A study on the election factors of an ACM Fellow based on the co-authorship relations

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ABSTRACT

Prior research on successful groups of scientists has predominantly focused on recipients of top international awards, while investigations into the Association for Computing Machinery (ACM) Fellow award - an esteemed academic honor in the field of Computing Machinery - have been relatively scarce. This article seeks to address this gap by examining the relationship between the success of ACM Fellows and their co-authorship characteristics with previous Fellows. Using a sample of ACM Advanced Member Grades from 2015 to 2020 in four sub-domains, relevant indicators were selected to measure the cooperative relationship between candidates and previous Fellows. The relationship between successful elected ACM Fellows and their co-authorship with previous Fellows was analyzed using correlation analysis and binary logistic regression methods. The results indicate that a cooperative relationship with previous Fellows is indeed beneficial for the candidate's selection as a potential ACM Fellow. Several significant factors impact the probability of becoming a Fellow, including (a) the contribution ratio of previous Fellows to Fellow candidates, (b) the number of cooperative previous Fellows towards the Fellow candidate, (c) the degree of cooperation with previous Fellows, and (d) the propensity to cooperate with "growing together type" Fellows. Additionally, the impact of the nature of the collaboration on the campaign varies across different sub-fields. The findings not only suggest a potential closing on the Fellowship circle, but also serve as a safeguard against biases and opportunistic tendencies that may undermine the recognition of deserving Fellows.

Keywords: Co-authorship studies; Academic awards; ACM Fellows; Association for Computing Machinery; Computer Science.

INTRODUCTION

International academic awards, including the Nobel Prize, Turing Prize, and Fields Medal, as well as professional recognitions such as the Association for Computing Machinery (ACM) Fellow and Institute of Electrical and Electronics Engineers (IEEE) Fellow, serve as emblems of prestige and scholarly eminence (Erfanmanesh and Moghiseh 2018). These accolades signify the recognition and commendation of academic accomplishments and contributions by the global academic community in respective fields. Academic institutions and researchers have consistently pursued these prestigious awards. Several talent programs were organized to support researchers in winning awards (Shaplen 1964), and also providing certain rewards to the laureates. For them, winning the top prize is a success (Zuckerman 1967).

Some scientometric studies have been conducted to further understand the scientific rewards practices and its pattern. For instances, Ma and Uzzi (2018) performed a large-scale study involving 10,455 prize-winners worldwide covering 3000 different scientific prizes in diverse disciplines for over 100 years. However, the findings of their study revealed that despite the abundance of awards granted, there was a high concentration of research ideas and scholars, leading to limited diversity. However most of the research on prizes and accolades has focused on the Nobel Prize, including research on the selection mechanism (Crawford 1984), the analyses of specific winners (Barkan 1994; Björk 2001), and exploring a particular pattern for winners that would distinguish them from the rest of the scientific community (Zheng and Liu 2015; Gingras and Wallace 2009).

Due to the rarity and restrictive nature of Nobel Prizes, some important international academic awards, such as the Templeton Prize, the Crawford Prize, the Charles Stark Draper Prize, the Fields Medal, and the Balzan Foundation Prize are established to supplement the Nobel Prizes (Zuckerman 1992), thus extend the research scope of the awards. Studies have began to pay attention to the Howard Hughes Award (Azoulay, Stuart, and Wang 2014) and Fields Medal (Borjas and Doran 2015). However, few research paid attention to the career honor of a Fellow that is recognized as an authoritative and significant professional achievement in the academic community. This paper will focus on investigating the successful election process by using the example of a Fellow in the field of computer science.

SITUATIONAL ANALYSIS

The Association for Computing Machinery (ACM), founded in 1947, is the first and the world's largest professional academic organization in the field of computing. After decades of development, ACM members have continuously contributed to today's information age and awarded various awards and honors for outstanding contributions. Most of their achievements are published in the ACM printed journals. ACM Advanced Member Grades is one of the awards for scientists' career contributions in the field of computer, classified as Fellow, Distinguished Member and Senior Member, among which ACM Fellow is the highest honor. Since 1994, only 1 percent of ACM members that made outstanding contributions in the field of computer science are eligible for a Fellowship each year.[1] Its status and value are self-evident, and it has become the honor that scholars of various institutions in the field of computer science strive to pursue.

As a leading international organization, ACM is entrusted with the task of identifying and selecting the most accomplished talents in the computing and technology fields on a global scale. However, due to the intense competition and high stakes involved, there exists a risk of bias, opportunism, and other unjust practices in the selection process. Therefore, a rigorous and systematic examination of the selection mechanism is essential not only for ensuring the integrity and fairness of the process, but also for creating a supportive and conducive environment for the growth and development of outstanding talents.

The scientific society exhibits social stratification (Cole, Cole and Beaver 1974). The study of ACM Fellow selection has the potential to significantly improve the developmental trajectory of talents at different levels. A meticulous exploration of this topic can reveal the underlying patterns that lead to success and identify the factors that influence the selection process. Such knowledge can be applied in future towards the formulation of more effective talent training policies that better equip aspiring candidates with the requisite skills and knowledge. It can also help in conducting more comprehensive scientific talent evaluation research that ensures deserving candidates are recognized for their contributions. Moreover, it can aid in the construction of talent echelons that ensure a healthy and thriving talent ecosystem across varying strata, thereby enabling the sustained growth of the field.

Through the investigation of selection processes for ACM Advanced Member Grades, the study found that both nominations and endorsements of the candidates require the participation of ACM professional members. Therefore, it is acknowledgeable that the candidates must know at least one of the nominees or endorsers, which arouses the study's great research interest. The acquaintances in academic circles are usually established through scientific research cooperation, which is always reflected by co-authorships (Ponomariov and Boardman 2016; Melin and Persson 1996).

Previous research on awards and honors is only limited to the top scientific research awards of the discipline, but after all, top awards are scarce. With the increase of various kinds of honors in recognition of contributions, it is of practical significance to expand the research scope to the Fellow level. With verification of the importance and benefits of cooperation for scientific progress, scientists are inclined to establish cooperative relationship with someone who can contribute to their research (Ponomariov and Boardman 2016). Additionally, policy makers also encourage scientific collaboration. Yuret (2022) made a Network analysis of all econometric society fellows and found that as the

[1] ACM Advanced Grades of Membership (see https://awards.acm.org/advanced-member-grades)

Network gets closer over time, the percentage of Fellows who have not co-authored a paper with another Fellow or have not worked in the same institution with another Fellow decreases.

OBJECTIVE AND RESEARCH QUESTIONS

This study acknowledges the existence of closer collaboration among ACM fellows, and therefore, the primary focus is placed on investigating the cooperation between Previous Fellows and candidates. This approach aims to uncover the nature of collaboration within this esteemed honor. Consequently, this paper explores the potential relationship between the election of ACM Fellow and the extent of cooperation between candidates and previous Fellows. The objective is not to predict Award winners, but rather to examine cooperation as a factor influencing the Fellow election process. Thus, this study explores the relationship between the honor of ACM Fellow and their co-authorship with previous Fellows. The paper addresses the following research questions through the analysis of bibliometric information.

(a) Does collaboration or lack of collaboration with previous Fellows have an impact on a scientist's election as an ACM Fellow?
(b) How does the cooperation with previous Fellow affect the award of a Fellow in four classified sub-domains of computer science?
(c) How does the nature of collaboration with previous Fellows influence the likelihood of a scientist being elected as a Fellow in computer science?

The empirical analysis focused on a selected list of ACM Advanced Member Grades from 2015 to 2020 in four sub-domains. The study utilized relevant indicators to assess the cooperative relationship and analyzed the correlation between cooperation with previous Fellows, and the successful attainment of Fellow status. This analysis was carried out using correlation analysis and binary logistic regression method. The findings not only suggest a potential closing on the Fellowship circle, but also serve as a safeguard against biases and opportunistic tendencies that may undermine the recognition of deserving Fellows. By identifying and correcting such influences, the study contributes to ensuring that the ACM Fellowships are awarded based on merit and scholarly excellence, rather than on extraneous factors or personal connections.

LITERATURE REVIEW

Researchers have carried out extensive studies and investigations on renowned prize winners and the patterns of their professional development. Some studies use content analysis utilizing curriculum vitae (CV) data to examine the factors contributing to the growth and success of leading scientists. These studies gather and organize information from the educational background, work experience, skills, and achievements of these individuals to gain insights into their career trajectories. For example, Jalil and Boujettif

(2005) conducted an empirical study to examine the factors contributing to the success of Nobel laureates. Their study analyzed various aspects such as learning styles, familial and social environments, work attitudes, and the influence of their childhood experiences. Some studies have used citation analysis or measures of impact to differentiate award winners. Garfield and Welljamsdorof (1992) for instance, discovered that Nobel laureates exhibited significantly higher citation rates compared to non-Nobel laureates, providing a means to distinguish their scientific impact. Furthermore, the presence of cooperative relationships has emerged as a significant factor influencing scientists' chances of receiving prestigious awards. Jenkin (2001) investigated the unique collaborative research dynamics between Nobel Prize winners William Henry Bragg and William Lawrence Bragg, focusing on their father-son relationship as a key aspect of their scientific cooperation. Chariker et al. (2017) also focused on the relationship between Nobel laureates and their doctoral student-dissertation advisors. The study revealed a non-random pattern in the academic genealogy of Nobel Prize winners, with Nobel laureates having a higher number of laureate ancestors, descendants, mentees / grandmentees and local academic family, suggesting an assortative process in mentor and mentee selection.

According to Han et al. (2014), there has been a decline in the percentage of single-author papers in the 21st century, while the trend of collaborative papers has been on the rise. Melin (2000) observed that the growing recognition of collaboration in scientific endeavours has resulted in an intensified emphasis on the topic of collaboration itself. Scientific collaborations can enable scientists to share knowledge, expertise and technology, speed up the research process, increase visibility (Katz and Martin 1997; Sonnenwald 2007) and create new knowledge that embodies new research questions, new findings, and new theories (Stokols et al. 2005). Previous early studies (Lee and Bozeman 2005, Bordons et al. 1996), have validated that a significant portion of the rise in individual scientific productivity is attributed to collaboration or co-authorship. In order to keep up with scientific progress both at the individual researcher level and on a broader scale, most governments are actively seeking to enhance collaboration through targeted programs. Participating universities in the Russian University Excellence Initiative have shown an increased number of publications, especially in high-quality journals, through co-authorship with other organizations (Matveeva, Sterligov, and Yudkevich 2021). According to Asai's (2020) study collaborating with large publishers proves to be an effective approach for enhancing the international reach and influence of institutions' official journals, especially in non-English-speaking countries.

Adegbola (2013) defines "Newton's premise of standing on the shoulders of giants" (p.17) as the process in healthcare area where a scholar makes a quantum jump in their career by collaborating with prominent experts. In the contemporary research environment, there is a consensus on the importance of identifying influential literature to better leverage the insights from notable contributions, as opposed to the conventional approach of merely referencing papers. Numerous studies have explored benefits of collaborating with esteemed researchers, often referred to as "giants" in their respective fields. Collaborating with such accomplished scholars can significantly impact the work of scholars, more so if the collaborators hold senior positions (Amjad et al. 2016a; Amjad et al. 2016b). Amjad et al. (2017) demonstrated that working with leading experts can lead to a successful career for young researchers. For the same reason, collaboration with top-funded scientists can be an opportunity for accumulating valuable experience and tacit knowledge, resulting in higher and better scientific production (Mirnezami, Beaudry, and Tahmooresnejad 2020). Wagner et al. (2015) discovered a significant increase in the average number of collaborators per paper among Nobel Prize winners post-award compared to before the recognition. This finding further reinforces the notion of how distinguished researchers, such as ACM Fellows qualify to be considered as leading figures in their respective fields, similar to the concept of 'giant's shoulder' in the scientific community.

The pertinent literature and related works have been examined and summarized in Table 1, with the final row presenting the current research conducted in this study. This study differs from existing works in several ways. Primarily, it focuses on the cooperation between past ACM Fellows and candidates, which has not been explored previously. Moreover, it broadens the research scope beyond the top scientific research awards of the discipline to the Fellow level, hence increases the importance as various kinds of honors are being conferred in acknowledgement of contributions. Lastly, it incorporates the benefits of collaboration in science and the influence of collaborating with renowned experts (i.e. 'giants') into the research question, offering a unique perspective on the factors that might influence the election of ACM Fellows.

Table 1: Overview of Related Literature

Study	Fields	Research Objective	Factors	Collaborators
Garfield and Welljamsdorof (1992)	All	Nobel laureates	Citations	/
Jenkin (2001)	Physics	Nobel laureates	Father-son relationship	Nobel laureate
Jalil and Boujettif 2005	All	Nobel laureates	Learning styles, home and social circles, work attitudes, and their childhood	/
Chariker et al. (2017)	All	Nobel laureates	Academic guidance relationship	Nobel laureates
Amjad et al. (2016)	Computer science	Authors from database Aminer	Collaboration	All co-authors
Amjad et al. (2017b)	Computer science	Young scholars	Collaboration	Elite researchers
This work	Computer science	ACM Fellow candidates	Collaboration	Previous Fellows

MATERIALS AND METHOD

The ACM Digital Library (DL) is a research, discovery and networking platform provided by ACM, the world's largest computing society.[2] It contains the full-text collection of all ACM publications, including journals, conference proceedings, technical magazines, newsletters and books, as well as a collection of curated and hosted full-text publications from more than 5,000 other selected publishers. The biggest advantage of the DL for this research lies

[2] ACM Digital Library, 2021, [online] Available: https://dl.acm.org/.

in its extensively interconnected network of associations among authors, works, institutions, and specialized communities. In the DL, each author has his dedicated homepage comprising three parts: profile, publications, and colleagues. Moreover, every author is assigned a unique number that is being displayed in his homepage's URL (e.g. https://dl.acm.org/profile/81100545599 is the URL for Abadi, Daniel J). This unique identification system allows for the collection of author's information, eliminating the need to consider multiple name variations of the same author. This ensures higher accuracy in data processing for the study.

Datasets

This study involves 3 datasets：

(1) 1216 Previous Fellows as special cooperators from 1994 to 2019, simplified as PF(s);

(2) 353 Fellows list and 524 Non-Fellows list from 2015 to 2020, simplified as AO(s), and their 57,370 publications between the first co-authorship with PF(s) and award year;

(3) AOs' 6,790 publications co-authored with PF(s) before award year. All the publication data includes their titles, publication dates, authors, and authors' URL.

The Fellows list from 1994-2020, as well as the Distinguished Members, Senior Members, and the Non-Fellow lists from 2015-2020 were first obtained from the ACM website (https://awards.acm.org/fellows/award-winner). These details encompass the authors' names, subject areas and corresponding DL URLs. The DL URLs were cross-referenced to ensure their alignment with the authors listed in the Fellow list. Three exceptional cases were identified: authors with no URL in the web page list, incorrect links, and instances where the number of publications in the URL was less than 10. To enhance the completeness of the third dataset, a search was conducted to identify authors with abnormal links according to their names and organization information in the DL. Correct URL links were then acquired and subsequently incorporated into the Fellow list, ensuring the accuracy of the information stored. For the Non-fellows, the study focused on those individuals whose information was available for comparative analysis, specifically those who displayed a URL link on the webpage list. The data collection process involved clearing the lists and the crawling all the publications information of 2015-2020 Fellows and Non-Fellow. This was achieved by employing a Python program (see Figure 1) which accessed each author's homepage to retrieve the necessary data.

During the data cleaning stage, the study focused on investigating the honor acquisition mechanism. To achieve this, all articles published after the award year of each author were excluded. By cross-referencing the previous Fellow collaborators, it was ensured that every author in the publication had his own URL information, which allowed the presence of any previous fellow among the article's authors. To facilitate this process, a python program was developed, and the results are depicted in Figure 2. The sample size of Non-fellows averaged around 80 per year, with the exception of 142 in 2020. Meanwhile, the sample size of Fellows averaged around 50 per year, except for 95 in 2020.

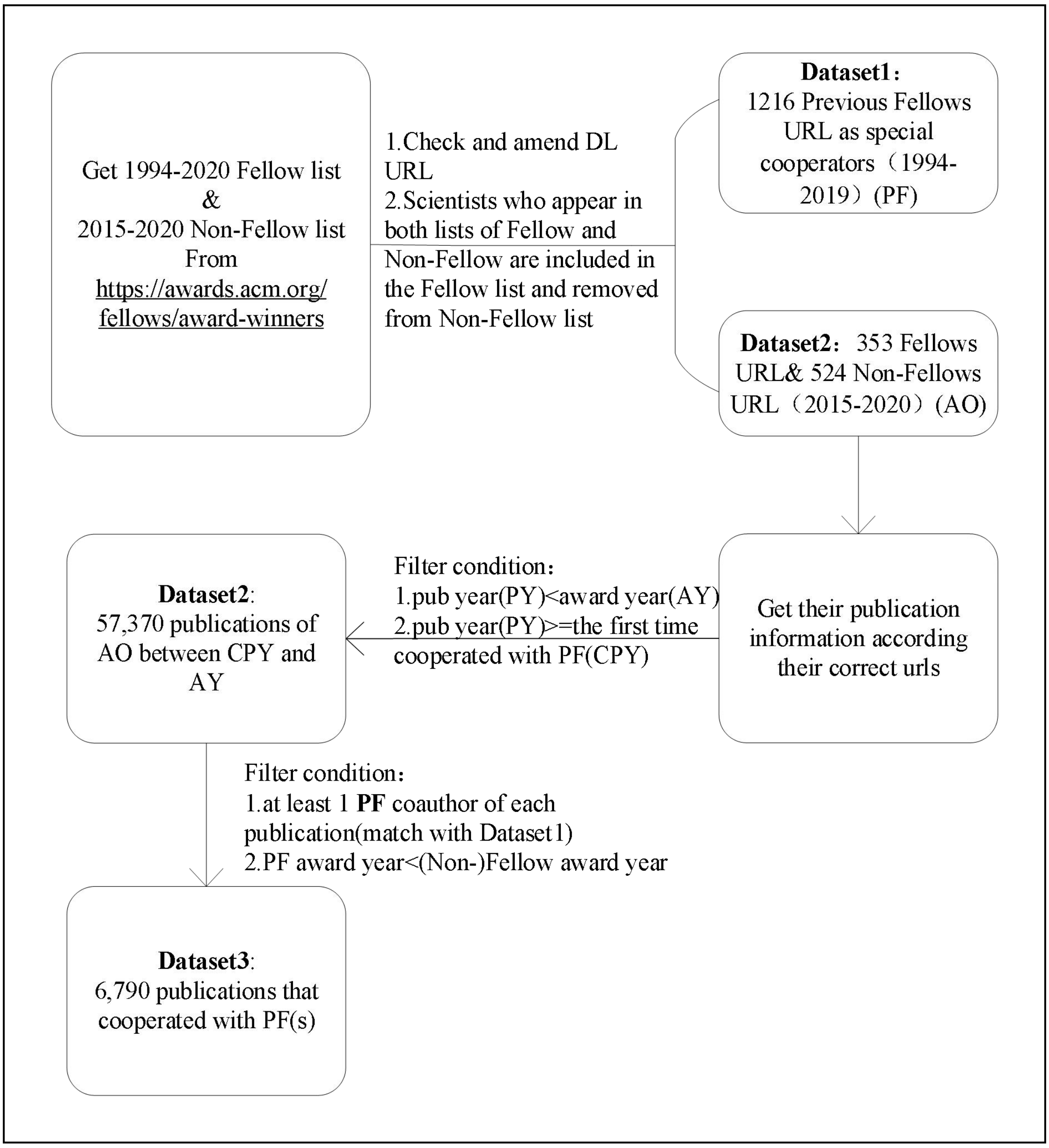

Figure 1: Data Collection and Processing Workflow

Data Analysis and the Indicators

This paper mainly studies the cooperation between AOs and PFs in the Computing Machinery field, and the correlation between the collaboration and AOs' award. Researchers do not necessarily have specific top scientist collaborators on their way to success. Amjad et al. (2017) found that working with leading experts can lead to a successful career, however it is not the only way. Qi et al. (2017) also used this method to study the influence of cooperation with outstanding scientists on the career of young scholars. This provided ideas for our first step, where we divided the cooperation into two categories according to the existence of cooperation, namely, cooperation and no cooperation, to analyze the correlation between cooperation/no cooperation and AOs' award.

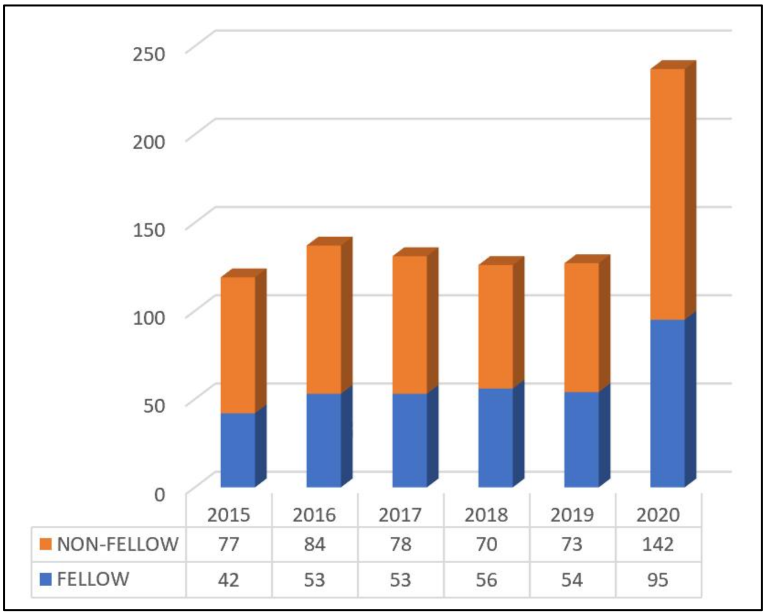

Figure 2: Data Filtering and Sample Sizes of Non-Fellows and Fellows for Each Year

The ACM Advanced Member Grades covers almost all aspects of computer science. There are many ways to classify the research areas of computer science. Association for Computing Machinery Computing Classification System[3] is a taxonomy of computing topics used to classify papers, articles, and presentations in the field of computer science. CSRankings[4] stands for a metrics-based ranking of top computer science institutions around the world, presenting a categorized computer-related subjects. This paper classifies the AOs according to research areas before starting the cooperative relationship research. The study referenced the official ACM CCS (Association for Computing Machinery Computing Classification System), which comprised 13 main areas and CSRankings' classification which includes 4 main areas. The subject areas of each AO were combined with CCS areas, considering the CCS area that accounted for the largest share as AOs' major research area (Liu and Hu 2021). Next, these areas were mapped to the corresponding CSRankings areas based on Table 2. This approach enabled the assignment of a main research area to each AO, facilitating the study's description of the collaboration characteristics across the 4 designated areas.

This paper also focuses on analyzing the correlation between collaborating with PF(s) and the recognition of AOs through awards. Additionally, it examines the degree of the influence of such collaboration on AOs' award within each research area. When examining correlation, the common approach involves calculating the correlation coefficient and performing regression analysis. If the correlation coefficient indicates a strong relationship between variables, conducting regression analysis becomes more informative, as it helps identify the precise form of correlation. Through analyzing the correlation between independent and dependent variables with the correlation coefficient, it is possible to

[3] https://dl.acm.org/ccs
[4] https://csrankings.org/#/index?all

identify the significant parameters that are highly correlated with the dependent variable. This enables the determination of independent variables to construct the regression model and ensure its accuracy.

Table 2: CCS Areas Corresponding to CSRankings Areas

CCS Areas	CSRankings Areas
Applied computing	Interdisciplinary
Computer systems organization	Systems
Computing methodologies	Artificial Intelligence
General and reference	Systems
Hardware	Systems
Human-centered computing	Interdisciplinary
Information systems	Systems
Mathematics of computing	Theory
Networks	Systems
Security and privacy	Systems
Social and professional topics	Interdisciplinary
Software and its engineering	Systems
Theory of computation	Theory

The method used for correlation analysis depends on the nature of the data being analyzed. For continuous variable data that conform to normal distribution and exhibit a linear relationship, the suitable correlation coefficient used is Pearson correlation coefficient. However, if the data does not meet these conditions, the appropriate choice is the Spearman correlation coefficient. The Spearman correlation coefficient is a rank correlation coefficient that focuses on the monotonic relationship between variables and attenuates the influence of outliers on the results.

Regression analysis is also a common method used in data processing and analysis in various research fields. Linear regression and logistic regression are examples of such methods. However, when dealing with dichotomous variables (e.g. whether a scientist is elected as an ACM Fellow in this study), linear regression is not appropriate. Instead, the binary logistic regression model is used to address this issue. Compared to the Probit model, which is also used to study dichotomous variables, the Logistic model is more suitable for distribution selection when optimizing utility.

In this study, we employed Spearman's correlation coefficient analysis and the binary logistic regression method to analyze the relationship between cooperation indicators and the probability of being elected as a Fellow in computer science. Prior to introducing the independent and dependent variables, we provide an overview of several cooperation indicators, which offer distinctive insights into the nature and quality of scientific collaboration.

(a) Contribution Index

Currently, the most widely used indicators of academic influence, such as the H index and its derivative index, G index, do not account for the number of co-authors and the order of authorship. This limitation leads to inaccuracies in measuring an author's impact, sometimes resulting in an inflated number of citations, akin to a “bubble” effect. In general, the order of authors is determined according to the author’s contribution to the publication, and the author’s signature order is the most intuitive way to reflect how much the author has contributed (Abbas 2011). In the current landscape, scientific research outcomes are mostly presented in the form of co-authorship among multiple researchers, necessitating the consideration of variations in authors' contributions. Waltman (2012) also emphasized the importance of devising a well-defined plan for attributing contributions and conducting fair evaluations and distributions of contributions among all co-authors when multiple researchers work together towards a common goal of generating new knowledge.

At present, there is considerable research conducted on the distribution algorithm of co-author contributions. The distribution schemes based on the co-author's signature order include three categories: linear, curve, and ‘other’ (Xu et al. 2016). In this paper, we adopt the positional-weight algorithm (VanHooydonk 1997; Abbas 2011) to calculate the AOs’ and Co-PFs’ contribution. To maintain simplicity and practicality, the corresponding author is not considered in this calculation. A fundamental requirement for the positional-weight algorithm is that the weights assigned to each author of a paper must sum up to one. Consider a scenario where a scientific paper involves n authors, and weights $w=\{w_i\}$ are assigned to each author i, where i ranges from 1 to n. The weight w_i of the i-th author can be determined using the following formula:

$$w_i = (2 * (n - i + 1)) / (n * (n + 1)) \quad (1)$$

Where, $0 \leqslant w_i \leqslant 1$, and $\sum_{i=1}^{n} w_i = 1$.

This scheme has the advantage of considering the order of authors in a paper, which is a widely accepted practice in the scientific community. Additionally, it also accounts for the total number of authors, ensuring that the weights assigned are proportional to the actual contributions of each author.

As per Equation (1), the size of the contributions made by both AO and their collaborating PF(s) in a collaborative article can be computed. However, simply having the absolute values of everyone's contributions does not intuitively reflect their relative magnitudes. To address this, the study opts to calculate the relative values of authors' contributions. Specifically, it determines the ratio of the contribution made by the PF(s) to the contribution made by the AO, in each collaborative paper. This ratio is represented in Equation (2):

$$CPF = \sum w_{PF} / w_{AO} \quad (2)$$

Here, the variable w_{PF} represents the contribution value of a single collaborating PF in a collaborative paper. The variable $\sum w_{PF}$ denotes the summation of the contribution values of all collaborating PFs that may exist in a collaborative paper.

Once the CPF of each collaborative paper between AO and PF(s) were calculated, the relative contribution values of all collaborative papers for each AO can be more accurately determined using Equation (3):

$$\text{Avg\_CPF}= \sum_{m=1}^{j} CPF_m / j \qquad (3)$$

Where, m ranges from 1 to j, when an AO has collaborated on j papers with PF(s).

Through the calculation of this ratio, it can be determined whether the contribution of the AO is greater than that of the PF(s) in collaborative articles, or vice versa.

(b) Collaboration Indicators

Collaboration indicators have been widely used to study authors' cooperative ability, pattern, and tendency (Abramo, Apponi, and D'Angelo 2021). These indicators encompass a range of measures, including the 'degree of collaboration' (Subramanyam 1983), the 'collaboration index' (Lawani 1986), 'Coefficient of Cooperation' (Ajiferuke, Burell, and Tague 1988), to 'Revised Coefficient of Cooperation' (Egghe 1991) and lastly, the central indicator of the research cooperation network (Bavelas 1950). However, none of these indicators adequately capture the distinct characteristics of cooperation with 'giants' co-authors. To address this limitation, Zhang, Shi, and Situ (2021) introduced a weight indicator called CW. This indicator represents the proportion of author-editor collaboration articles in the total articles published, allowing a more comprehensive examination of the author-editing cooperation relationship. This indicator reflects the degree of author-editing cooperation. In the current study, this indicator was utilized in designing a calculation formula (Equation (4)) that effectively captures the AO-PF partnership：

$$\text{CT}= j / N \qquad (4)$$

Where, j represents the number of papers that AO cooperated with PF(s), and N represents the total number of papers published by AO from the first collaboration with PF(s) to AO's year of candidacy for Fellow.

The purpose of this equation is to gauge the level of partnership and collaboration between the AO and the PF(s) before the AO's year of candidacy for Fellow. A higher value of CT signifies a stronger partnership and collaboration between the AO and the PF(s), as it indicates a higher percentage of jointly published papers. In essence, the equation quantifies the degree of their collaborative work leading up to the AO's candidacy for Fellow.

(c) Initial Cooperation Model

Scientific cooperation often stems from various relationships such as teacher-student, classmate, colleague or kinship connection (Li et al. 2019). Moreover, cooperation can also be established through indirect means. Given the positive impact of scientific collaboration on career growth, partnerships with top scientists are particularly desirable, as they are likely to result in higher academic achievements (Amjad et al. 2017). The current study observed that some AOs had established cooperative relationships with PF(s) prior to the PF(s) receiving Fellow honor, whereas others established the partnership after the PFs had been honored. It is reasonable to speculate that the latter group was motivated by the potential for accelerated success through collaboration with Fellow(s).

In order to gain a more comprehensive understanding of how AOs initially collaborated with PFs, we classified PFs into two distinct categories based on their first cooperated paper with the AO: the "growing together" type and the "growth-supporting" type.

The "growing together" type of collaboration involves a mutual growth and development between the AO and PF, with more equal contributions in terms of expertise, experience, and academic achievements. This type of partnership is likely to be sustained and long-term, with the AO and PF collaborating on multiple projects over time. Whereas the "growth-supporting" type of collaboration involves an established and successful PF providing mentorship, guidance, or other support to a less experienced or accomplished AO. The partnership may be more one-sided, with the PF providing more guidance and expertise, and the AO benefiting more from the partnership in terms of learning and career advancement.

To determine the categorization of the PF for each AO, comparison were made between the year of the first co-authored paper (CPY) with the year the PF received the Fellow honor (PF's AY). If the CPY is greater than PF's AY, the PF is identified as the growth-supporting type; otherwise, it is categorized as the "growing together" type. The study calculated the initial cooperation tendency (FCP) for each AO by measuring the proportion of PFs belonging to the "growing together" type out of all PFs associated with that AO, using Equation (5):

$$\text{RI} = {}^{k}/_{AC} \qquad (5)$$

Where, k is the number of PFs who belong to "growing together" type for a particular AO, and AC is the total number of PFs who have cooperated with that AO.

If RI is equal to or greater than 50%, a value of 1 is assigned to the FCP of the AO, indicating a tendency towards "growing together" cooperation; otherwise, the FCP was assigned a value of 0, indicating a tendency towards "growth-supporting" cooperation. The study arrived at the decision to use a threshold of 50% as it provides a clear cut-off point for determining whether the majority of an AO's collaborations are of one type or the other.

Following the introduction of the main cooperative characteristic indicators, all variables underwent correlation analysis and binary logistic regression. An overview of the variables used in the analysis is provided in Table 3.

Table 3: Description of Variables

	Variables	Description
Independent variables	CS	Dichotomous variable:0 for No Cooperation with PF(s);1 for Cooperated with PF(s).
	AC	The total number of PFs that each AO cooperated with from CPY to AY.
	CT=j/N	The proportion of co-PF papers in total papers from CPY to AY for each AO.
	Avg_CPF= $\sum_{m=1}^{j} CPF_m / j$	The average CPF of each AO per co-PF paper.
	FCP	Dichotomous variable:0 for growth supporting,1 for growing together
Dependent variable	ID	Dichotomous variable:0 for Non-fellow,1 for Fellow

Time period: Extends from CPY to AY, mirroring the time frame of the datasets collected for this study.

RESULTS

Correlation between Researcher's Award (ID) and Cooperation Relationship with Previous Fellows (CS)

Analysis was carried out to observe whether there is statistical correlation between AO's award and the existence of cooperative relationship with previous Fellows. Since both variables are nominal dichotomous variables, a cross-tabulation was chosen to perform descriptive statistics and Pearson's chi-square test analysis on the variables. As shown in Table 4, among the research objects of selected Fellows, 94.33 percent of the Fellows have cooperative relationships with previous Fellows, while only 60.50 percent of the Non-Fellows have cooperative relationships with previous Fellows. A statistically significant difference was present between both group（χ2=125.886， P<0.0001. Moreover, it is also obvious that CS was positively correlated with ID (Φ=.379**， P<0.0001).

Table 4: Pearson's Chi-square Test Results for ID and CS

		CS		**CS=1 percentage**	**X2**	**P**	**Phi Coefficient**
		0	1				
ID	0	207	317	60.50%	125.886	.000	Φ=.379**
	1	20	333	94.33%			

**. p<0.01

Table 5 shows the results of the binary logistic regression obtained using the Prism software. The probability of being selected as a Fellow occurring in the 'cooperated' group is 10.87 times higher than that in those without (OR=10.87, 95%CI: 6.862~18.15). With p<0.0001, it indicates a statistically significant relationship between the independent variable and the dependent variable. Overall, the results suggest that cooperation with previous Fellows is an important factor that contributes to a candidate's election as a Fellow. The odds ratio (OR) value represents the increase or decrease in the odds of the dependent variable (ID) for a one-unit increase in the independent variable, holding all other variables constant.

Table 5: Binary Logistic Regression Analysis Results

	B	Std. Error	OR	95%CI for OR	P
CS (1)	2.386	0.247	10.87	6.862~18.15	<0.0001

CS = independent variable; ID = dependent variable)

These findings indicate that the possibility of being awarded as a Fellow is significantly affected by the cooperative relationship between Fellow candidates and previous Fellow. This implies that having the opportunity to cooperate with previous Fellows has a better chance of success compared to not having such collaborations. This observation aligns with the findings of Li et al. (2019) who noted that junior researchers working with top scientists experience a sustained competitive advantage. Furthermore, Lee (2019) posits that working with prolific, high-quality collaborators also impacts the future career trajectory of scientists.

Correlation between Researcher's Award (ID) and Cooperation Characteristics with Previous Fellows in 4 Main Areas (CS=1)

Due to its expansive nature, computer science spans various research fields. As a result, a study that covers the cooperation characteristics between Fellow and Non-Fellow from different fields would be able to shed light on the possible research collaboration between the two groups. Additionally, such a study can offer valuable insights on the advantages for such collaborations for Awards application. As shown in Table 6, there are significant differences in the total number of publications per AO in each field. Fellow's per capita publications are larger than Non-Fellows'. However, the per capita number of publications cooperating with PF is not much different, except for the non-Fellow in the Systems field, which has more cooperative publications per capita than Fellows. In other fields, non-Fellows have slightly less co-authored publications per capita. This is perhaps due to Systems, a basic field with a long history and numerous researchers, providing a solid foundation for any new studies, and the competition is far greater than other fields, especially in emerging fields.

Among the four indicators that represent the characteristics of cooperation (refer to Table 3), AC, CT, and Avg_CPF are continuous variables, and FCP is a binary variable. Box plots were used to describe the characteristics of continuous variables, while the description of FCP variables used a Chi-square test. Figure 3 shows the performance of the indicator AC in the Fellow group and the Non-Fellow group in four areas. There are differences in the AC values of the four fields, and the AC values of the Fellow group are higher than those of the Non-Fellow group. However, the difference in Artificial Intelligence field is not obvious. There are many high values in the Systems field, especially in the Fellow group. The maximum value reaches 36, which means that a certain Fellow has worked with 36 former Fellows before receiving the honor. In contrast, the cooperation PF of researchers in other fields remains below 20.

Table 6: Cooperation Publications Characteristics of AOs in 4 Computer Science Fields

CS area	ID	Numbers of AO	Total Publications	Co-PF Publications	Avg_Pubs	Avg_Co-PF Pubs
Artificial Intelligence	Non-Fellow	31	1,726	202	56	7
	Fellow	56	6,956	620	124	11
Interdisciplinary	Non-Fellow	70	3,628	584	52	8
	Fellow	23	1,900	207	83	9
Systems	Non-Fellow	193	12,460	2,295	65	12
	Fellow	176	20,380	1,694	116	10
Theory	Non-Fellow	23	1,872	260	81	11
	Fellow	78	8,448	1,042	108	13
	Total	650	57,370	6,904		

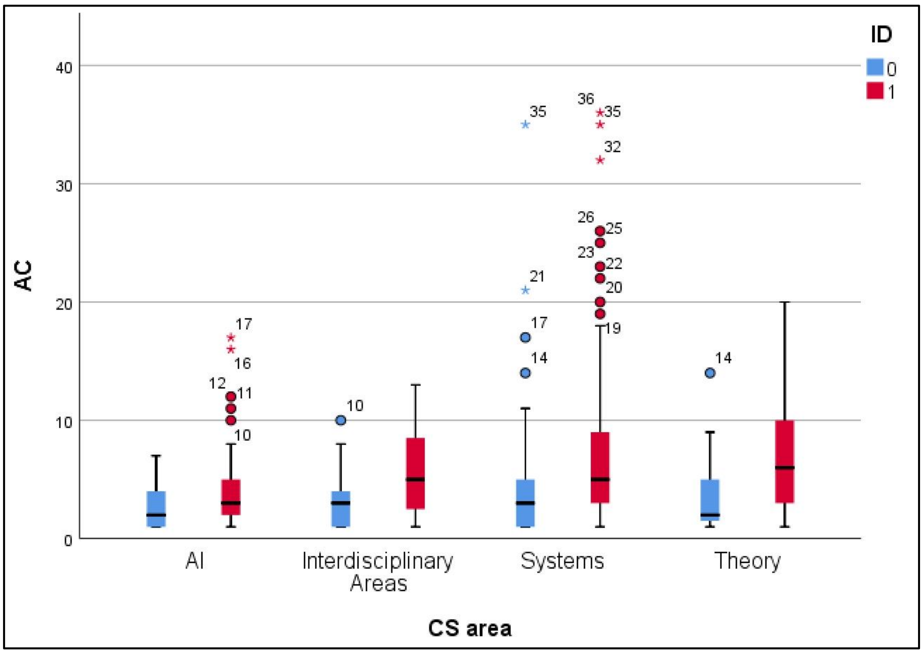

Figure 3: Observation of AC in 4 Computer Science Areas

It can be seen from Figure 4 that there are noticeable differences in the index CT performance between the two groups in each field. Particularly, the CT of the Fellow group is lower than that of the Non-Fellow group (with the exception of the Theory field). This implies that the proportion of papers co-authored by non-Fellow group and PF in all their articles is greater than that of the Fellow group. Perhaps, this indirectly suggests that the volume of papers in the Fellow group is much greater than that of the Non-Fellow group. The Artificial Intelligence field exhibits the most significant difference in the degree of cooperation between AO and PF between the Fellow and the Non-Fellow groups, compared to other fields. For emerging research fields, researchers often need the support of top experts to gain recognition, and co-authoring is considered the most effective means of support. The difference shown in Figure 5 is less pronounced than that observed in the first two variables. In general, the larger sample size in the Systems field leads to more substantial and larger values.

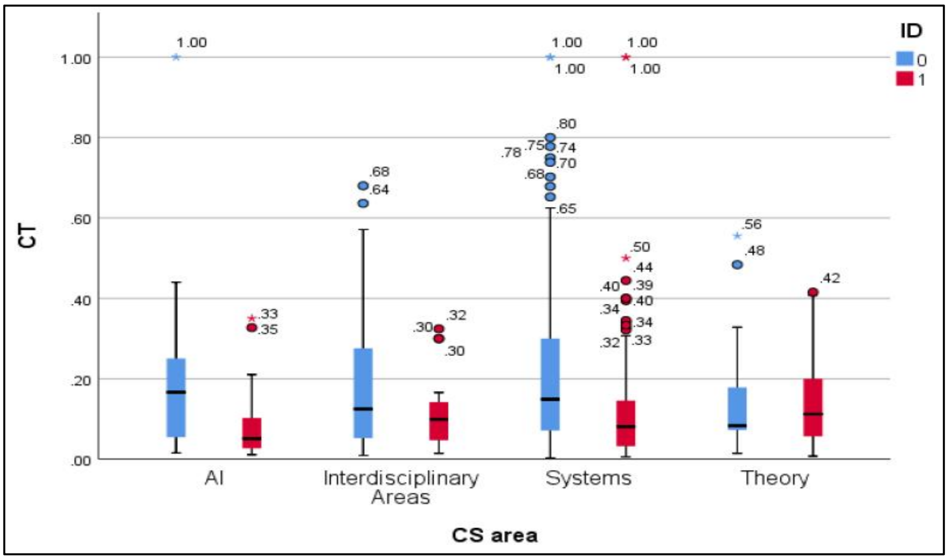

Figure 4: Observation of CT in 4 Computer Science Areas

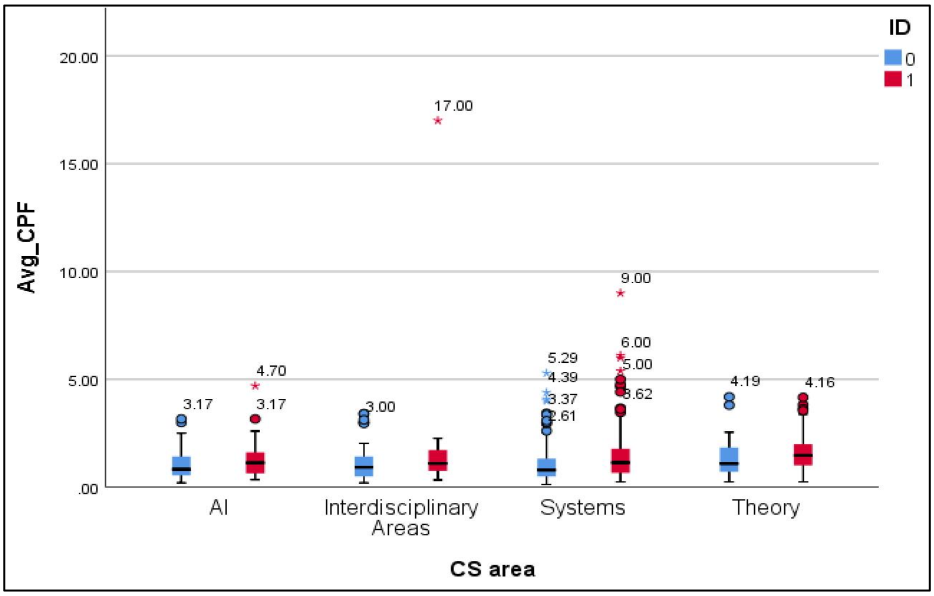

Figure 5: Observation of Avg_CPF in 4 Computer Science Areas

The indicator FCP is a dichotomous variable, hence a cross-tabulation was used to describe the FCP in the four areas, as shown in Table 7. The common growth type of the Fellow group consistently shows relatively high values. However, in the Systems field, the difference between the Fellow group and the Non-Fellow group in the Systems field is not as large as in other fields, with the former being only about 11 percent higher than the latter.

Table 7: Observations of FCP in 4 Computer Science Areas

CS Area			FCP 0	FCP 1	FCP=1 percentage
Artificial Intelligence	ID	0	11	20	64.52%
		1	10	46	82.14%
Interdisciplinary	ID	0	40	30	42.86%
		1	4	19	82.61%
Systems	ID	0	85	108	55.96%
		1	57	119	67.61%
Theory	ID	0	8	15	65.22%
		1	13	65	83.33%
Total			228	422	64.92%

The results of the variable description show that each indicator shows some differences between the two groups in the four fields, providing a certain basis for correlation analysis. As there are both binary and continuous variables, a Spearman's correlation analysis was chosen to explore the relationship between these variables. As shown in Table 8, the correlation results of the variable ID with other variables in each field are different. In the field of Artificial Intelligence, ID only has a negative correlation with CT (ρ=-.365**, $p<0.01$) indicating that as the partnership and collaboration between the AO and the PF(s) become stronger, the likelihood of being elected as a Fellow tends to decrease. Conversely, in the Theory field, only the AC indicator has a positive correlation with ID (ρ= .318**, $p<0.01$). This means that as the number of PFs that AO cooperated with increases, the likelihood of being elected as a Fellow tends to increase as well.

In the Interdisciplinary field, being awarded as Fellow shows a positive correlation with the indicator AC (ρ= .302**, $p<0.01$). This suggests that as PFs that AO cooperated with increases, the likelihood of being elected as a Fellow tends to increase as well. Additionally, ID also exhibits a positive correlation with FCP (ρ= .344**, $p<0.01$). This indicates that as the ratio of PFs belonging to the “growing together” type increase, the likelihood of being elected as a Fellow tends to increase as well. However, the indicators of ID and CT show a weak negative correlation (ρ= -.204*, $p<0.05$), indicating that as the partnership and collaboration between the AO and the PF(s) become stronger, the likelihood of being elected as a Fellow tends to decrease slightly.

In the Systems field, compared to other fields, all indicators are correlated with ID.

Specifically, AC and ID are positively correlated (ρ=.337**, p<0.01), indicating that as PFs that AO cooperated with increases, the likelihood of being elected as a Fellow tends to increase as well in the Systems field. CT and ID are negatively correlated (ρ=-.314**, p<0.01), indicating that as the partnership and collaboration between the AO and the PF(s) become stronger, the likelihood of being elected as a Fellow tends to decrease slightly. This suggest that a higher degree of collaboration with previous Fellows may not necessarily guarantee a higher chance of being elected as a Fellow. The results also reveal a positive correlation between Avg_CPF and ID (ρ=.232**, p<0.01), indicating that as the contribution of PF(s) increases, the likelihood of being elected as a Fellow tends to increase. Additionally, there is also a positive but weak correlation between FCP and ID (ρ=.120*, p<0.05), meaning that the ratio of PFs of "growing together" type increases, the likelihood of being elected as a Fellow tends to increase slightly.

Table 8: Correlation Test of Variables

	CS Area	AC	CT	Avg_CPF	FCP
ID	AI	0.201	-.365**	0.108	0.197
	Interdisciplinary Areas	.302**	-.204*	0.131	.344**
	Systems	.337**	-.314**	.232**	.120*
	Theory	.318**	-0.025	0.163	0.187

**. p<0.01; *. p<0.05

Our analysis shows that a lower degree of cooperation with the Previous Fellow is associated with a higher likelihood of becoming a Fellow. This pattern is observed in all subdivided fields, except for the Theory field, where there there is no significant relationship with the degree of cooperation. The index of cooperation degree in this study measures the proportion of the number of papers co-authored with PF in the total papers. The result of a negative correlation shows that when the number of collaborative papers is roughly the same, the larger total number of papers is associated with a higher likelihood of becoming a Fellow. Additionally, the more Previous Fellows that Fellow candidates collaborate with, the higher their chances of being elected as a Fellow, except in the Artificial Intelligence field. Avg_CPF, the indicator that indicates the ratio of PF contribution to author contribution, is only significantly related to ID in the Systems field. This suggests that if PF(s) create bigger impacts, AO can also gain recognition and fame. Regarding FCP, it shows a positive correlation with ID in the Interdisciplinary field and the Systems field. This indicates that in these two fields, if a researcher aspires to become a Fellow, he/she cannot solely rely on the pre-existing success of the senior collaborators, but rely more on his/her own hard work and contributions.

Correlation between Researcher's Award (ID) and Cooperation Characteristics with Previous Fellows (CS=1)

In the computer science field, the Fellowship status of the research subjects and its relationship with the cooperative relationship exhibit certain variations across the four sub-fields. To provide an overall understanding of the computer science field, continuous variables were examined and organized into groups (Table 9). The sample size of the Fellow group and the non-Fellow group is approximately the same, yet differences can still be observed in each indicator.

Table 10 presents the FCP index data. In the Non-Fellow group, less than 55 percent of the research subjects demonstrates the tendency to grow together with the PF, while in the Fellow group, nearly 75 percent of the researchers do so. This implies that most people in the Fellow group have more than 50% cooperation with PF before the award time of PF. The Spearman correlation analysis results suggest that ID has significant correlations with all variables. ID has a weak positive correlation with Avg_CPF (ρ=.228**, at 0.01 level), indicating that as the ratio of PF contribution to author contribution increases, the likelihood of being elected as a Fellow tends to slightly increase. ID has a positive correlation with AC (ρ= .327**, at 0.01 level), indicating that there is a higher chance of being awarded as a Fellow.

Table 9: Descriptive Statistics of Indicators

	Variables	N	Average	Maximum	Minimum	SD
ID=0	Avg_CPF	317	1.09	5.29	0.13	0.82
	AC	317	3.61	35.00	1.00	3.43
	CT	317	0.21	1.00	0.00	0.19
ID=1	Avg_CPF	333	1.51	17.00	0.25	1.36
	AC	333	6.38	36.00	1.00	5.39
	CT	333	0.11	1.00	0.01	0.12

Table 10: Observations of the FCP Indicator

		FCP		FCP=1 percentage
		0	1	
ID	0	144	173	54.57%
	1	84	249	74.77%

If a candidate for Fellow has more collaboratively authored papers PFs, their ID exhibits a weak negative correlation with CT (ρ= -.279**, at 0.01 level). This suggests that as the ratio of co-authored papers to all papers of an AO increases, the likelihood of being elected as a Fellow tends to decrease slightly. On the other hand, the ID shows a significant positive correlation with FCP (ρ=.212**, at 0.01 level), indicating that as the ratio of PFs of the "growing together" type increases, the likelihood of being elected as a Fellow tends to increase slightly. The correlation heatmap, as shown in Figure 6, visually represents these relationships between the variables. Similarly, after the variables are correlated, the study conducted a binary logistic regression analysis (Table 11) to determine the effect of the independent variables on the dependent variable. The results indicate that all four independent variables have a significant effect on the dependent variable ID, suggesting that they have a significant influence on the likelihood of being elected as a Fellow.

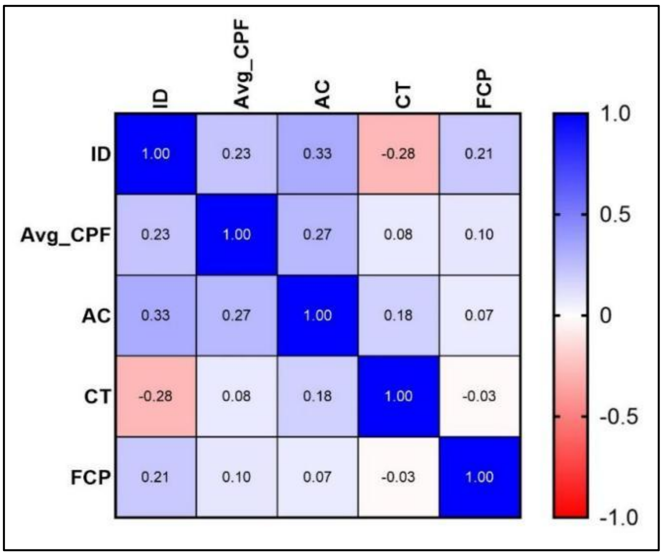

Figure 6: Spearman Rank Correlation Heatmap of indicators

Table 11: Results of Binary Logistic Regression Analysis

	B	Std. Error	OR	95%CI for OR	P
Avg_CPF	0.3498	0.1072	1.419	1.163~1.765	0.0011
AC	0.2074	0.0288	1.231	1.166~1.305	<0.0001
CT	-6.144	0.8222	0.002	0.0004~0.01	<0.0001
FCP (1)	1.01	0.1956	2.746	1.878~4.046	<0.0001

Independent variable = Avg_CPF, AC, CT, FCP; Dependent variable= ID)

Based on the results presented in Table 11, it can be observed that Avg_CPF, AC, and FCP have a positive relationship with ID. This implies that as these variables increase, the likelihood of being elected as a Fellow also increases. The OR values from the analysis reveal the following relationships with ID:

(a) A one-unit increase in Avg_CPF and AC (corresponds to a 1.419 and 1.231 respectively) increase in the odds of being elected as a Fellow.

(b) FCP shows the highest OR value of 2.746, suggesting that a one-unit increase in FCP corresponds to a 2.746 increase in the odds of being elected as a Fellow.

(c) In contrast, CT has a negative relationship with ID. A one-unit increase in CT corresponds to a 0.002 decrease in the odds of being elected as a Fellow.

During the analysis of Fellow candidates across the entire computer science field, this study made a pleasant discovery, and the results were consistent with those observed in the Systems field. The study found that several factors related to PFs significantly influence the likelihood of becoming an ACM Fellow. These factors include the contribution rate of PF to the research subjects; the number of cooperative PFs of the Fellow candidates; the degree of cooperation with PF; and the type of propensity for cooperation with PFs. If PF plays a significant role as a contributor to AO in the article, it can substantially enhance AO's influence. PF not only contributes to the quality of articles, but also impacts the number of collaborative partners. As an author accumulates more PFs, AO receives greater support in his/her quest to achieve the prestigious Fellow honor. Moreover, most PFs who collaborated with AO were already engaged in joint work before being elected as Fellows. However, the degree of cooperation with these PFs matter. If the degree of cooperation is relatively lower, AO will need to exert more effort to increase the number of publications and enhance the possibility of being elected as a Fellow.

DISCUSSION

In answer to research question 1, our study finds that scientists who have engaged in collaborations with ACM Fellows are more likely to achieve the prestigious Fellow title. This finding is consistent with previous research that emphasizes the importance of influential collaborators in boosting researchers' success (Amjad et al. 2017; Qi et al. 2017). Successful organization members are naturally interconnected, as discussed in Liu et al. (2022). The current ACM Fellow selection mechanism requires nomination by existing Fellows, highlighting the importance of networking within the organization. While there may be occasional exceptions to this pattern, this analysis conducted in this study suggests that scientists who establish collaborative relationships with ACM Fellows are more likely to achieve Fellow status. It should be noted that the findings of this study suggest a potential closing on the Fellowship circle.

In response to research question 2, the study observed that the relationship between collaboration and the honor of becoming a Fellow varies when research objects are assigned to 4 sub-areas. In the Artificial Intelligence field, only the degree of cooperation has a negative impact on the likelihood of being elected as a Fellow. In the Theory field, only the number of cooperating previous Fellows has a positive effect on the probability of being elected. In the Interdisciplinary area, results align with the overall computer science, except for one difference - the contributions made by top scientists compared to the collaborative authors do not affect the probability of being elected as a Fellow. In the Systems domain, the results are consistent with the overall computer science findings. On the other hand, the field of Artificial Intelligence is known for its rapid development and extensive application. It is characterized by frequent communication and collaboration between researchers, often involving teamwork and interdisciplinary collaboration. As a result, collaboration alone may not be a significant factor for scientists in the Artificial Intelligence when running for the Fellow title. In contrast, the Theory area is a more fundamental field where researchers tend to focus on the depth rather than the breadth of their research. In this field, only the number of collaborators who are already ACM Fellows has an impact on the likelihood of candidates being elected as Fellows.

In regard to research question 3, the study found that the higher the number of previous

Fellows a candidate had collaborated with, the better their chances of being elected as a Fellow in computer science. And the higher the contributions made by top scientists compared to the collaborative authors, the more conducive it is for the candidates to be elected as a Fellow. In other words, in involvement of top scientists in collaborative research plays a significant role, and enhances the chances of authors being elected as Fellows. Therefore, it is evident that the success of candidates in becoming ACM Fellows is influenced not only by the quantity but also the quality of their collaborative research. Working with top scientists not only provides knowledge, experience and reputation, but also leads to recognition within the academic community. Scholars are well aware of this fact. Hence, from a competition perspective, seeking cooperation with top scientists would be the usual initiative taken, as it increases the chance of being nominated and ultimately elected as a Fellow.

The study also found that the proportion of papers published by scientists and previous Fellows during their collaboration period affects their chances of being elected as a Fellow. When the total number of papers published by scientists is equal, having few papers published in collaboration with previous Fellows is more favorable. The data revealed that the number of co-authored papers between scientists and Fellows was not much different, reinforcing the positive impact of the total number of papers on their success. This finding further supports the notion that scientists' individual research efforts plays a crucial role in contributing to their success in obtaining the Fellow title.

Finally, a closer percentage of “growing together” type in relation to the total collaborative efforts with previous Fellows warrants the likelihood of candidates becoming a Fellow. While opportunists may exist in academia, seeking collaboration with renowned scientists to gain rapid recognition, the findings demonstrate that many scientists have achieved the Fellow honor through consistent joint efforts, with higher chances of success resulting from having more collaborative partners.

CONCLUSIONS

This paper shifts the focus of honorary research from Nobel Prizes, Turing Prize, and Fields Medal to ACM Fellow in the field of computer science, taking 2015-2020 Advanced Member Grades as the research objects, using statistical correlation analysis to study whether their cooperation with previous Fellows, a specific intimate group, affects the selection of the scientists as Fellows. The study explored how cooperation with previous Fellows affects the award of Fellow in 4 classified sub-domains of computer science and how the nature of collaboration with previous Fellows influences the likelihood of a scientist being elected as a Fellow in computer science.

In line with most research findings, a cooperative relationship between the candidates and previous Fellows increases the chances of the candidates being successfully elected as Fellows. When cooperation is present, several significant factors come into play affecting the likelihood of becoming a Fellow, including the contribution rate of previous Fellows to the Fellow candidates; the number of cooperative previous Fellows of the Fellow candidates; the degree of cooperation with previous Fellows; and the propensity to cooperate with "growing together type" Fellows. Furthermore, the nature of collaboration's influence on the candidacy process varies across different sub-fields. Overall, the study suggests that increasing one's own publication output through hard work is a key strategy for achieving success in the field of computer science. The results can also inform policies and practices for organizations such as the ACM in their selection of Fellows.

This paper makes several important contributions to the field of computer science research. Firstly, it introduces two novel indicators that effectively capture the nature and degree of collaboration with senior scientists. These indicators can help researchers to better understand the significance of senior collaborations in their research careers. Secondly, the paper extends the scope of research success by exploring the relationship between collaboration with senior scientists and the election of Fellows. This provides a more nuanced understanding on how such collaborations can impact one's professional recognition in the academic community. Finally, this paper further subdivides the field of computer science, allowing for a more detailed exploration of the impact of collaborations in different sub-fields. This paper provides valuable insights into the factors that contribute to research success in computer science.

Although it is more beneficial for scientists to enter the Fellow circle by collaborating with the current Fellows, it is without doubt that there are still a small percentage of scientists who have not worked directly with previous Fellows. Understanding the specific reasons for their success becomes a focal point of interest for this study and will be explored in future work. Furthermore, this study recommends further investigation to address the issue of cooperation in the field of computing. Given the diversity and complexity of disciplines within the field, the impact of scientific research cooperation may vary significantly. In addition, the relationships that promote the success of scientists include close relationships such as teacher-student relationship and colleague relationship (Liu et al. 2022; Yuret 2022), as well as "inheritance relationships" resulting from socially recognized high-level awards and honors (Wagner et al. 2015). The study will expand the data set to larger scope and conduct more exploration on the relationship between the perspective of specific collaboration and success, to obtain more specific and detailed research results.

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AUTHORS DECLARATION

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