31.98	664
22	S. C. Ganguly	India	65.523	0.004433	41.73	844
23	P. D. Collingwood	England	64.758	0.004741	39.50	697
24	S. B. Styris	New Zealand	64.627	0.005155	37.69	663
25	Shoaib Malik	Pakistan	64.263	0.005298	38.90	685
26	R. R. Sarwan	West Indies	63.823	0.004680	48.99	780
27	G. Gambhir	India	62.207	0.004319	44.93	722
28	A. B. de Villiers	South Africa	61.920	0.004008	55.53	803
29	W. U. Tharanga	Sri Lanka	60.773	0.003835	37.38	663
30	A. J. Strauss	England	60.650	0.003881	37.29	698
31	M. S. Atapattu	Sri Lanka	60.328	0.003837	44.77	738
32	Shahid Afridi	Pakistan	58.139	0.004976	24.39	663
33	S. P. Fleming	New Zealand	54.770	0.003231	36.20	697
34	Inzamam ul Haq	Pakistan	53.965	0.003072	40.68	801
35	K. P. Pietersen	England	53.804	0.003069	43.54	833
36	Yousuf Youhana	Pakistan	53.255	0.003473	52.36	Not Available
37	M. E. Trescothick	England	52.613	0.002360	40.48	797
38	M. V. Boucher	South Africa	52.510	0.003781	32.72	621
39	S. K. Raina	India	51.335	0.002705	37.90	658
40	Abdul Razzaq	Pakistan	49.876	0.003503	35.05	328
41	S. R. Watson	Australia	49.387	0.003247	43.70	773
42	A. Symonds	Australia	49.098	0.002789	46.49	776
43	I. R. Bell	England	46.834	0.002560	38.96	702
44	C. D. McMillan	New Zealand	43.952	0.002434	30.86	648
45	V. Kohli	India	42.868	0.001593	55.23	799
46	Salman Butt	Pakistan	42.253	0.001602	44.66	683
47	Shakib Al Hasan	Bangladesh	41.856	0.002256	36.31	659
48	H. M. Amla	South Africa	40.457	0.001523	65.48	886
49	B. R. M. Taylor	New Zealand	40.289	0.002036	36.57	654
50	Tamim Iqbal	Bangladesh	39.593	0.001845	33.77	629

(B) we compare the ranking obtained from in-strength and PageRank algorithm with bowling average. We observe a low positive correlation between the different ranking schemes. We observe that according to in-strength values Sri Lanka's *M. Muralitharan* emerges as the most successful bowler in the history of Test cricket (1877–2011) followed by *S. K. Warne* (AUS), *G. D. McGrath* (AUS), *A. Kumble* (IND) and *C. A. Walsh* (WI) (see Table 3). As before we generate a gradient network of bowlers and apply the PageRank algorithm. It is interesting to note that the top five bowlers according to PageRank score are *M. Muralitharan* (SL), *S. K. Warne* (AUS), *G. D. McGrath* (AUS), *F. S. Trueman* (ENG) and *C. A. Walsh* (WI) (see Table 3). Thus, according to the quality of 'dismissal' and relative 'popularity' of bowlers *M. Muralitharan* emerges as the most successful bowler in Test cricket. Interestingly, *M. Muralitharan* is the highest wicket-taker in Test cricket. His success could be *a posteriori* justified by his long and successful career spanning 18 years (between 1992 and 2010). During his entire career *M. Muralitharan* dismissed 800 batsmen (highest in Test cricket) which included the likes of *S. R. Tendulkar* (dismissed 14 times), *R. Dravid* (dismissed 12 times) and *B. C. Lara* (dismissed 9 times). In addition to this he holds the record of a maximum

Table 3
Ranking of top 50 bowlers in the history of Test cricket (1877–2011). We compare the rank of the bowlers according to their In-strength and compare them with the corresponding PageRank score, Batting average and best ever points according to ICC ratings.

Rank	Bowlers	Country	In strength	PageRank score	Bowling average	ICC points
1	M. Muralitharan	Sri Lanka	1838.727	0.081376	22.72	920
2	S. K. Warne	Australia	1600.098	0.037871	25.41	905
3	G. D. McGrath	Australia	1581.467	0.035376	21.64	914
4	A. Kumble	India	1207.115	0.028108	29.65	859
5	C. A. Walsh	West Indies	1206.669	0.028407	24.44	867
6	C. E. L. Ambrose	West Indies	1118.653	0.014483	20.99	912
7	M. D. Marshall	West Indies	1077.349	0.027349	20.94	910
8	S. M. Pollock	South Africa	1060.700	0.008220	23.11	909
9	D. K. Lillee	Australia	907.015	0.011724	23.92	884
10	Wasim Akram	Pakistan	906.455	0.007559	23.62	830
11	Imran Khan	Pakistan	891.679	0.012749	22.81	922
12	A.A. Donald	South Africa	842.499	0.003900	22.25	895
13	M. Ntini	South Africa	836.285	0.004674	28.82	863
14	Waqar Younis	Pakistan	832.806	0.004918	23.56	909
15	F. S. Trueman	England	791.479	0.034600	21.57	898
16	N. Kapil Dev	India	778.960	0.006425	29.64	877
17	Harbhajan Singh	India	761.382	0.004886	32.22	765
18	I. T. Botham	England	720.371	0.004315	28.40	911
19	R. G. D. Willis	England	719.321	0.005895	25.20	837
20	D. L. Underwood	England	697.950	0.008028	25.83	907
21	W. P. U. J. C. Vaas	Sri Lanka	668.274	0.003754	29.58	800
22	D. W. Steyn	South Africa	663.894	0.003566	23.07	902
23	J. Garner	West Indies	647.740	0.002803	20.97	890
24	B. Lee	Australia	624.158	0.002397	30.81	811
25	M. A. Holding	West Indies	615.905	0.003025	23.68	860
26	L. R. Gibbs	West Indies	607.816	0.010326	29.09	897
27	R. R. Lindwall	Australia	593.348	0.008941	23.03	897
28	C. J. McDermott	Australia	590.881	0.002318	28.63	794
29	J. N. Gillespie	Australia	585.951	0.002121	26.13	812
30	J. B. Statham	England	575.871	0.007935	24.84	810
31	S. F. Barnes	England	575.551	0.011649	16.43	932
32	Z. Khan	India	574.541	0.003255	31.78	752
33	A. V. Bedser	England	573.140	0.006187	24.89	903
34	D. L. Vettori	New Zealand	558.336	0.003616	33.65	681
35	A. K. Davidson	Australia	531.038	0.004510	20.53	908
36	M. J. Hoggard	England	523.946	0.001646	30.56	795
37	J. C. Laker	England	522.186	0.004353	21.24	897
38	G. D. McKenzie	Australia	518.735	0.003349	29.78	846
39	Saqlain Mushtaq	Pakistan	513.114	0.001625	29.83	771
40	R. Benaud	Australia	512.006	0.003863	27.03	863
41	C. V. Grimmett	Australia	509.586	0.024239	24.21	901
42	J. H. Kallis	South Africa	500.176	0.003184	32.51	742
43	Mohammad Asif	Pakistan	499.581	0.001268	24.36	818
44	B. S. Bedi	India	488.933	0.002868	28.71	804
45	J. M. Anderson	England	486.732	0.002245	30.46	813
46	A. R. Caddick	England	483.068	0.001447	29.91	732
47	K. R. Miller	Australia	476.808	0.003903	22.97	862
48	J. A. Snow	Australia	468.001	0.002138	26.66	835
49	D. Gough	England	457.295	0.001287	28.39	794
50	W. W. Hall	West Indies	455.804	0.003022	26.38	898

number of five wickets in an innings (67 times) and ten wickets in a match (22 times). We also observe that *S. K. Warne*, the second best bowler in Test cricket, has the second highest number of dismissals (708) to his credit. Both these bowlers had extremely long and successful careers spanning almost two decades. Australia's *G. D. McGrath*, who has been considered one of the best fast bowlers in cricket, holds a better average than that of his immediate predecessors. However, his in-strength rank and PageRank score indicates that his quality of dismissal were not better than *Muralitharan* or *Warne*. This leads to the question—are bowling averages the best indicator of a bowler's ability? In our all time top 50 list we observe that England's *S. F. Barnes* has the best bowling average of 16.43 and the highest ICC points of 932 among all the bowlers (as listed in Table 3). However, like *George Lohmann*, *S. F. Barnes* too enjoyed favorable pitch conditions. The batsmen playing in such pitches usually averaged lower than the recent batsmen. Hence, for players like *S. F. Barnes*, the QIB is low which in turn affects his in-strength. However, his PageRank score is higher than most of the modern age bowlers indicating his relative 'popularity' or supremacy over other bowlers. A similar situation is seen with Pakistan's *Imran Khan*. Although his in-strength is lower than that of *Wasim Akram* or *D. K. Lillee*, his PageRank score is higher than most of his predecessors. Rankings based on SNA show little agreement with traditional methods of performance evaluation.

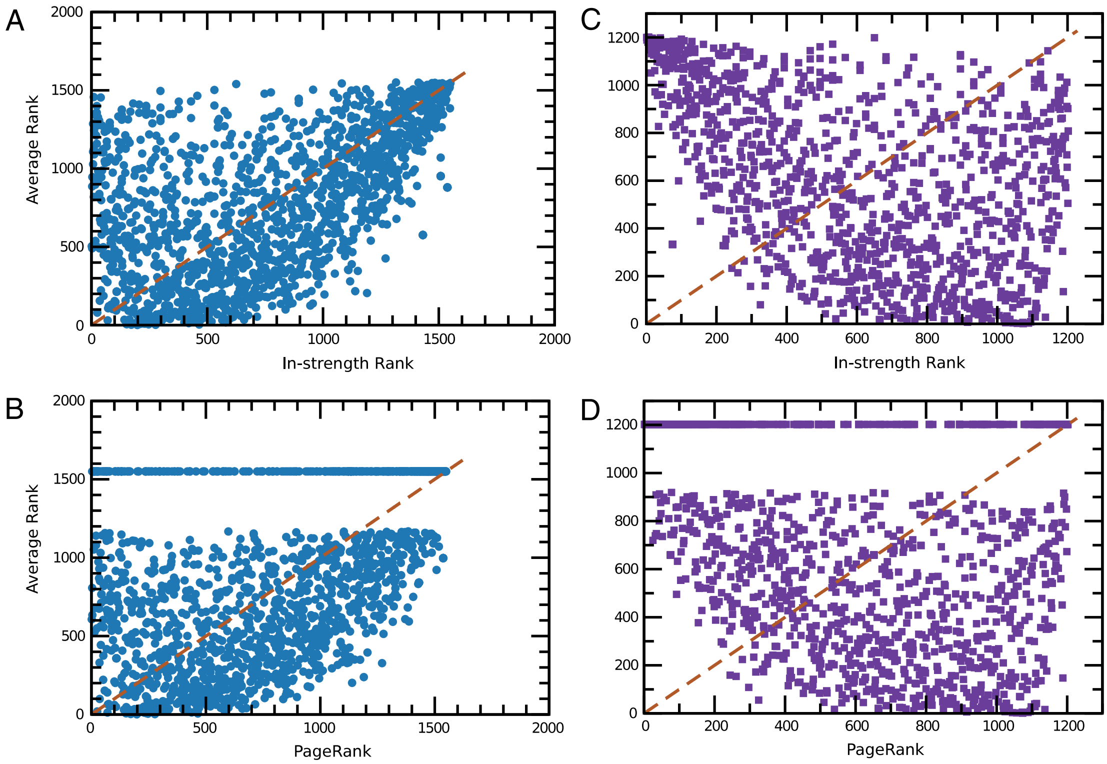

Fig. 5. (Color online) (A) Scatter plot of between the rank positions obtained according to bowling average rank and In-strength rank for Test cricket (1877–2011); Spearman correlation $\rho = 0.53$. (B) Scatter plot of between the rank positions obtained according to bowling average rank and PageRank score for Test cricket (1877–2011); Spearman correlation $\rho = 0.46$. (C) Scatter plot of between the rank positions obtained according to bowing average rank and In-strength rank for ODI cricket (1971–2011); Spearman correlation $\rho = -0.44$. (D) Scatter plot of between the rank positions obtained according to bowling average rank and PageRank score in ODI cricket (1971–2011); Spearman correlation $\rho = -0.34$.

In ODI history (1971–2011) too, Sri Lanka's *M. Muralitharan* leads the list of top 50 bowlers, followed by Pakistan's *Wasim Akram*, Australia's *G. D. McGrath*, Pakistan's *Waqar Younis* and South Africa's *S. M. Pollock* (Table 4). PageRank scores reveal that *M. Muralitharan* is the most successful bowler followed by *Wasim Akram* (PAK), *Waqar Younis* (PAK), *G. D. McGrath* (AUS) and *B. Lee* (AUS). Although *G. D. McGrath* has a slightly better average than *M. Muralitharan*, he falls short of the latter in terms of in-strength, PageRank score and ICC points. Again, judged by the number of dismissals, *M. Muralitharan* heads the list with 534 wickets, with *Wasim Akram* and *Waqar Younis* occupying the second and third position respectively. There are few surprises in the list. India's *A. B. Agarkar* is placed above in comparison to *N. Kapil Dev* (IND), *C. E. L. Ambrose* (WI) or *C. A. Walsh* (WI) whom cricket experts consider as better bowlers. However, what goes in favor of *A. B. Agarkar* is the 'quality' of the wickets he took. Thus, even though he went for runs and did not have a long career, he was able to dismiss most of the batsmen with a good average. In Fig. 5(C), (D) we compare the ranks obtained from in-strength and PageRank with bowling average. We observe that ranking schemes obtained from PageRank (and in-strength) are anti-correlated with the bowling average. This is not surprising in the sense that the bowling average is not a proper way of judging a player's performance. Also in the ODIs, there has been a practice of bringing in part-time bowlers who have low-averages. This is paradoxical in the sense that it indicates part-time bowlers are better than the regular bowlers.

We find that our scheme provides sensible results that are in agreement with the points provided by the ICC. The rankings provided by the ICC take into account several factors like wickets taken, quality of pitch and opposition, match result etc. However, due to its opaqueness, ICC's methodology is incomprehensible. Our approach is both novel and transparent. For comparison, we choose the top 200 bowlers according to ICC rankings[2] and compare them with in-strength rank and PageRank. Fig. 6 shows that a strong correlation exists between ranks obtained by network based tools and that provided by the ICC. This demonstrates that our network based approach captures the consensus opinions.

Finally we propose a linear regression model for in-strength that takes into consideration known ranking schemes like PageRank, batting (bowling) average and ICC ranking,

$$s(i) = A_0 + A_1\,\rho(i) + A_2\,B_{\mathrm{Avg}}(i) + A_3\,\delta(i), \tag{6}$$

2 Since the information of ICC points is not consistently stored we choose the information of the top 200 bowlers in ODI and Test.

Table 4
Ranking of top 50 bowlers in the history of ODI cricket (1971–2011). We compare the rank of the bowlers according to their In-strength and compare them with the corresponding PageRank score, Batting average and best ever points according to ICC ratings.

Rank	Bowlers	Country	In strength	PageRank Score	Bowling average	ICC points
1	M. Muralitharan	Sri Lanka	607.375	0.170207	23.08	913
2	Wasim Akram	Pakistan	601.274	0.111784	23.52	850
3	G. D. McGrath	Australia	473.596	0.029389	22.02	903
4	Waqar Younis	Pakistan	471.019	0.030567	23.84	778
5	S. M. Pollock	South Africa	440.701	0.018813	24.50	917
6	B. Lee	Australia	437.882	0.020709	23.18	852
7	W. P. U. J. C. Vaas	Sri Lanka	426.005	0.019129	27.53	860
8	Saqlain Mushtaq	Pakistan	381.207	0.011874	21.78	804
9	A. A. Donald	South Africa	331.312	0.011041	21.78	794
10	M. Ntini	South Africa	305.877	0.007624	24.65	783
11	J. Srinath	India	305.067	0.008372	28.08	742
12	S. K. Warne	Australia	296.573	0.007119	25.73	786
13	A. Kumble	India	293.592	0.009605	30.89	797
14	A. B. Agarkar	India	283.160	0.005718	27.85	675
15	Shahid Afridi	Pakistan	281.853	0.007799	33.37	623
16	D. L. Vettori	New Zealand	266.683	0.006241	31.48	788
17	Z. Khan	India	262.253	0.006112	29.03	700
18	Harbhajan Singh	India	261.937	0.005727	33.40	735
19	C. E. L. Ambrose	West Indies	259.694	0.005700	24.12	877
20	D. Gough	England	247.125	0.004335	26.42	767
21	S. T. Jayasuriya	Sri Lanka	236.641	0.006771	36.75	591
22	N. Kapil Dev	India	234.467	0.009698	27.45	845
23	J. H. Kallis	South Africa	234.421	0.005161	31.69	641
24	Abdul Razzaq	Pakistan	234.380	0.004718	31.83	678
25	K. D. Mills	New Zealand	218.920	0.003573	25.94	722
26	C. J. McDermott	Australia	212.171	0.003862	24.71	808
27	H. H. Streak	Zimbabwe	211.982	0.003212	29.82	717
28	J. Garner	West Indies	209.613	0.006778	18.84	940
29	S. E. Bond	New Zealand	208.962	0.002790	20.88	809
30	C. A. Walsh	West Indies	203.122	0.004218	30.47	801
31	N. W. Bracken	Australia	202.785	0.002428	24.36	805
32	C. L. Cairns	New Zealand	197.498	0.003479	32.80	784
33	A. Flintoff	England	192.269	0.002707	24.38	755
34	J. M. Anderson	England	191.432	0.003190	30.83	687
35	M. G. Johnson	Australia	187.358	0.002140	25.22	724
36	C. R. D. Fernando	Sri Lanka	186.151	0.003019	30.20	624
37	B. K. V. Prasad	India	177.538	0.000349	32.30	692
38	Imran Khan	Pakistan	174.633	0.005972	26.61	780
39	L. Klusener	South Africa	174.271	0.000358	29.95	657
40	Abdur Razzak	Bangladesh	173.970	0.002919	28.12	675
41	M. A. Holding	West Indies	160.605	0.004294	21.36	875
42	C. Z. Harris	New Zealand	159.101	0.002170	37.50	659
43	M. D. Marshall	West Indies	158.326	0.003466	26.96	891
44	S. C. J. Broad	England	158.194	0.000867	26.95	701
45	C. L. Hooper	West Indies	154.591	0.002299	36.05	679
46	S. L. Malinga	Sri Lanka	154.017	0.002022	26.35	674
47	J. N. Gillespie	Australia	150.864	0.002121	25.42	823
48	G. B. Hogg	Australia	149.910	0.000216	26.84	688
49	I. K. Pathan	India	148.536	0.000352	29.89	722
50	S. R. Waugh	Australia	147.948	0.002199	34.67	680

where $s(i)$ is the in-strength, and $\rho(i)$ is the PageRank of a player i. B_{Avg} represents the batting (bowling) average of player i and $\delta(i)$ is a dummy variable which takes the value 1 if a player is placed in the top 100 of the ICC player ranking [43], and 0 otherwise. As shown in Table 5, we observe that for bowlers in Test cricket (1877–2011), the bowling average has no significant effect for in-strength, thus justifying the absence of correlation observed earlier in Fig. 5(C), (D).

4. Conclusion

To summarize, we quantified the performance of batsmen and bowlers in the history of cricket by studying the network structure of cricket players. Under the usual qualification of 2000 balls bowled, *George Lohmann* emerges as the best bowler. Again, if we apply the qualification of at least 10 dismissals, then *C. S. Marriott* is the best bowler. These constraints are arbitrary and hence gauging a bowler's potential according to the bowling average is not robust. The advantage of network analysis is that it does not introduce these 'constraints' and yet provides consistent results. In this situation, in-strength and PageRank score stands out as an efficient measure of a bowler's ability. We would like to mention that although our study includes the 'quality' of bowling attack or 'quality' of dismissal of a batsman, we do not consider the fielding abilities

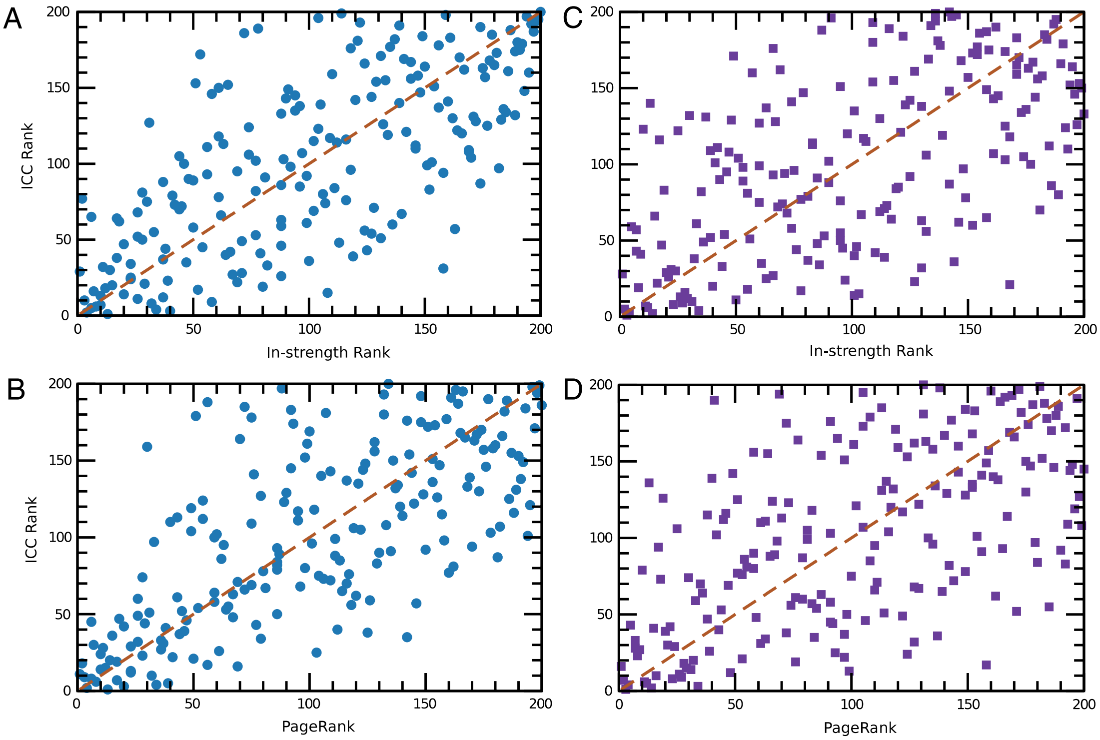

Fig. 6. (Color online) (A) Scatter plot of between the rank positions obtained according to ICC points and In-strength rank for Test cricket (1877–2011); Spearman correlation $\rho = 0.69$. (B) Scatter plot of between the rank positions obtained according to ICC points and PageRank score for Test cricket (1877–2011); Spearman correlation $\rho = 0.71$. (C) Scatter plot of between the rank positions obtained according to ICC points and In-strength rank for ODI cricket (1971–2011); Spearman correlation $\rho = 0.58$. (D) Scatter plot of between the rank positions obtained according to ICC points and PageRank score in ODI cricket (1971–2011); Spearman correlation $\rho = 0.59$.

or wicket-keeping abilities of the fielders. It is not possible to quantify the fielding ability of a fielder, other than by the number of catches, which is not a true measure of a fielder's ability. Some fielders are more athletic than others. Slip fielders always have a higher chance of taking a catch than others. Again, a batsman deserves more credit if he is able to beat athletic fielders like Jonty Rhodes, Ricky Ponting or Yuvraj Singh. Secondly, a bowler's ability is also judged by the nature of wicket. An excellent bowling performance on a batsman-friendly pitch holds greater merit than that on pitches which help bowlers. Similarly, scoring runs on difficult tracks always gets more attention than scoring runs on good batting tracks. In our analysis, due to non-availability of this information, we did not include these 'external factors' in our analysis.

Nevertheless, a network based approach could address the issue of relative performance of one player against another. Our study shows that SNA can indeed classify bowlers and batsmen based on the 'quality' of wickets taken or runs scored and not on the averages alone. Team selection is extremely important for any nation. SNA could be used as an objective way to aid the selection committee. A proper analysis of a player's domestic performance would help his(her) selection in the national squad. Additionally, owners of the cash rich Indian Premier League (IPL) teams spend lots of money to hire players on a contract basis. The owners along with the coaches can identify talent based on the past 'performance' of a player. Potentially our study could identify the greatest batsman of all time, based on complete player-vs-player information, which at present we are unable to identify due to non-availability of data. Our analysis does not aim at replacing the existing system of ICC player ranking, which is based on expert opinions and has been optimized and almost perfected for many years. It serves as an alternate method to refine the existing ranking scheme of players and quantify the performance of a player.

There are many additional features that could be included in the networks. For example, the networks in our analysis are static. A dynamic version of the network can be constructed following the ball-by-ball commentary and obtain a detailed analysis. Again, for batsmen there are players who score differently in different innings. There are leadership effects as well. Some players perform well under different skippers.[3] Bowlers are categorized into different categories based on their bowling style—pacers, medium pacers and spinners. Quantifying the 'style' of bowling and effect of pitch conditions thus remains an open area of research. A rigorous analysis backed by a complete dataset of player-vs-player could very well answer the question—Was *Sir Don Bradman* the greatest ever? In our quest to judge the most successful bowler in the history of cricket, one fact stands out: *M. Muralitharan* remains *il capo dei capi*.

[3] The 1981 Ashes series where Ian Botham displayed tremendous performance under the inspiring leadership of Mike Brearley.

Table 5
Results for the linear regression We mark in bold font the coefficients that are statistically significant (p-value < 0.05).

Number of bowlers	Test	1877–2011	2616	
Number of bowlers	ODI	1971–2011	1914	
Number of batsmen	Test	2001–2011	599	
Number of batsmen	ODI	1999–2011	1027	
		Model		
		Coef.	Std. err.	p-value
Model for s for bowlers in test (1877–2011)				
Intercept		**−8.16**	1.12	$<1 \times 10^{-16}$
PageRank	ρ	**128093.4**	1324.76	$<1 \times 10^{-16}$
Bowling average	B_{Avg}	0.042	0.025	0.091
Dummy	δ	**24.05**	1.12	$<1 \times 10^{-7}$
R-squared		0.8843		
Model for s for bowlers in ODI (1971–2011)				
Intercept		**−2.41**	0.438	$<1 \times 10^{-16}$
PageRank	ρ	**37766.47**	312.61	$<1 \times 10^{-16}$
Bowling average	B_{Avg}	**0.036**	0.011	0.001
Dummy	δ	**16.98**	1.73	$<1 \times 10^{-16}$
R-squared		0.9265		
Model for s for batsmen in test (2001–2011)				
Intercept		**−1.78**	0.822	0.031
PageRank	ρ	**825.39**	50.37	$<1 \times 10^{-16}$
Batting average	B_{Avg}	**0.289**	0.036	$<1 \times 10^{-16}$
Dummy	δ	**26.55**	1.496	$<1 \times 10^{-16}$
R-squared		0.7201		
Model for s for batsmen in ODI (1999–2011)				
Intercept		−0.029	0.53	0.956
PageRank	ρ	**1005.56**	48.39	$<1 \times 10^{-16}$
Batting average	B_{Avg}	**0.159**	0.022	$<1 \times 10^{-16}$
Dummy	δ	**30.122**	1.203	$<1 \times 10^{-16}$
R-squared		0.6627		

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