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Comprehensive world university ranking based on ranking aggregation

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Abstract

Many university rankings have been proposed in recent decades. The remarkable divergence among various rankings leads to confusion for decision-makers. In this paper, we propose to generate a comprehensive world university ranking by aggregating existing individual university rankings. We present a new graph-based rank aggregation method by defining a competition graph of universities, in which each node represents a university and each directed edge represents an outranking relation between two universities. We propose to measure the quality of a university by the out-in degree ratio based on which we rank all universities. Moreover, We evaluate the effectiveness of our comprehensive world university ranking from the perspectives of normality and impartiality, respectively. It is shown that the aggregated ranking will be applied as a blend integrating all the information from individual university rankings and can efficiently eliminate the outliers and regional partiality as a "smoother".

Keywords Partial ranking aggregation · Consensus ranking · Competition graph · Normality · Impartiality

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1 Introduction

In such a fully interconnected world, new and advanced knowledge and high technology, which are in most cases imparted and incubated in higher education system, are of paramount importance for economic and social growth. Therefore, a good education in university is one of the most powerful factors for the success of individuals, regions and even nations (Kerr 2001). The high value that individuals and society place on their education broadly increases the need for information in the quality of universities and higher education systems (Docampo 2013). Candidate students and their parents are the prominent readers of university rankings for the purpose of choosing an appropriate university and acquiring a successful career (Griffith and Rask 2007; Bowman and Bastedo 2009; Çakır et al 2015). Besides, a higher position can provide universities with opportunities to promote the popularity and competitiveness, gain financial resources and attract more outstanding students (Dill and Soo 2005; Bastedo and Bowman 2011). For companies, it is also one of the most important references for recruiting new employees (Hazelkorn 2007; Sponsler 2009; Salmi and Saroyan 2007). In recent decades, various agencies and institutions have proposed many university rankings, among which the first world known university ranking is the Academic Ranking of World Universities (ARWU).

With the concern of high education and university rankings, various studies have analyzed and criticized the university rankings and their methodologies (Van Raan 2005; Buela-Casal et al 2007; Ioannidis et al 2007; Saisana et al 2011; Safón 2013; Bougnol and Dulá 2015). Usher and Savino (2007) discussed the indicators and the sources of 16 national and 3 global ranking systems. Ranking indicators were categorized into 7 classes with respect to the common themes among systems. Different weights and indicators led to various university rankings. The authors also identified regional differences among national ranking systems. Pavel (2015) analyzed the similarities and differences in the methodology, criteria, indicators and weights of the three most influential rankings and identified the differences between the top-ten universities in these three rankings and the different regional distributions of the top-twenty universities. Moed (2017) deeply analyzed a series of statistical properties and indicators of 5 ranking systems. The conclusion is that the various ranking methodologies do indeed measure different aspects. There is no single, 'final' or 'perfect' operationalization of academic excellence. Huang (2011) compared the results of three typical rankings in 2009 and indicated that the Quacquarelli Symonds World University Rankings (QS) obviously favored European universities more than the other two systems and more significant disagreement lies in the rankings of Asian universities. Sorz et al. (2015) used the data of ARWU and the Times Higher Education World University Rankings (THE) and analyzed the dynamics of change in score and ranking position from year to year. They found that year-to-year results do not correspond in THE and ARWU Rankings for universities beyond rank 50. The bewildering array of rankings and the difference among them confuse people to make a decision.

To solve this problem, we propose to generate a comprehensive university ranking using a rank aggregation method. Aggregating individual preferences into a consensus which represents the overall preference has been studied extensively during the past decades (Cook and Kress 1990; Chen et al 2013).Aggregation methods can be catego-

rized into two categories: one is the Borda's method (BM) and its variants, by simply sorting the sum of ranking or grade of the object to obtain the aggregation ranking, those methods are very simple and widely used, but not competent on the Aggregation of incomplete information lists, such as Borda's method (BM) (Langville and Meyer 2012), average rank method (ARM) (Langville and Meyer 2012), Dowdall method (DM) (Reilly 2002). The other is the objective function method, which is led by minimum violations ranking (MVR) (Pedings et al 2012), and solves the problem of aggregation ranking by solving the optimal problem. The result is more accurate than the first type but Overly more complex. Our approach from the network science point of view, by comparing the gap between each pair of universities to make the results more accurate, and from the system point of view to simplify the calculation.

The rest of this paper is organized as follows. We select 5 university rankings and simply introduce them in Sect. 2 and then compare them in Sect. 3. In Sect. 4, we introduce our method and apply it to university ranking aggregation. We propose two indicators from normality and impartiality to measure the effectiveness of the aggregated rankings in Sect. 5. We conclude in Sect. 6, where we describe the study's contributions and future works.

2 Data sets

To generate the comprehensive university rankings, we choose five well-known global-scaled university rankings whose ranking results are internationally visible. Is is worth noting that the five university rankings used in this paper are merely for illustration purpose, our method can however be applied to many other general rankings.

- The U.S. News and World Report Best Global Universities (USNEWS). It was first published in 2014 by U.S. News and World Report. Its ranking methodology is based on 10 different indicators that measure universities' academic performance and reputations. The data and metrics in the ranking are provided by Thomson Reuters. USNEWS is the first American publisher to publish the global university ranking.
- Academic Ranking of World Universities (ARWU). It was first published in 2003 by the Shanghai Ranking Consultancy, also known as Shanghai Ranking. The league table was originally compiled and issued by Shanghai Jiaotong University in 2003, the first global ranking with multifarious indicators. The publication currently includes the world's overall and subject league tables, alongside independent regional Greater China Ranking and Macedonian HEIs Ranking.
- The Quacquarelli Symonds World University Rankings (QS). It was published by the Quacquarelli Symonds Company. Previously known as THE-QS World University Rankings, the publisher had collaborated with Times Higher Education magazine to publish its international league tables from 2004 to 2009 before both started to announce their versions. The QS system now comprises the global overall and subject rankings, alongside five independent regional tables (Asia, Latin America, Emerging Europe and Central Asia, the Arab Region, and BRICS). It

is the only international ranking to have received International Ranking Expert Group (IREG) approval,

- The Times Higher Education World University Rankings (THE). It was published by Times Higher Education magazine. The publisher had collaborated with Quacquarelli Symonds to publish the joint THE-QS World University Rankings from 2004 to 2009 before it turned to Thomson Reuters for a new ranking system. The publication now comprises the world's overall, subject, and reputation rankings, alongside three regional league tables, Asia, Latin America, and BRICS and Emerging Economies which are generated by consistent methodology.
- The University Ranking by Academic Performance (URAP). It was published by the Middle East Technical University since 2010. The scientometrics measurement of URAP is based on data obtained from the Institute for Scientific Information via Web of Science and inCites. For global rankings, URAP employs indicators of research performance including the number of articles, citation, total documents, article impact total, citation impact total, and international collaboration.

3 Divergence among various rankings

Considering that ARWU only have top 200 precise ranking and the gap between adjacent universities has become imperceptible with the decline in rankings, we extract top 200 universities from five well-known global-scaled university rankings in 2018 and analyze the differences among them. There are a total of 311 universities in five rankings in 2018, but only 118 universities are overlapped in all five rankings. In the remaining 190 universities, 75 universities appear in only one ranking. Even among the 118 overlapped universities which appear in all rankings, their ranks have significant differences in the five rankings as shown in Fig. 1. The fluctuations of their ranks are more remarkable for the universities with lower ranks, such as the University of Hong Kong (141st in ARWU while 26th in QS) and Washington University in St. Louis (20th in ARWU while 100th in QS). To explore the divergence among various rankings, we also show the correlations between the five rankings in Fig. 2 and Table 1. The disordered scatter plots suggest that there are significant differences among various rankings, especially for those low-ranking universities.

It is worth pointing out that in spite of the differences in the details of various rankings, there is a powerful first principal component related to bibliometric information (Robinson-Garcia et al 2019). It is shown that the bibliometric information is the most important factor for the inherent consistency of each ranking, and other indicators will also be indirectly contributed by bibliographic information. The difference among the rankings is mainly due to the different indicator structure and indicator weight in the methodology, especially the proportion of survey (Robinson-Garcia et al 2019).

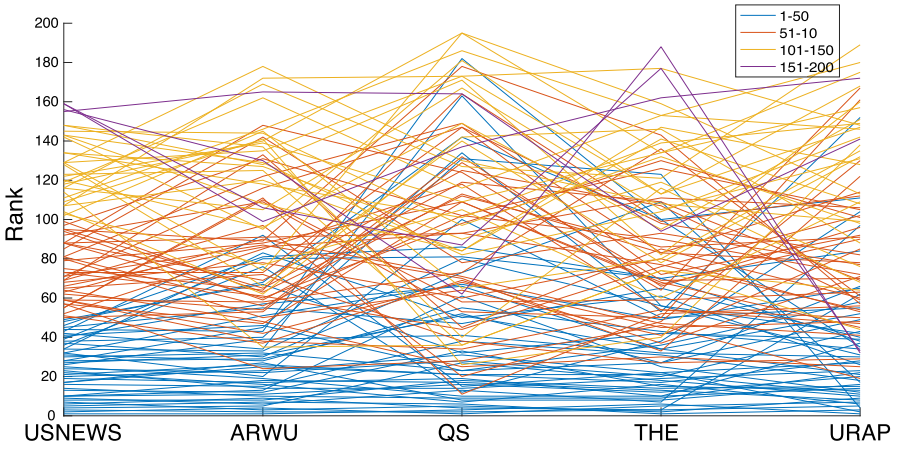

Fig. 1 The ranks of universities in five individual rankings in 2018. Each solid line represents a university. We only show the 118 overlapped universities, which are divided into 4 levels according to their rankings in USNEWS (1–50, 51–100, 101–150 and 151–200)

4 Comprehensive ranking based on ranking aggregation

Suppose that there are N individual rankings of M universities. Denote by $R_t = [r_{t1}, r_{t2}, ..., r_{tM}]$ a ranking, where r_{ti} is the rank of a university u_i in R_t. The smaller the rank of the university is, the better the quality of the university is. Note that an individual ranking may only give the ranks to a subset of the M universities, we denote by $L_t \leq M$ the length of the ranking R_t and let $r_{ti} = L_t + 1$ if the university u_i is not included in the original ranking R_t.

The task of rank aggregation is then to combine all individual rankings into a consensus ranking. However, for the reason that previous rank aggregation methods, such as Borda's method (BM) and its variants, do not perform well in the case of partial rankings aggregation, we next present a new graph-based rank aggregation method.

Denote by $P^t(p^t_{ij})_{M\times M}$ the transfer matrix for a ranking R_t, where p^t_{ij}=1 and p^t_{ji}=0 if $r_{tj} > r_{ti} > 0$; $p^t_{ij} = p^t_{ji} = 1$ if $r_{ti} = r_{tj} > 0$; $p^t_{ij} = p^t_{ji} = 0$ if r_{ti} or $r_{tj} = L_t + 1$. Based on the transfer matrices, we define a competition graph G_c of universities, in which each node represents a university and each directed edge e_{ij} represents an outranking relation from the university u_i to the university u_j. Denote by $A(a_{ij})_{M\times M}$ the adjacency matrix for a competition graph of universities, where $a_{ij} = 1$ and $a_{ji} = 0$ if $\sum_{t=1}^{N} p^t_{ij} > \sum_{t=1}^{N} p^t_{ji}$; $a_{ij} = a_{ji} = 1$ if $\sum_{t=1}^{N} p^t_{ij} = \sum_{t=1}^{N} p^t_{ij} > 0$; $a_{ij} = a_{ji} = 0$ if $\sum_{t=1}^{N} p^t_{ij} = \sum_{t=1}^{N} p^t_{ji} = 0$. Denote by $d_i^- = \sum_{j=1}^{N} a_{ji}$ the in-degree and $d_i^+ = \sum_{j=1}^{N} a_{ij}$ the out-degree of a node u_i. The large value of the out-degree d_i^+ of a node u_i suggests that the university u_i outranks many other universities. In the extreme case of $d_i^+ = 0$, it means that the university u_i ranks last in all rankings. The large value of the in-degree d_i^- of a node u_i suggests that the university u_i is outranked by many other universities. In the extreme case of $d_i^- = 0$, it means that the university u_i is at the end of all the universities. Thus we define the out-in degree

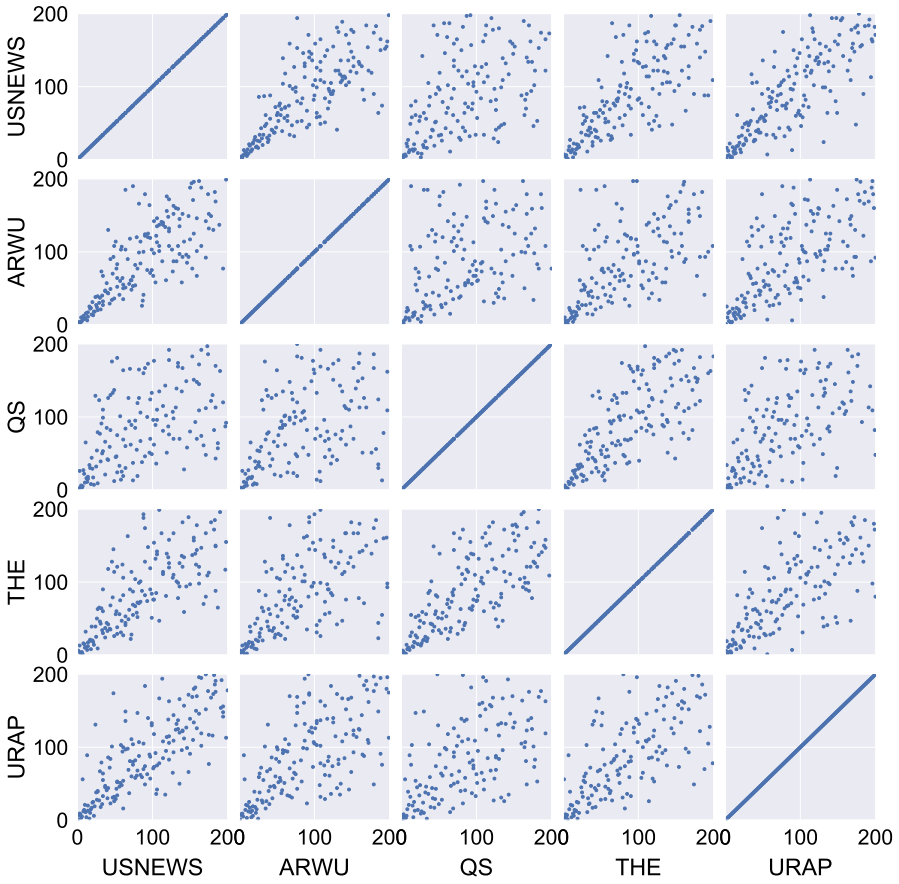

Fig. 2 The correlation between the five individual rankings in 2018. Here each point represents a university.The number of point is 118 representing the 118 overlapped universities

Table 1 Pearson correlation matrix of selected rankings in 2018

Ranking	USNEWS	ARWU	QS	THE	URAP
USNEWS	1.000	0.768	0.522	0.739	0.793
ARWU	0.768	1.000	0.439	0.605	0.668
QS	0.522	0.439	1.000	0.737	0.555
THE	0.739	0.605	0.737	1.000	0.683
URAP	0.793	0.668	0.555	0.683	1.000

ratio $\alpha_i = (d_i^+ + 1)/(d_i^- + 1)$ to characterize the quality of a university u_i and rank all universities based on their out-in degree ratios. The item '1' in the definition of α_i is to avoid the case $\alpha_i \to \infty$. For each university, the larger the out-in degree ratio, the better the quality, and the higher the rank.

Using the graph-based rank aggregation method above, we aggregate the USNEWS, ARWU, QS, THE and URAP in 2018 into a comprehensive world university ranking

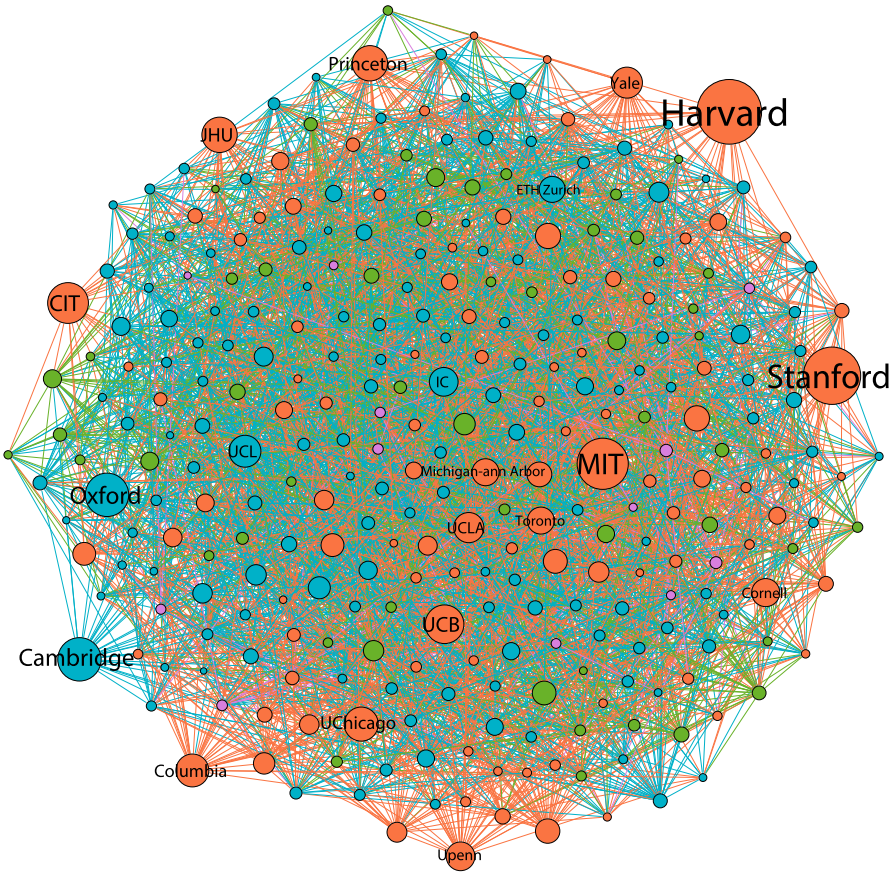

Fig. 3 The competition graph of 311 universities in 2018. There are totally 311 nodes (universities) and 48,205 edges (outranking relations). For the better visual effect, we only show 10% edges. The size of each node is proportional to its out-in degree ratio α_i. The color of each node represents their region: orange for North America, blue for Europe, green for Asia/Oceania and purple for others. The color of each directed edge is same as the color of its source node (color figure online)

(AGUR). The competition graph is shown in Fig. 3 and the top 20 universities in AGUR are shown in Table 2 (see the complete results in Supplementary Information). It is shown that Harvard University ranks first in our AGUR, even though slightly lower in QS (3nd) and THE (6th). Stanford University ranks second in the aggregated ranking, Although it does not rank first in any of the five lists. Figure 4 shows the geographic distribution of the top 100 universities in AGUR in 2018. We can clearly observe the significantly unbalanced geographic distribution. 82 universities are concentrated on the coast of the United States and Western Europe. A small number of universities are scattered in East Asia and Australia but the ranks are mainly distributed in 50–100. In the vast land of Africa and South America, there is not even a university in the top 100. The above-mentioned reveals the significant difference in the regional distribution of

Table 2 The top 30 universities of AGUR in 2018

University	Country	USNEWS	ARWU	QS	THE	URAP	AGUR	α_i
Harvard University	United States	1	1	3	6	1	1	220.4286
Stanford University	United States	3	2	2	3	5	2	146.619
Massachusetts Institute of Technology (MIT)	United States	2	4	1	5	7	3	109.7143
University of Oxford	United Kingdom	5	7	6	1	3	4	90.1765
University of Cambridge	United Kingdom	7	3	5	2	9	5	72.8095
Columbia University	United States	8	8	18	14	15	6	25.7241
University of Chicago	United States	14	10	9	9	22	7	25.2712
University of California, Berkeley	United States	4	5	27	18	10	7	25.2712
Johns Hopkins University	United States	10	18	17	13	8	9	24
University College London	United Kingdom	22	16	7	16	6	9	24
Yale University	United States	10	11	16	12	20	11	22.8462
Imperial College London	United Kingdom	17	27	8	8	16	12	20.6783
University of Pennsylvania	United States	19	17	19	10	14	13	19.8054
California Institute of Technology	United States	6	9	4	3	62	14	18.4969
University of California, Los Angeles	United States	13	12	33	15	13	15	18.1358
Cornell University	United States	23	14	14	19	23	16	16.6136

Table 2 continued

University	Country	USNEWS	ARWU	QS	THE	URAP	AGUR	α_i
University of Michigan-Ann Arbor	United States	17	25	21	21	11	17	16.033
University of Toronto	Canada	20	23	31	22	2	18	15.5775
Swiss Federal Institute of Technology Zurich	Switzerland	25	19	10	10	37	19	15.0622
Duke University	United States	21	26	21	17	28	20	13.2857
University of California, San Diego	United States	16	15	38	31	18	21	12.6564
University of Washington	United States	10	13	61	25	12	22	12.1915
Princeton University	United States	9	6	13	7	97	23	11.3016
Northwestern University	United States	24	22	28	20	43	24	10.6981
The University of Edinburgh	United Kingdom	30	32	23	27	49	25	8.8413
University of British Columbia	Canada	27	31	51	34	21	26	8.7179
The University of Melbourne	Australia	26	39	41	32	30	27	8.4801
The University of Tokyo	Japan	57	24	28	46	19	28	8.1176
University of Wisconsin - Madison	United States	31	28	55	43	34	29	7.3333
Tsinghua University	China	64	48	25	30	25	30	7.2888

The table also shows the ranks of these universities in USNEWS, ARWU, QS, THE and URAP as comparison. The whole university ranking can be found as Supplementary Table S1 online

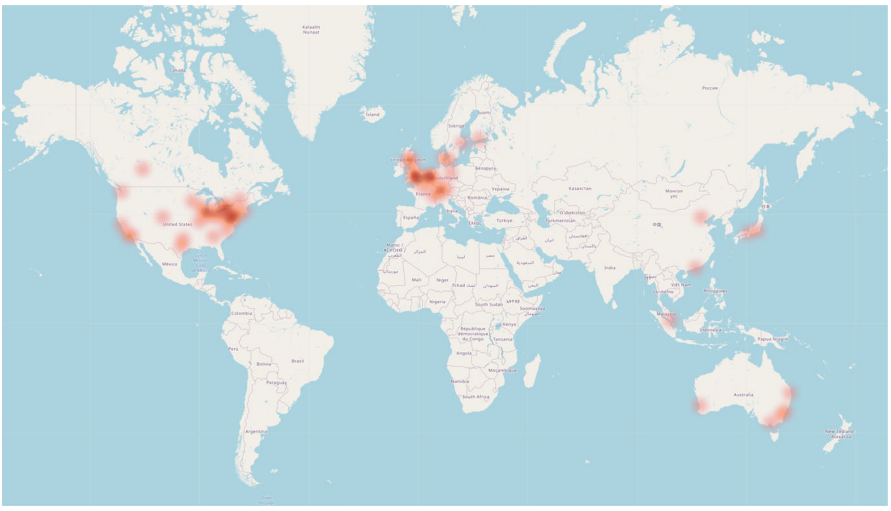

Fig. 4 The geographic distribution of the top 100 universities in AGUR in 2018. The shade of the color indicates the density of Top100 university in this area. More university the area, the deeper the color (color figure online)

the higher education system. The rankings of universities in a region tend to be directly related to the level of economic development in the region.

5 Effectiveness of comprehensive ranking

Comparing individual university rankings, we will find some universities ranks extremely high or low in only one ranking. The abnormal ranks are outliers providing some inappropriate information to users. And universities in one region may rank different in different rankings for the raw data and indicators. A good university ranking is expected to have less outliers and to be impartial for different regions. We next compare our AGUR with individual university rankings from the perspectives of normality and impartiality, respectively.

Denote by $U = \{u_i | \prod_{t=1}^{N} r_{ti} \neq 0\}$ the overlapped universities set in all individual rankings. For each university $u_i \subset U$ in a ranking R^t, we define $\psi_i^t = (r_{ti} - \bar{r_i})/\sigma_{r_i}$ to measure the normality of the rank of the university u_i in the ranking R^t, where $\bar{r_i}$ is the mean rank of university u_i and σ_{r_i} is the standard deviation of ranks of university u_i. If $\psi_i^t > 0$, it means that the university u_i ranks lower than its average rank in the ranking R^t. Whereas if $\psi_i^t < 0$, it means that the university u_i ranks higher than its average rank in the ranking R^t . The absolute value of ψ_i^t represents the distance between the r_{ti} and the population mean $\bar{r_i}$ in units of the standard deviation. If $|\psi_i^t|$ is too large, we can suppose that the rank of the university u_i in the ranking R^t is abnormal. Then, we define $\Psi^t = \sum_{i \in U} |\psi_i^t|$ as the overall normality of a ranking R^t. The smaller Ψ^t, the more normal the ranking R^t. As shown in Fig. 5, most universities in AGUR have a smaller $|\psi_i^t|$ than those in other individual rankings. As a whole,

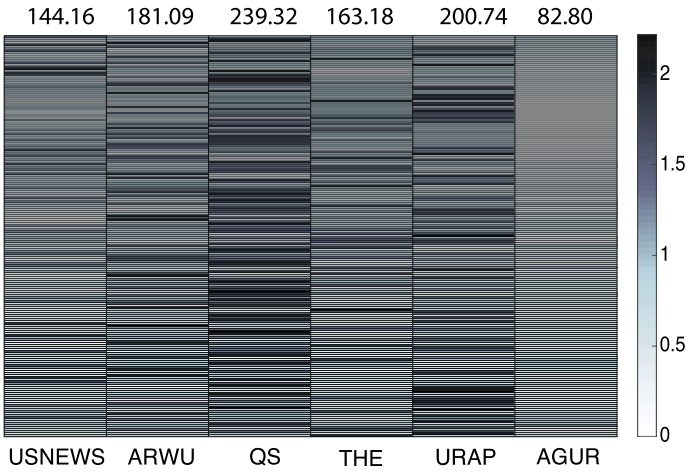

Fig. 5 The normality of various universities rankings. Each row represents a university. The top 200 universities in the AGUR are listed from bottom to top. The color of each block represents the absolute value of the normality of a university u_i in a ranking R^t. The overall normality Ψ^t of a ranking R^t is also shown in the top of each column

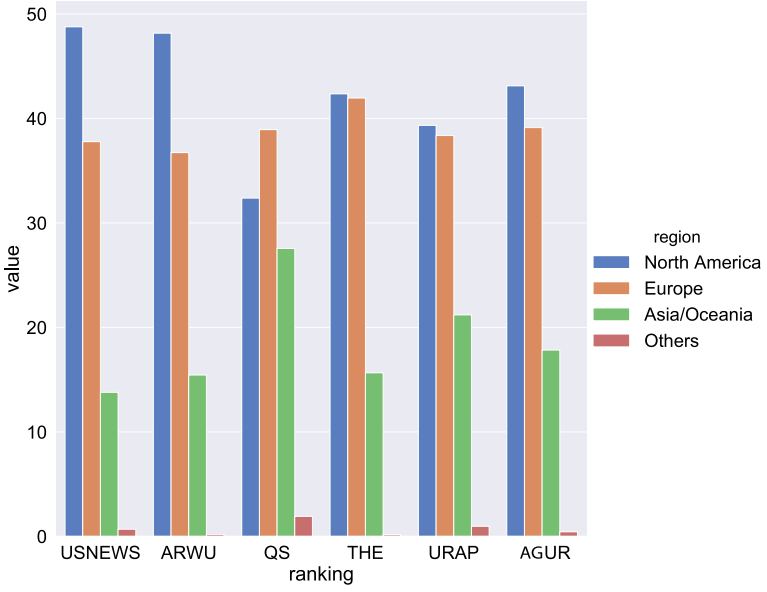

Fig. 6 The regional university quality in various universities rankings. Each bar represents a regional university quality. Each color represents a region

Table 3 The impartiality of various universities rankings

Ranking	ϕ_k^t				Φ^t
	North America	Europe	Asia/Oceania	Others	
USNEWS	0.970	− 0.494	− 0.871	− 0.130	2.466
ARWU	0.880	− 1.028	− 0.579	− 0.836	3.324
QS	− 1.451	0.091	1.556	1.572	4.670
THE	0.023	1.628	− 0.542	− 0.864	3.057
URAP	− 0.423	− 0.197	0.436	0.257	1.313
AGUR	0.136	0.190	− 0.158	− 0.469	0.953

ϕ_k^t represents the impartiality of a ranking R_t for a group S_k and Φ^t represents the overall impartiality of a ranking R_t

We find that Ψ^t of AGUR is also significant smaller than others. It means that our comprehensive ranking can correct abnormal ranks in individual rankings which is significantly lower or higher than those in other rankings. For example, the California Institute of Technology ranked 62nd in URAP dramatically, markedly lower than its ranks in other four individual rankings (6th, 9th, 4th and 3rd). In our AGUR, the California Institute of Technology ranks 14th. It is similar to Princeton University (23rd in tied in our AGUR), which is 97th in URAP and 9th, 6th, 13th and 7th in USNEWS, ARWU, QS and THE, respectively.

We next investigate the regional impartiality of a universities ranking. We first divide the world into four regions: North America, Europe, Asia/Oceania and other areas. Thus the universities in top200 are divided into four groups S_k $(k = 1, 2, 3, 4)$ according to their regions. We characterize the regional university quality of a group S_k in a ranking R^t by $Q_k^t = \sum_{i \in S_k} (201 - r_{ti})$. The more universities and the higher ranks in the group, the higher the regional university quality of the group. Then we define $\phi_k^t = (Q_k^t - \bar{Q}_k)/\sigma_{Q_k}$ to measure the impartiality of a ranking R_t for a group S_k, where $\bar{Q}_k$ and σ_{Q_k} are the mean and the standard deviation of Q_k^t in all rankings R^t, respectively. If $\phi_k^t > 0$, it means that the ranking R^t has an partiality for the group S_k. Whereas if $\phi_k^t < 0$, it means that the ranking R^t has a prejudices for the group S_k. Finally, we define $\Phi^t = \sum_{k=1}^4 |\phi_k^t|$ as the overall impartiality of a ranking R^t. The smaller Φ^t, the more impartial the ranking R^t. We show in Fig. 6 the regional university qualities in various university rankings. It is clear that North America has the highest regional university quality in all rankings. However, we also find that the regional university qualities of North America in USNEWS and ARWU are remarkably higher than other rankings. It suggests that USNEWS and ARWU have a partiality for the North America region compared with other rankings. Similarly, THE has a clear partiality for the Europe region. To explore in depth the impartiality of various rankings for the four regions and the overall impartiality of various rankings, we present the specific values of ϕ_k^t and Φ^t in Table 3. We find that North America has a clear advantage in USNEWS and ARWU with $\phi_k^t = 0.970$ and $\phi_k^t = 0.880$, respectively. But in QS ranking, universities in North America are suppressed with $\phi_k^t = -1.451$. Moreover, THE seems to favor universities in Europe ($\phi_k^t = 1.628$)

but USNEWS and ARWU do not. On the whole, we find that URAP and our AGUR have better impartiality with $\Phi^t = 1.313$ and $\Phi^t = 0.953$, respectively. But other four rankings have significant regional partiality.

6 Discussion

In the past decades, many world university rankings have been proposed and received growing attention. However, due to the different methodologies and indicators, it has been shown that there is remarkable divergence among various rankings, which leads to confusion for decision-makers. More importantly, there exists inevitably a certain degree of abnormality and partiality in individual university rankings. To solve these problems, an intuitive idea is to take an "average" of various individual university rankings. Thus, in this paper, we proposed to generate a comprehensive world university ranking by aggregating existing individual university rankings.

Considering that individual university rankings are usually incomplete and previous rank aggregation methods does not work well in the case of partial rankings, we have presented a new graph-based rank aggregation method. In our method, we defined a competition graph of universities, in which each node represents a university and each directed edge represents an outranking relation between two universities. We proposed to measure the quality of a university by the out-in degree ratio and rank all universities based on their out-in degree ratios. To evaluate the effectiveness of our comprehensive ranking, we quantitatively characterize the normality and impartiality of a ranking. We have shown that our comprehensive ranking just likes a cocktail consisting of all the information from individual university rankings and can efficiently eliminate the outliers and regional partiality just like a "smoother".

Our comprehensive world university ranking will provide a reliable and efficient reference for candidates and their parents, university administrators and human resources departments. Moreover, our method can be applied to other related fields, such as brand ranking, web ranking and sports ranking.

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