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Collaborative authorship patterns in computer science publications

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Based on the analysis of data we observe that the share of single-authored papers was significantly high in theoretical computer science, while collaborative efforts dominate computer science system research like PL, AI, ML, etc. Collaborative authorship is higher in journals over conferences. Further, values of collaborative indicators are also high for journals except for the Machine Learning (ML) subfield. In addition, the author distribution patterns are different for conferences and journals. The findings also exhibited diversity in authorship trends across sub-fields of CS research. Our results show collaboration trends in conferences and journals of major CS subfields. Such collaborative patterns benefit the funding agency, policymakers, scientific community, and researchers to plan and execute their research.

Keywords: Research Collaboration, Co-authorship, Computer Science, Conferences Journals

Introduction

In the past few decades, the field of research collaboration has gained significant attention in the scientific literature. It has become an essential aspect of the scientific community and is viewed as a prominent attribute of the research activity. The multidisciplinary and complex nature of problems in the scientific community motivates researchers toward more significant collaborative work. Research collaboration is usually termed as working together, exchanging ideas, sharing resources, etc. to achieve a common goal[1]. It has been widely acknowledged that such a collaboration amplifies the quality, productivity, and citation impact along with the attention of the research work[2,3]. However, collaboration practices vary from one domain to another[4]. Humanities and arts have negligible collaboration, whereas physics, biology, engineering, and medical sciences witness high collaboration levels[2]. Thus, assessing collaboration behavior is crucial in bibliometric research.

Moreover, co-authorship is one of the prevalent ways to assess and analyze key aspects of collaboration[1,5]. Studies have found the lowest share of single-authored papers[4,6,7], whereas multiple-authored papers account for a higher percentage[8,9,10]. In addition, the cardinality of authors has also been considered by researchers for analyzing the collaborative trend. Ibanez et al. analyzed that three-authored papers accounted for the highest percentage[4].

Others have assessed that the largest share of papers contributed by more than four authors[7]. There have been supportive as well as contradictory views presented by various authors; there have been studies highlighting different aspects and issues concerning collaboration. Researchers also demonstrated the perceptions of collaborative research based on a survey study[11]**.** For example, several researchers have presented coauthor-based studies to analyze the research productivity and collaboration behavior of particular discipline. However, the author also suggested an index for multi-authored papers[12].

Furthermore, it is believed that collaboration-based research enhances the impact of publications in terms of citation counts. Hence, numerous studies have been dedicated to analyzing the level of collaboration and its citation impact. A group of researchers found that papers with international collaboration gained more citations than those of nationally and institutionally collaborated papers[4]. The citation performance of co-authored papers was significantly higher than papers with a single author[9]. However, citations increased faster in the case of single-authored review papers than in co-authored review papers[13]. Others have explored the trend of collaboration in the field of

Artificial Intelligence (AI) and concluded that there is a slightly negative relationship between the number of authors and their citations in the AI area[14]. Hence findings of the previous study vary to collaboration level, document type, geographical area, and sub-fields of Computer Science (CS) research. There were supportive as well as contradictory findings; these may not be generalized across disciplines and sub-fields of CS.

Numerous studies have compared conference and journal publications of CS in terms of acceptance rate, citation impact, review process, and others. Journals hold a more diverse portfolio of authors and their affiliated institutions that vary across subfields when publication patterns are explored for both conferences and journals[15]. However, findings have been mixed[16,17,18], and are a topic of further research. Moreover, very few studies compared the authorship patterns between conferences and journals. The past studies have been limited to a specific institution, subfield, country, etc. Therefore, a combined analysis of conferences and journals of different subfields is crucial in CS research.

In this paper, we study conferences and journals publication data of three major CS sub-fields that have very distinct characteristics, namely, Artificial Intelligence (AI)/Machine Learning (ML), Programming Languages (PL), and Theoretical CS (TCS).

Review of literature

Several studies have presented the dynamics and evaluation of co-authorship trends in the CS discipline. A group of researchers analyzed publication data of Harvard University during 2000-2009 and assessed that 86% of CS publications were multi-authored[9]. Ibanez et al.[4] explored faculty publications of the Spanish University during 2000-2009. They concluded that a small percentage of papers were published by a single author, whereas three-authored papers account for the highest share. Jokić investigated the bibliometric perspective of LIS subfields of Central and Eastern European countries[7]. They specified that authorship trends of CS subfields are considerably different from LIS subfields. For example, in CS, the most significant portion of papers was published by four and above authors, whereas single-authored articles account for the lowest share.

Fernandes[6] analyzed the changing co-authorship trend in the Software Engineering discipline from 1971-2012 who found changing trend in authorship (dominated by articles with three or four authors). A different perspective analyzed by researchers is that CS publications have a moderate collaboration level as compared to other disciplines. According to researchers, a little collaboration of two or at most three, but not more than that, is typical in CS[8]. Singh et al.[10] have presented a detailed analysis of CS research publications of the top 100 most productive institutions in India (I100) and the World (W100). They also concluded that 30% of papers were published with more than three authors for I100, while this share was 50% for W100. Thus, previous findings show that authorship pattern varies according to datasets belonging to a subfield, region, etc.

Barrios et al.[19] have explored the dynamics of the research collaboration from 1997 to 2012. Researchers concluded that more than 30% of CS papers are internationally collaborated, according to the NSF dataset. Similarly, Singh et al.[10] has also analyzed that 30% of the research output of W100 are internationally co-authored papers while only 19% of I100 institutions. A different perspective assessed by researchers is that the domestic co-authored publications are significantly higher than international collaboration[9].

In the context of citation impact, Ibanez et al.[4] have found no positive relationship between the number of authors and citation impact; however, the study shows that papers involved with international collaboration have a higher citation rate than that of institutional and national collaborations. Further, Fan et al.[14] presented the citation impact of publication data of AI discipline. They found a slightly negative association between the authors' cardinality and the citation impact. Other dimensions have also been included by researchers, such as document type and citation impact. For example, co-authored papers' citation-based performance is higher than papers with a single author[9]. However, others concluded that single-authored review papers gain citations at a faster rate than review papers with co-authors[13].

Researchers have also assessed the collaboration levels between conferences and journals. In the main, Franceschet[8] explored the productivity of CS research and concluded that only 19% of the papers are single-authored in conferences, whereas 30% are in journals. These findings indicate that journals have a higher trend towards solo publication than conferences. Moreover, the researchers also stated that conference papers show a more collaborative nature than journal papers.

Others have presented significant trends in the Computer Networks (CN) discipline. Based on a comparative study of conferences and journals, they concluded that the spread of authorship is significantly higher in top conferences than in journals in the CN discipline[20]. Additionally, Fernandes[6] examined the authorship trends in the Software Engineering field. They assessed that, on average, journal papers have fewer authors than conference papers. They found that journal papers have 2.48 authors (average number of authors) while conference papers have 2.68 authors. Franceschet[8] has also concluded that conference papers show more collaboration as compared to journal papers. Kim[21] has explored the publication trends of conferences and journals of CS; they also found similar trends that in conferences, researchers' collaboration is higher than in journals.

Objectives of the study

- To explore the productivity of authors and how it varies according to subfields or venues;
- To examine the proportion of single and multiple-authored papers;
- To study the authorship distribution based on the cardinality of co-authors; and
- To assess the different collaborative measures in conferences and journals of three major subareas of CS.

Data sources

This study is based on publication data from conferences and journals of three subfields of CS research. The data contains published articles of such avenues for eleven years, from 2010 to 2020. Here, avenues refer to conferences and journals of selected sub-fields. We present the list of sub-fields and corresponding selected conferences and journals in (Table 1). These avenues are seed publication avenues of CS, and we have selected them from the defined list by researchers[22]. The included conferences are: POPL[23], ICML[24], and STOC[25], and selected journals are: TOPLAS[26], MLJ[27], and JACM[28]. We first crawled a year-wise list of published papers and their co-authors for all the selected avenues. Such information is collated for each avenue from their respective website.

Table 1—List of selected conferences and journals

Subfields	Conferences	Journals
Programming Language	ACM Symp. Principles of Prog. Lang.(POPL)	ACM Trans. Prog. Lang. Sys.-(TOPLAS)
Machine Learning	Int. Conf. Machine Learning (ICML)	Machine Learning Journal (MLJ)
Theoretical Computer Science	ACM Symp. Theory of Computing (STOC)	Journal of the ACM (JACM)

In some cases, we also utilized publicly available data sources, namely Google Scholar, DBLP, and ACM Digital Library, for data collection. This study focuses on authorship trends of published articles in conferences and journals. So, we created a dataset that contains the number of co-authors for each paper. We maintained a year-wise dataset for each conference and journal as well.

Method

We include various numerical and statistical measures for assessing authorship patterns, e.g., count of single and multiple-authored papers, authorship distribution, maximum co-authors, etc. Multiple-authored papers represent the count of papers with more than one author. The authorship distribution represents the share of papers regarding co-authors' cardinality. To show the distribution, we have arranged papers into groups such as 1-authored, 2-authored, 3-authored, 4-authored, and above four. Figure 1 presents the summary of the publication distribution based on the authors' cardinality.

Further, maximum co-authors represent the highest number of co-authors who have collaborated to write a paper in a particular year. The above information is presented in varying time intervals, e.g., annual and 11-year aggregation, to a comprehensive analysis of co-authorship. In annual representation, we calculate the share of single and multiple-authored papers in each year for the entire period of 2010-20. The aggregated data for 11 years represent a complete trend of authorship patterns during the study period. We also present the year-wise distribution of papers based on the number of authors in (Fig. 1). Further, we have utilized and defined a few indicators for comprehensive analysis of collaboration in conferences and journals. Such measures are defined as follows:

Collaboration indicators

fj = *the number of papers having j authors in the collection;*

h = *the maximal number of authors in a single paper;*

N = *the total number of papers;*

n = *total number of authors in the collection*

Collaborative Index (CI)

Lawani[29] defines this indicator. It represents the mean number of authors per paper.

$$CI = \frac{\sum_{j=1}^{h} jf_j}{N} \quad \ldots (1)$$

Degree of Collaboration (DC)

Collaboration helps to understand the trend and structure of collaborative practices and scientific research. With the help of DC, we measure the proportion of multiple-authored papers[30]. This index is mathematically represented as,

$$\mathrm{DC} = \mathrm{Nm}/\mathrm{Nm} + \mathrm{Ns} \quad \ldots (2)$$

where,

DC = Degree of collaboration
Nm = Number of multiple-authored Papers
Ns = Number of multiple-authored Papers

Collaborative Coefficient (CC)

This Collaborative index is defined by Ajiferuke et al.[31]. Such an index includes some of the merits of both CI and DC. The value of the CC index lies between 0 and 1. It tends to zero as single-authored papers dominate.

$$CC = 1 - \frac{\sum_{j=1}^{h}(1/j)f_j}{N} \quad \ldots (3)$$

Growth Rate of Multiple-Authored Papers

The growth percentage represents the annual growth rate of multi-authored papers in conferences and journals during the study period. Based on this index, we show the rate of change of co-authored papers.

$$GP = \left[\left(N_P SY - N_p PY\right)/N_P\, PY\right] * 100 \quad \ldots (4)$$

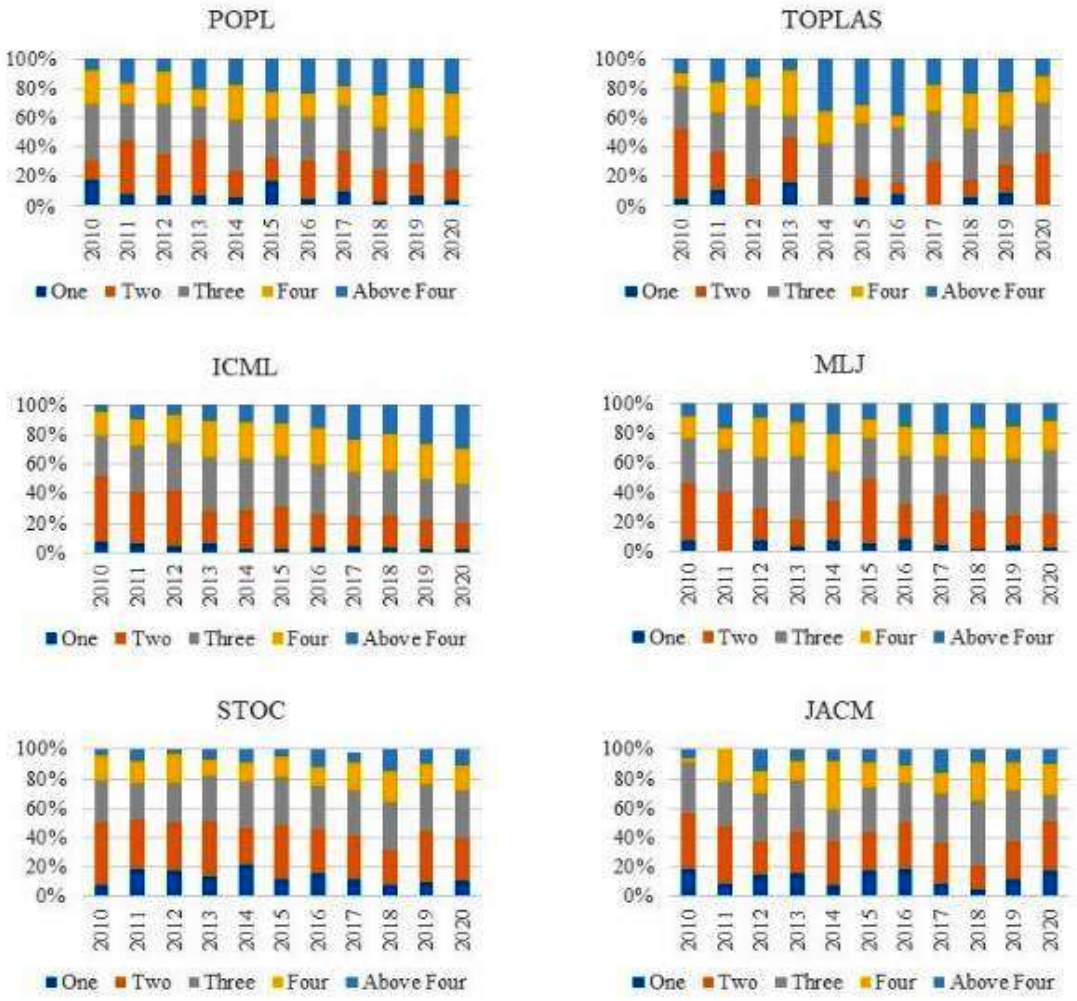

Fig. 1 — Distribution of articles based on the number of authors in conferences and journals

where,

GP = Growth Percentage

$_{NpSY}$ = Number of co-authored papers in Selected Year

$_{NpPY}$ = Number of co-authored papers in Previous Year

Thus, based on the above sources and measures, this study aims to analyze authorship trends in conferences and journals.

Analysis

Using the publication data of conferences and journals of the three subfields of CS research, as mentioned above, this section explores and analyzes the authorship trends during 2010-2020. We present the evolution of published papers and authors in each selected avenue. We discuss the annual proportion of single and multiple-authored papers. Then, we show the authorship distribution in conferences and journals. Further, we assess the different collaboration indicators.

Evolution of published papers and authors in conferences and journals

Figure 2 plots the evolution of publications and the authors during 2010-2022. The number of published papers and authors varies according to selected subfields as well as avenues. We observe that such a pattern widely varies across the selected subfields and their avenues. Such numbers also differ concerning the subfields of the CS domain. Figure 2 shows that the number of published papers increased in both avenues from 2010 to 2020, whereas at conferences, a sharp increase in publications and authors can be seen. Such findings indicate that the number of authors increased significantly from the selected years.

Moreover, the number of journal papers lies in the range of 13-82, whereas in conferences it is 39-86. However, the number of authors is also significantly less in journals than in conferences. The number of authors lies between 52 to 261 in journals, whereas 115 to 4193 in journals. Figure 2 shows that the

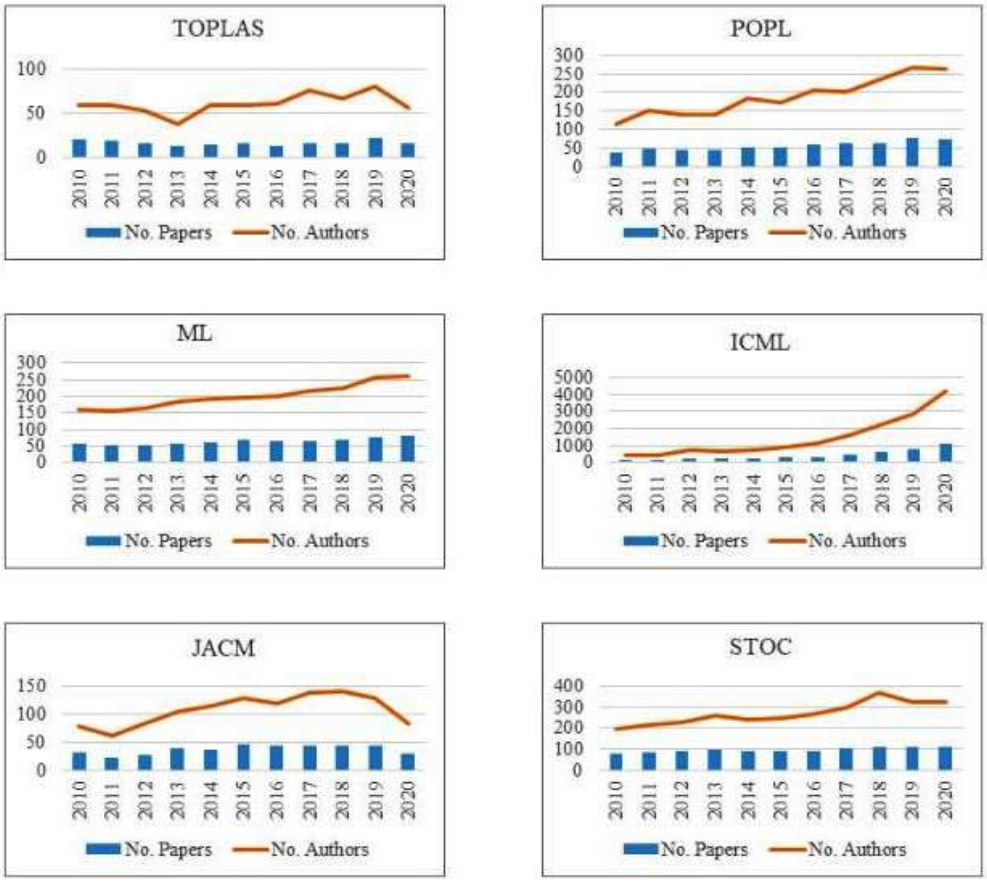

Fig. 2 — Number of publications and authors in conferences and journals

highest number of papers and authors were at the ICML conference.

The main difference is that some areas are systems-based, and there is high collaboration. High growth can be seen in the ML subfield, specifically at the ICML conference. For example, at the ICML conference, there is exponential growth in the number of authors during 2010-2020, indicating a fast-growing field.

Single and multiple-authored papers in conferences and journals

We grouped publication data of each conference and journal into two categories: single-authored and multiple-authored, to present the annual authorship trend. Figure 3 shows the distribution (in percentage) of single and multiple-authored papers. We observe that the proportion of multiple-authored publications has increased over the years as compared to single-authored. Particularly in the POPL conference, the share of papers with a single author is below 10% except in two years (2010 and 2015). In such years, 17% of the total publications are single-authored. However, multiple-authored papers are in the range of 82-96% during 2010-19. In the ICML conference, single-authored papers are between 2-7%, while 92-98% of publications are multi-authored during the research period. We can observe a slightly higher range of single-authored papers in the STOC compared to other conferences. In the STOC conference, 8 to 21% of publications are single-authored, and 78-91% are multiple-authored.

Results of single vs. multiple-authored publications show more diversity in journals than in conferences. In the few years of TOPLAS (2012, 2014, and 2017) and MLJ (2011) journals, there has been an almost negligible number of solo-authored papers. The remaining years have 4-15% single-authored publications in the TOPLAS and 1-7% in the MLJ journal. On the other hand, multi-authored papers are in the range of 84-100% in the TOPLAS journal and 92-100% in the MLJ journal during 2010-2020. Further, in the JACM journal, 4% to 18% are single-authored papers, while 81-95% papers are multiple-authored.

The above findings show that the proportion of single vs. multiple-authored publications varies across avenues and subfields. We compare the distribution of data for conferences and journals. The highest range of single-authored publications is in the Theoretical CS subfield, specifically in the STOC conference. In contrast, the multi-authored papers have a higher range in the journal of the ML subfield. Thus, it can be seen that the range of multiple-authored papers in journals is significantly higher than in conferences. Such findings indicate that researchers are highly interested in collaborating with journals.

Authorship distribution in conferences and journals

Next, we explore the distribution of publications and analyze the authorship pattern in conferences and

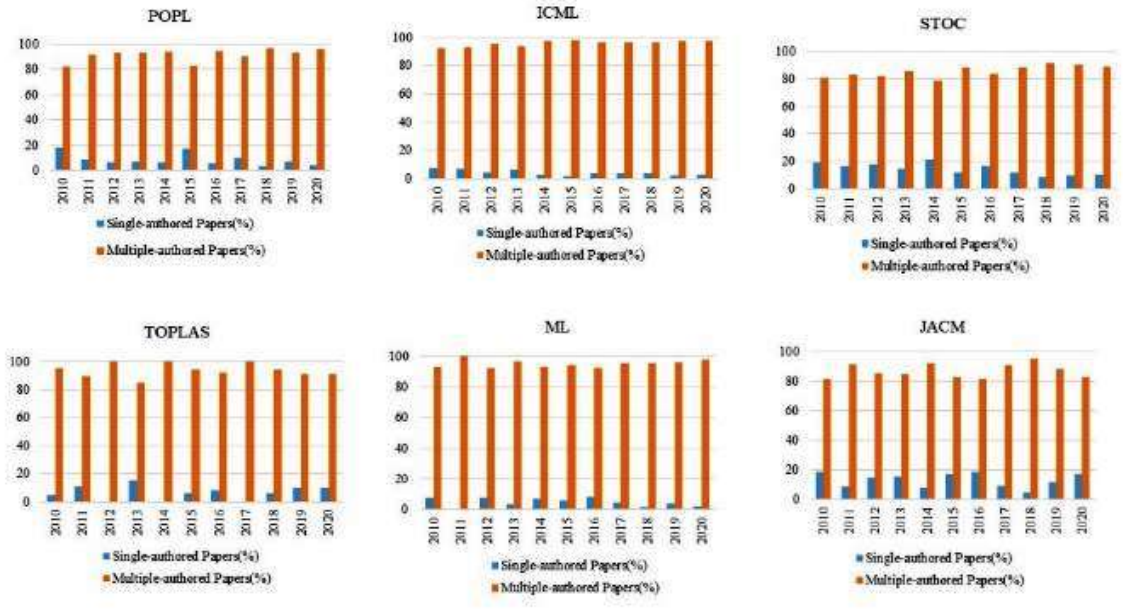

Fig. 3 — Percentage of single and multiple-authored papers in conferences and journals

journals. The authorship distribution of papers has been represented in terms of the cardinality of co-authors. Here, we explore the distribution of multiple-authored papers into four subsets (i.e., 2-authored, 3-authored, 4-authored, and above four).

Year-wise authorship distribution

Figure 1 shows that 2- or 3-authored articles dominated in each conference and journal during 2010-20. However, there has been a decline in 2-authored papers in all avenues from 2010 to 2020 except at the POPL conference. We conclude that the highest share of 2-authored publications lies in the STOC conference (23-42%) followed by the ICML conference (17-44%). Moreover, the percentage of 3-authored papers has witnessed a surge from 2010 to 2020 in conferences and journals except at the POPL conference. Specifically, TOPLAS and MLJ journals have the highest proportion (on average) of 3-authored papers.

Overall, 2-authored publications range from 12-44% in conferences while 0-47% in journals during the study period. Moreover, 3-authored articles have wider ranges in journals. This range is 15% to 50% in journals and 22-38% in conferences. In addition, the share of papers with four authors showed an increasing trend during 2010-20, with a slight exception at the STOC conference. During 2010-20, 4-authored papers are between 11-29% in conferences and 3-32% in journals. The share of papers with more than four authors varies between 3% to 29% in conferences, whereas 0-38% in journals during 2010-20. Thus, these findings infer that 4-authored publications are slightly higher in conferences, though journals also have a significant proportion of publications with the above four authors. The highest percentage of 4-authored papers is found in the ML subfield; the PL subfield has the highest share of papers with more than four authors. Thus, findings indicate that the distribution of publications varies in conferences and journals with respect to authors' cardinality. Theoretical subfields have low while system subfields have high cardinality.

Authorship patterns for aggregated eleven-year duration

Using aggregated data, we show authorship distribution in each conference and journal from 2010-2020. Figure 4 represents the distribution of papers to understand collaborative research in a specific domain for eleven years. It can be observed from (Fig. 4) that publications of 1-authored, 2-authored, 3-authored, 4-authored, and above four varies depending on the avenue. During 2010-20, the percentage of single-authored papers is significantly very low compared to other authorships. In conference and journal publications of the PL and ML subfields, the share of single-authored papers ranges below 10%, whereas it goes up 13-14% for the TCS subfield.

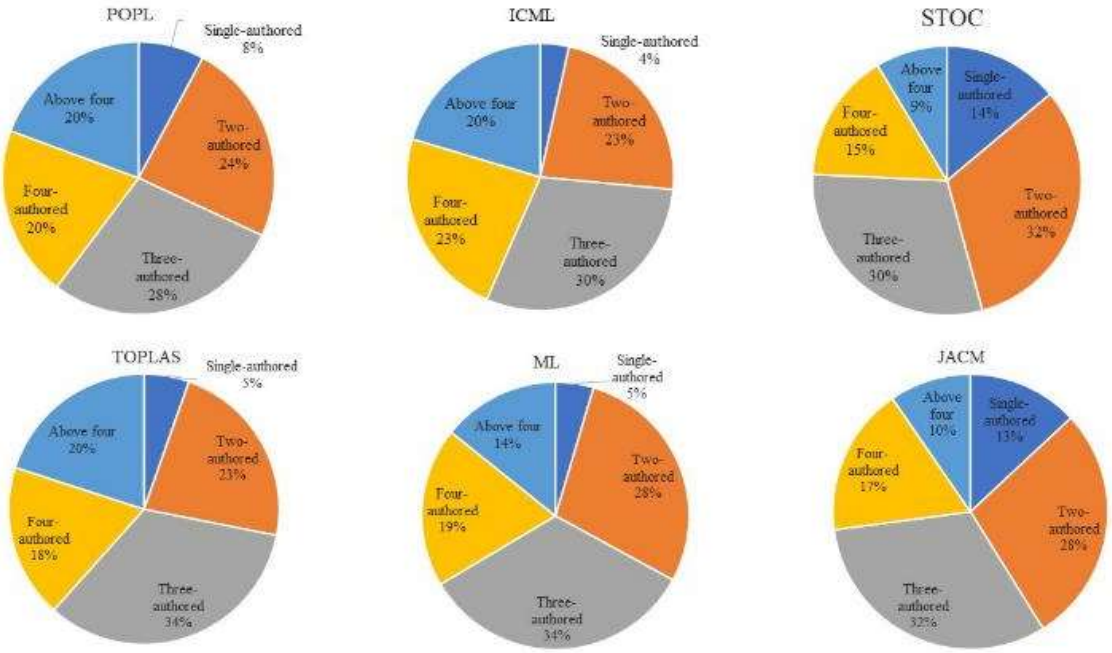

Fig. 4 — Aggregated eleven-year data distribution of authorship in conferences and journals

The proportion of 2-authored publications varies between 23-32% in conferences and 23-28% in journals. Moreover, 3-authored papers are between 32-34% in journals, whereas 28-30% in conferences. Such findings of eleven-year aggregated data indicate that 2-authored papers have a slightly higher proportion in conferences, and 3-authored publications have the same in journals. From Figure 4, we can observe that 4-authored papers have a higher proportion in conferences than in journals, with a slight exception in the TCS subfield. Likewise, the proportion of papers with more than four authors is almost equal for both avenues except the ML subfield.

Collaborative indicators in conferences and journals

Based on the collaborative measures, namely, collaborative index (CI), degree of collaboration (DC), and collaborative coefficient (CC) as defined in the methodology section, we present the results based on these indicators for the three conferences and journals.

Collaborative Index (CI): Concerning Eqn. 1, we calculate the year-wise value of CI in conferences and journals. Figure 5 shows a varying pattern of CI among CS subfields. The highest value of CI can be seen for the PL subfield, followed by ML and TCS subfields. Among selected avenues, journals have higher CI values except for the ML subfield. The highest value lies for TOPLAS journals in the range of 2.8 to 4.7. However, for the ML subfield, the ICML conference shows a higher value of CI (2.65-3.86) after the year 2014. Thus, the value of CI indicates that the mean number of authors per paper is high in journals except in the ML subfield.

Degree of Collaboration (DC): We have utilized the DC index to analyze the proportion of multiple-authored papers. Based on Eqn. 2, we calculate the year-wise value of DC in each selected avenue. Moreover, Figure 6 shows the year-wise trend of DC in conferences and journals of three subfields. We can observe the increasing value of DC in both avenues during 2010-20. The higher value of DC can be seen for the ML subfield and the lowest for the Theoretical CS. For conferences, the ICML conference (0.92-0.98) has the highest value of DC. Among journals, ML journal (0.92-1) has a higher value of DC. Thus, a higher value of DC represents a higher proportion of multiple-authored papers. Based on the results of DC, we conclude that journals based a higher proportion of multiple-authored papers than conferences.

Collaborative Coefficient (CC): We used the CC index (Eqn. 3) to analyze the collaboration pattern in conferences and journals. Figure 7 shows the year-wise results of the CC value of three conferences and journals of selected subfields. Journals have a higher CC value except for the ML subfield journal. It can be

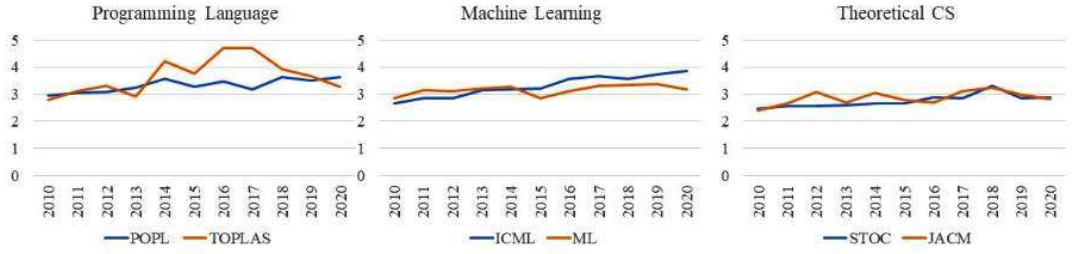

Fig. 5 — Collaborative index (CI) of conferences and journals of three subfields

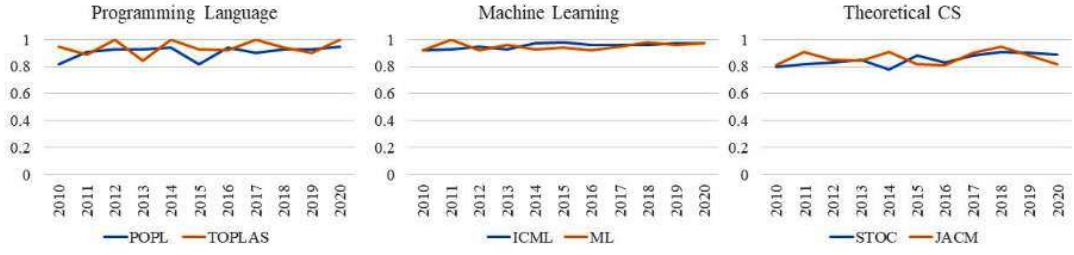

Fig. 6 — Degree of Collaboration (DC) of conferences and journals of three subfields

seen that the highest value of CC is for the PL subfield, followed by ML and Theoretical CS. Among journals, the higher value of CC lies for the TOPLAS journal and the lowest value for the JACM journal. However, among conferences, the higher CC value lies for the ICML conference, followed by POPL and STOC.

Growth Rate: Our study also assessed the growth rate for analyzing the pattern of collaborative publications in three subfields. Using Eqn. 4, we calculate the growth rate of multi-authored papers for each conference and journal during 2010-20. From Figure 8, we can observe that after 2014, there is almost a growth rate except for a few exceptions in conferences. Mainly, the highest growth rate can be seen for the ICML conference. However, the growth rate does not show any systematic pattern.

Collaborative patterns in conferences and journals

Journals are the sole medium of publication in most scientific disciplines. However, CS qualifies as a unique domain where conference publications are given more or at the least equal credentials to journal publications. Considering the diverse nature of CS, we focus on the variation of authorship patterns for both avenues in three major subfields.

The analysis of the annual distribution of publications informs us that conferences have a slightly higher share of single-authored papers than journals. The difference exists between 2-21% for conferences and 0-18% for journals. In contrast, the proportion of multiple-authored publications is significantly higher in journals (81-100%) than in conferences (78-98%). However, there are apparent variations among subfields. The single-authored

Fig. 7 — Collaborative Coefficient (CC) of conferences and journals of three subfields

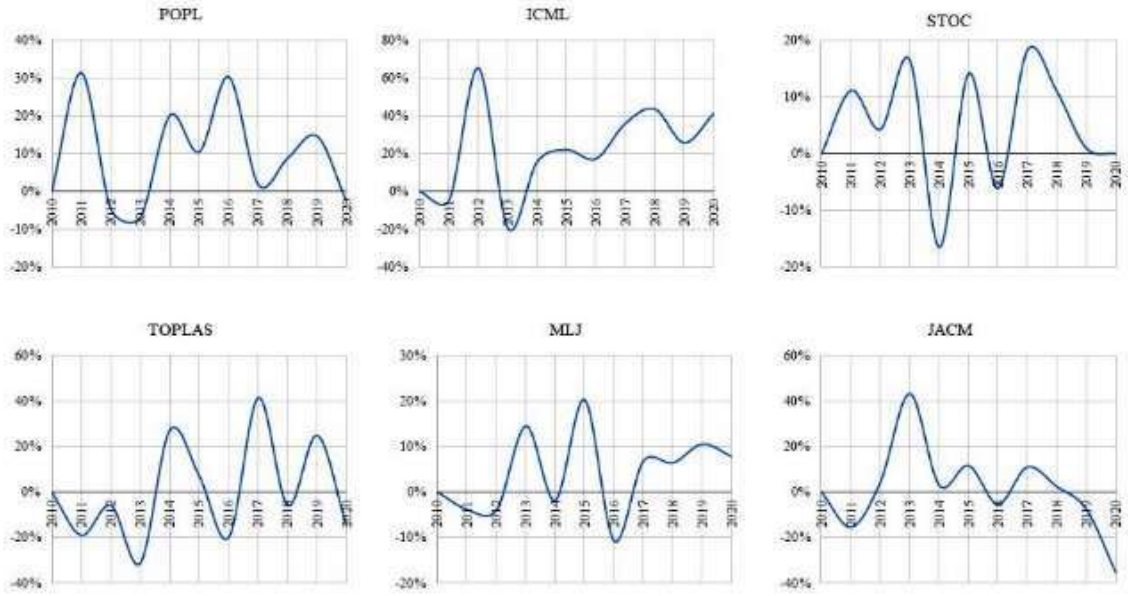

Fig. 8 — Growth rate of multi-authored papers in conferences and journals of three subfields.

papers have the highest range in the Theoretical TCS Subfield (4-21%), whereas it stands lowest for the System based ML subfield (0-7%). Contrary to this, the ML subfield has the highest proportion of multiple-authored publications during 2010-20.

The difference in the authorship distribution across conferences and journals can also be noticed in terms of authors' cardinality. We found the share of 2- or 3-authored publications dominate in conferences and journals during 2010-20. During 2010-20, the percentage of 2-authored papers in conferences and journals ranges between 12-44% and 0-47%, respectively. At the same time, 3-authored papers have a wider range in journals (15-50%) than in conferences (23-38%). Especially the STOC conference has a higher range of 2-authored papers, and the TOPLAS journal has that of 3-authored papers. These indicate distinct collaborative patterns for theoretical subfields over the system subfields of AI/ML.

Furthermore, the proportion of 4-authored publications is marginally high in conferences than in journals during 2010-20. However, the above four author papers have a higher share in journals, especially in the TOPLAS journals, compared to conferences. The above findings imply noticeable variations in the authorship distribution across subfields and avenues. The system subfield of PL has higher cardinality and is still high for journals.

Additionally, the results of eleven-year aggregated data convey that conferences have a higher range of 2-authored publications, while journals have that of 3-authored papers. However, the average share of 4-authored papers is almost equal in both avenues during eleven-year aggregation. Likewise, the average proportion of papers with more than four authors shows similar values in both avenues. Based on the results of collaborative indicators, we conclude that journals have higher values of CI, DC, and CC, except for the ML subfield. The ICML conference has high CI and CC indicators for the ML subfield. Analogously, these values are high for system subfields over the theoretical subfield.

Moreover, our study also explored the maximum number of co-authors annually for both conferences and journals. During the research period (2010-20), the maximum number of co-authors in conferences ranges from 5 to 69, whereas, in journals, it lies between 5 to 25 during the same research period. This implies that conferences exhibit higher variation in the yearly maximum co-authors than journals. Thus, various analyses show that conferences and journals have considerable variations in the authorship pattern in CS research.

Conclusion

This study provided insights into the authorship trend of published articles in conferences and journals of CS research. Such patterns exhibit that the authorship trend varies across different venues and subfields and is dynamic over time. There are distinct differences in collaboration behavior between conference proceedings and journals as publication avenues in computer science discipline. It also indicated diversity in authorship trends across the subfields of CS research. Collaboration patterns offer advantages to the funding agency, policymakers, scientific community, and researchers by providing insights for planning and conducting research. Accordingly, it would also motivate other researchers to carry out further research in other disciplines. In the future, to enrich our study, we would like to include more diverse and crucial subfields so that the findings can be analyzed across the wider CS discipline.

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