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Uncovering diffusion trends in computer science and physics publications

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Abstract

Purpose – The purpose of this paper is to trace the knowledge diffusion patterns between the publications of top journals of computer science and physics to uncover the knowledge diffusion trends.

Design/methodology/approach – The degree of information flow between the disciplines is a measure of entropy and received citations. The entropy gives the uncertainty in the citation distribution of a journal; the more a journal is involved in spreading information or affected by other journals, its entropy increases. The citations from outside category give the degree of inter-disciplinarity index as the percentage of references made to papers of another discipline. In this study, the topic-related diffusion across computer science and physics scholarly communication network is studied to examine how the same research topic is studied and shared across disciplines.

Findings – For three indicators, Shannon entropy, citations outside category (COC) and research keywords, a global view of information flow at the journal level between both disciplines is obtained. It is observed that computer science mostly cites knowledge published in physics journals as compared to physics journals that cite knowledge within the field.

Originality/value – To the best of the authors' knowledge, this is the first study that traces knowledge diffusion trends between computer science and physics publications at journal level using entropy, COC and research keywords.

Keywords Computer science, Information flow, Physics

Paper type Research paper

1. Introduction

Knowledge is disseminated and spread among various social sectors and entities (Yan, 2014a). Contemporary knowledge is organized through disciplines which are the intellectual and social structures. The diffusion of disciplines uncovers the overlapped boundaries and similarities, and as a result, new cross-fields may arise as a significant variation that may affect the recognized order of knowledge. Researchers are not the only source to disseminate knowledge from one field to another; tools, methods and research articles play an important role as the carriers of knowledge between disciplines. The vital components in the progression of knowledge are the cross-citations across disciplines. Knowledge is diffused within and across the disciplines by publications (publishing in other journals or research area) or by citations (citing the articles published in other disciplines).

The quantifiable revisions of disciplines have used bibliographic information, for example, co-authorship (Amjad *et al.*, 2016, 2017, 2018; Amjad, Daud, Che, Akram, 2015; Newman, 2004; Oh *et al.*, 2005), co-citation (Oh *et al.*, 2005; White and McCain, 1998), and reference relations (Borgman and Rice, 1992; Cronin and Meho, 2008; Cronin and Pearson, 1990). The research and development based tasks in higher educational institutes are coupled with knowledge creation, transfer and diffusion and they enhance the knowledge diffusion process (Chen *et al.*, 2017). The process of information evolution from discovery-oriented science to applications-oriented science and vice versa detects evolutions between science and technology (Hu and Rousseau, 2018). These earlier endeavors have altogether enhanced our comprehension of the intellectual and social closeness of disciplines. This allows the scholars, practitioners and the general society to gain understandings of the composition of disciplines (Boyack *et al.*, 2005; Rosvall

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and Bergstrom, 2007). While earlier citation-based revisions have uncovered patterns of inter-organizational, inter-disciplinarity and international knowledge transfer, they lack a complete and dynamic examination of the question how disciplinary knowledge flows. In today's research communities, the boundaries across the disciplines are reducing because of overlap of disciplines and collaboration of researchers across these boundaries. Inter-disciplinarity collaboration has become a norm in academic practices (Amjad, Ding, Daud, Xu, Malic, 2015). Thus, the motivation behind the research is to study and examine the impact of interdisciplinary collaborations, which is principally indispensable when it comes to facing the challenges of growth in the scientific literature that is produced by scholarly societies. Information dissemination is a process which cannot be directly observed by the scholars. Therefore, this study aims to uncover the hidden diffusion trends among disciplines. As a testbed, the fields of computer science and physics are selected to investigate the impact and diffusion patterns across disciplines at the journal level.

The goal of this study is:

(1) to investigate the inter-disciplinarity and finding the assimilation level in top 12 journals of computer science and physics;

(2) to find how information can spread between computer science and physics publications; and

(3) to examine how different research keywords exhibit different diffusion patterns within and outside the discipline.

The rest of the paper is organized as follows: Section 2 gives an overview of the related literature, Section 3 describes the research methodology. In Section 4, the results are discussed and Section 5 finally concludes the work and gives future directions.

2. Literature review

There is a lot of empirical and theoretical literature on inter-disciplinarity research. Bibliometric and diversity indices are utilized to measure the interaction between disciplines researchers at the journal level. Literature includes the study of subfields of disciplines, the impact of inter-disciplinarity research on citations and status of researchers. Based on the type, we have divided the studied literature into two sections:

(1) inter-disciplinarity research; and

(2) topic-related diffusion.

2.1 Inter-disciplinarity research

A study was conducted on knowledge exchange between 15 disciplines by analyzing cross disciplines citation of 643,000 articles published in 1980–1999 holding 11m references (Rinia *et al.*, 2002). The subject-to-subject percentage of references is calculated, out of which physics shows the highest self-citations rate and shares 0.4 percent literature with computer science. In total, 7.9 percent of references are from computer science to physics. Ortega and Antell (2006) examine the cross-disciplinary citations (CDC) of physics, chemistry and biological sciences departments of 12 universities in 1985–2000. Their results show that 30 to 45 percent of all citations to physics, biological sciences and chemistry originate from other fields. For physics, the CDC increases in 1985 and 1990 and decreases in 1995 and 2000. Their CDC rates of physics for the four years is 36.4 percent, 39.0 percent for Chemistry and Biological Science holds 36.7 percent citations outside disciplines.

Cronin and Meho (2008) presented the information flow between Information Studies and other disciplines. The consequences of their examination uncover the degree to which Information Studies import and export knowledge from other disciplines. The citation data of 30 years from 1977 to 2007 covering 275 articles is used for analysis. In total, 52 percent citations (exports) are from the outside subject categories, *Lecture Notes in Computer Science* and *Lecture Notes in Artificial Intelligence* are top knowledge exporters from IS field, while knowledge is heavily imported from science (engineering and computer science), communication and management fields.

Two forms of diffusion were studied by Liu and Rousseau (2010). These are diffusion by publications and diffusion by citations. Diffusion by publications may initiate from an internal process in which researchers themselves expand their borders by publishing in different fields. Diffusion by citations involve external mechanism, for example, researchers from other fields use or become interested in a research group's expertise, considering that their articles published in more diverse fields are likely to be applied in these other fields. The effect of publications and citations is analyzed using a Gini evenness indicator based on the contextual analysis of mathematical articles. Indicators such as field diffusion intensity (number of citing articles) and field diffusion breadth (number of fields in which the article is cited) are proposed to quantify the scope of research impact at the journal level.

Porter and Rafols (2009) investigated six research domains to find variations in inter-disciplinarity degree from 1975 to 2012 using bibliometric indicators and Rao–Stirling diversity. They found an increase of 50 percent in the number of cited disciplines and references per article, while for co-authors per article it is about 75 percent, signifying noteworthy changes in research practices. They suggested that science is certainly becoming more interdisciplinary by mostly drawing from neighboring fields and slowly expanding the acquaintances with cognitive areas.

Yan (2014a) explored the matter of inter-disciplinarities and observed the patterns of knowledge diffusion. The study shows that citations from one discipline to another are a significant measure to examine the disciplinary knowledge flow. They constructed a network of knowledge flow in which the journal citation report is represented as nodes and citations from one subject category to another as nodes. The use of the concept of shortest path on dynamic discipline-level citation data set has aided improvement in the understanding of the features of disciplinary citation networks and revealed that information from science fields, for example, physics, chemistry and biomedicine can be easily retrieved by other fields, but the field of social science has a tendency to be more self-determining and therefore diverge from different areas as measured by citation gaps. Rorissa and Yuan (2012) analyzed the scholarly structure of information retrieval (IR) as the subfield of Library and Information Science. By analyzing the Web of Science citation data spanning over 10 years from 2000 to 2009, the most prolific authors and their influence on IR are predicted through authorship and co-authorship. The vastly cited publications and journal are from Computer Science, Telecommunication, Management, Engineering and Library Information Science, showing the contribution of the disciplines to the field IR.

A dynamic subfields analysis was performed by Zhu and Yan (2015). They have studied the traits of the subfields of computer science from the viewpoints of citation features, citation link features, network features and their dynamics. They have used several indicators comprising the incoming citations, the number of citing fields, cited or citing relationships, self-citations ratios, PageRank and betweenness centrality. They found that subfields such as Software, Artificial Intelligence, Information Systems and Computer Science Applications possessed higher scientific trading impact.

Yan (2016) studied and examined the patterns of dynamic disciplinary knowledge production and diffusion. They utilized the citations from the Scopus indexed journals and proceedings data set. In a three-step approach, they examined discipline's citation behaviors in trending directions. Afterward, they analyzed citation currents between couples of disciplines and at last, they used ego-centric citation networks to assess discrete discipline's citation course dive using Shannon entropy.

Knowledge diffusion was studied in the perspective of business research by Wu *et al.* (2017). They performed quantitative explorations on a substantial data set business journals ranging from 1997 to 2009 including 400,000 journal-to-journal citations. Their research discovered imperative arrangements of information diffusion in the field of business research. They identified that cross-disciplinary knowledge and diversity depend upon discipline. They emphasized that factors like papers published in the journal and the number of categorizations are not the only measure for cross-disciplinary diffusion but the journal quality also has a substantial influence on cross-disciplinary knowledge flow.

A detailed study was presented by Wang and Zhang (2018) that uses the time dimension to analyze the spatial effect of knowledge diffusion. They used publication citations to study the influence of terrestrial vicinity on the diffusion of information. They studied several transmission speeds, inside and outside the country along the timeline and discovered the benefit of physical proximity, although the spatial advantage is not constant. The study also finds out that social component makes the impact of geography significant in knowledge diffusion.

Recently, a comprehensive review was conducted by Kim *et al.* (2018) in which they covered a wide range of diffusion process from various research fields to identify real-world diffusion dynamics. They presented a classification of mutual key factors in diffusion dynamics. They interpreted the diffusion models in a hypothetical viewpoint of processes and compared them to study their effects on diffusion. They also emphasized that real-world diffusion dynamics can encourage transdisciplinary research.

Another recent study that evaluates two methodologies for quantifying interdisciplinary research output was conducted by Abramo *et al.* (2018). They performed the analysis of data from the Italian Observatory on Public Research. One of the proposed techniques examines the disciplinary diversity of the authors of a publication and the second method studies the disciplinary diversity of the references of the paper. They found that as the number of fields observed from the list of papers of authors increases, the diversity of the reference list increases as well in general. However, this behavior differs around subjects and exceptions were discovered at some paper level.

2.2 Topic-related diffusion

Research keywords or topics play a key role in information diffusion. Topic-related diffusion helps to identify communication patterns between disciplines.

Diverse citation behaviors and scholarly communication patterns of different subfields and topics within the same research field are explored by Yan (2014b), who proposed topic-based PageRank to calculate the scientific influence of research entities (e.g. papers, authors, journals and institutions) at the topic level. Diffusion patterns at macro-level crossways, the subdomains of computer science, are elevated using computer science publications network by Kim *et al.* (2014). They analyzed diffusion trends of research topics across different subdomains using popular keywords in computer science research. They used model-driven and model-free approaches based on entropy, and the two approaches give comparable results, but with different viewpoints. The Dynamic Influence Model shows the strength and directionality of influence. Macro-level information transfer gives only inter-relationships between the clusters. To measure the effect of an academic entity with esteem to a specified topic in a heterogeneous academic network having authors, papers and journals a topic-based heterogeneous rank (TH Rank) was proposed by Amjad, Ding, Daud, Xu, Malic (2015). The three topics Multimedia Information Retrieval, Medical Information Retrieval and Database and Query Processing are selected to prove the results and the TH Rank effectively finds the most prestigious author, paper and journals for the three selected topics. Amjad and Daud (2017) conducted a study on finding the productivity of scholars in their particular field of study. They proposed a Domain Specific Index (DSI) to index authors with respect to their field of study. Citation based on topics is used by DSI to find the position of an author in all topics of their interest. DSI proves to be helpful in finding the author's productivity in their field of interest. Various topics-based tactics are analyzed by Karunan *et al.* (2017) to show research dynamics, influence and diffusion of Information Science and Library Science publications data set. By using knowledge flow network and citation information, they have uncovered patterns of topic impact and acceptance. The authors also recognize a non-substantial relationship between topic popularity and impact, and contend for the necessity to use both variables in unfolding topic characteristics.

Term extraction has also been applied for content-based analysis, document retrieval, document summarization, and other similar tasks. Chen and Yan (2017) used domain-independent term extraction for the analysis of scientific publications. With the adaption of the C-value method, they proposed a rule-based method for term extraction and they have extended it with frequency lists and sigmoid function. The main aim is to build a term extraction system which is independent of domain.

An empirical study was conducted to examine topic extraction from articles by Zhang *et al.* (2018). They presented a k-means based method unified with a word embedding for topics extracted from bibliometric databases. They analyzed the effectiveness of their proposed method on a wide range of specialties. Along with the effectiveness of the proposed method, the results also discovered that overlapping and diverse research interest give an advantage to journal publishers, editorial boards and research communities.

From the study of related literature, we infer that scientific contributions are not always what they look from a direct citation perspective. Taking the knowledge diffusion patterns into account may help researchers to identify interesting facts and new developments. It is plausible that research can be transformed by studying knowledge diffusion relationships at the term level because the atomic connections among terms lay the ground for interdisciplinary knowledge flows. There is a need to study and examine the impact of interdisciplinary collaborations which is principally indispensable when it comes to facing the challenges of growth in the scientific literature that is produced by scholarly societies. This motivates us to study the knowledge diffusion patterns from the fields of computer science and physics to explore the hidden patterns across these domains.

3. Methodology

This study examines knowledge diffusion among the top 12 journals of computer science and physics. Shannon entropy, citations outside category (COC) and diversity of research keywords are employed as a method to find inter-disciplinarity index between computer science and physics journals. Claude E. Shannon (2001) introduced the concept of uncertainty. Entropy is disorder or uncertainty in a system, a concept drawn from thermodynamics, information theory and statistical mechanics. It is an index of diversity used to measure the strength of knowledge flow from one field to another giving disciplinary power. In this study, entropy can be used to find uncertainty of the system, in this case journal citation network. It measures inputs or outputs means incoming citations and outgoing citations from computer science journals to physics journals and vice versa. Here, we employ the same phenomenon to measure the topic diffusion. Higher entropy reflects more diversity across topic and vice versa. COC is an exceptionally productive bibliometric pointer for the study of cross-disciplinary research, initially introduced by Porter and Chubin (1985). According to this concept, a citation is categorized as COC when the focus theme of the referred journal is dissimilar from that of the referencing journal and it is quite robust within a category across journals as well as within journals overtime (Bordons *et al.*, 2004). Entropy and COC are used to find knowledge patterns between the computer science and physics disciplines. Using research keywords, this study examines how different research keywords exhibit different diffusion patterns within and outside the discipline.

The following steps are performed in this study:

(1) data is retrieved from Scopus then top 12 journals of both disciplines are identified using H-index;

(2) the citation matrix from one discipline to another is created to get citations from one journal to the journal in another field;

(3) entropy is calculated in terms of cited and citing dimension to analyze the amount of incoming and outgoing information from one discipline to another;

(4) COC is used to find specialty, inter-specialty and inter-disciplinarity index of the journals; and

(5) top keywords are analyzed to find diffusion patterns.

3.1 Data set

The experimental study is based on Scopus data set of computer science and physics publications, and scope is confined to the articles published in the years 2000–2016. The key attributes include authors, title of paper, year of publication, title of conference or journal, abstract, keywords, references and type of article (conference paper or journal paper).

To trace the trends of information diffusion across disciplines, the top 12 journals in each domain are recognized by using H-index (Hirsch, 2005) or SCImago Journal Rank indicator (Gómez-Núñez *et al.*, 2011), which is a measure of scientific influence. Along with H-index, the number of publications in each journal is also considered in selecting the top journals. For example, if a journal has high H-index, but less than 100 records in the data set then it is not considered as the top journal for this study. Afterward, citations among the top journals from one discipline to another are examined to uncover knowledge diffusion patterns between both disciplines. Table I presents selected computer science journals along with the abbreviation, and the selected physics journals with their abbreviation are listed in Table II.

3.2 Citations outside category (COC)

Analysis of references is a key part of communication. It gives experimental data to shed light on knowledge diffusion within and across the disciplines. References are the obvious relationships between publications that have some shared idea. Reference analysis is a way

No.	Computer science journals	Abbreviation
1	*Computer Methods in Applied Mechanics and Engineering*	*CMAME*
2	*Computer Physics Communication*	*CPC*
3	*IEEE Transactions on Image Processing*	*ITIP*
4	*IEEE Transactions on Information Theory*	*ITIT*
5	*IEEE Transactions on Pattern Analysis and Machine Intelligence*	*PAMI*
6	*Journal of Computational Physics*	*JCP*
7	*Neural Networks*	*NN*
8	*Bioinformatics*	*BI*
9	*Communications of the ACM*	*Comm.ACM*
10	*International Journal of Computer Vision*	*IJCV*
11	*Lecture notes in Computer Science*	*LNCS*
12	*Computers and Fluids*	*Comp.Fluids*

Table I. Computer science journals

Table II.
Physics journals

No.	Physics journals	Abbreviation
1	*Applied Physics Letters*	*App. Phy. Lett*
2	*Astronomy and AstroPhysics*	*Ast. Astro*
3	*Astrophysical Journal*	*Astr. J*
4	*Journal of Applied Physics*	*J. Appl. Phy*
5	*Journal of Chemical Physics*	*J. Chem. Phy*
6	*Langmuir*	*Langmuir*
7	*Optics Letters*	*Opt. Lett.*
8	*Physical Review A – Atomic, Molecular, and Optical Physics*	*Phy. Rev. A*
9	*Physical Review Letters*	*Phys. Rev. Lett*
10	*Reviews of Modern Physics*	*Rev. Mod. Phys.*
11	*Physical Review E – Statistical, Nonlinear, and Soft Matter Physics*	*Phy. Rev. E*
12	*Physics of Fluids*	*Phys. Fluids*

to investigate the degree and nature of added references and to understand the nature of computer science journals contribution to physics journals and vice versa. Reference contexts of computer science journal to the literature of physics and vice versa will be used as an active tracer to find where the top computer science journals illuminate knowledge in physics and vice versa. Most reviews take after the technique proposed by Porter and Chubin (1985) which measures the level of inter-disciplinarity of a journal by using the rate (percentage) of references contracted by the journal from another discipline or strength of the references it holds from another discipline. For example, a paper published in a computer science journal that takes in 10 references to papers published in computer science journals and 12 external references for a total of 20 references reaches an inter- disciplinarity index of 60 percent (12/20).

The study is based on the references made to computer science journals from physics or vice versa. The following three types of COC indices are calculated:

(1) specialty: the percentage of references made to papers published in the same journal;

(2) inter-specialty index: the percentage of references made to journals of the same discipline; and

(3) inter-disciplinarity index: the percentage of references made to journals of another discipline (physics).

3.3 Entropy

Entropy is disorder or uncertainty in a system. It is an index of diversity used to measure the strength of knowledge flow from one field to another giving disciplinary power. In this study, entropy is used to find uncertainty of the system, which in this case is the journal citation network. It measures the incoming citations our outgoing citations from computer science journals to physics journals and vice versa. Shannon entropy specifies uniformity of the distribution. It quantifies the amount of information an event contains.

Entropy in terms of citations can be computed as:

$$H = -\sum_{i=1}^{N} c_i \ln c_i, \tag{1}$$

where N is the number of journals, c_i in terms of citation can be defined as:

$$c_i = \frac{C_i}{C_{tot}},$$

where C_i is the number of citation of i^{th} journal, and C_{tot} is the citations of all journals.

For each journal, entropy is calculated for cited and citing dimension. Cited entropy gives the potential of the journal to be cited by other journals and citing entropy gives the amount of information it shares from other journals by citing them. In this study, we have interpreted the cited and citing entropy in four different ways explained in Table III.

3.4 *Topic-related diffusion*

Research keywords point to the hidden semantic topics and are connected and co-evolve across disciplines. The distribution of research themes across disciplines takes after the presumption that the more keywords the disciplines share, the more comparable these disciplines are. Research topics may illustrate diverse reference activities within and across disciplines. Therefore, the diffusion patterns across computer science and physics are analyzed through 15 research keywords shown in Table IV. By considering keyword variations and discarding vague and unspecific words, we select 15 keywords each of which cover almost 100 publications of the top journals. For the selected research keywords 15 data sets are generated one per keyword and inter and intra relationship of each keyword is calculated.

4. Results and analysis

This section presents the outcomes found from the real-world data set and detailed explanation of COC, entropy and diversity of keywords.

4.1 *Entropy of journals*

The entropy of journals is calculated in terms of cited (incoming) and citing (outgoing) dimensions. A citation network of top journals of computer science and physics is created in the form of aggregated journal-to-journal citations. The matrix is asymmetric means citations from Journal A to Journal B are not like citations from B to A.

Entropy of cited dimension	Entropy of citing dimension	Interpretation
Low	Low	All references are from its own field, a case of discipline-specific research. The journal takes information from its own field and its research is primarily interesting for scholars in its own field
Low	High	The journal alludes knowledge from other disciplines and transforms it into information that is useful for researchers in its in-line field
High	Low	The journal research line is in its own fields, but the research produced as output has the potential to be cited in other disciplinary journals
High	High	A specialized case, it includes references from other journals and has the potential to be cited by others

Table III. Role of Journal in cited and citing dimension

Keywords		
Algorithms	Differential equations	Molecular dynamics
Approximation theory	Entropy	Numerical Analysis
Computational Methods	Finite Element Analysis	Optimization
Computer Simulation	High Energy Physics	Problem Solving
Correlation Methods	Mathematical Models	Quantum mechanics

Table IV. Research keywords

The entropy of computer science journals is presented in Table V for the cited and citing dimension. Entropy greater than 1 is considered as high while less than 1 is considered as low.

The degree of inter-disciplinarity is high if cited and citing entropy is high. While low entropy gives the least uncertainty. Table VI gives cited and citing entropy of physics journals.

Computer Physics Communication, *Neural Networks* and *Lecture Notes in Computer Science* have highest cited entropy among all journals as shown in Figure 1, the knowledge produced by these journals is significant or thought-provoking for physics scholars hence they are receiving more citations from them. *Computer Methods in Applied Mechanics and Engineering*, *IEEE Transactions on Image Processing* and *Journal of Computational Physics* have highest citing entropy hence they share more knowledge from physics by citing them. *International Journal of Computer Vision* and *IEEE Transaction on Image Processing* has zero cited entropy means no uncertainty. *Computers and Fluids* has zero citing entropy that shows its discipline-specific nature. *Computer Physics Communication* is most influential as its both cited and citing dimensions are almost equal.

Astronomy and AstroPhysics and *Optics Letters* have highest cited entropy and *Physical Review E – Statistical, Nonlinear, and Soft Matter Physics* have high citing entropy among

Table V.
Cited and citing entropy of computer science journals

Computer science journals	Cited	Citing
Computer Methods in Applied Mechanics and Engineering	1.3256	2.6402
Computer Physics Communication	1.9955	2.0092
IEEE Transactions on Image Processing	0	2.2839
IEEE Transactions on Information Theory	0.8989	1.1248
IEEE Transactions on Pattern Analysis and Machine Intelligence	0.5163	0.9183
Journal of Computational Physics	1.4738	2.6077
Neural Networks	1.9121	2.1885
Bioinformatics	0.9146	1.8828
Communications of the ACM	0.8963	1.5
International Journal of Computer Vision	0	1.8690
Lecture Notes in Computer Science	2.4016	1.8628
Computers and Fluids	1.3609	0
Mean	1.1413	1.7406

Table VI.
Cited and citing entropy of physics journals

Physics journals	Cited	Citing
Applied Physics Letters	0.9493	1.3652
Astronomy and AstroPhysics	2.0247	0.9928
Physical Review Letters	1.4975	1.1703
Journal of Applied Physics	1.6394	1.7652
Langmuir	1.7153	1
Journal of Chemical Physics	0.8171	1.4785
Optics Letters	2.3436	0
Physical Review A – Atomic, Molecular, and Optical Physics	1.3341	1.9508
Reviews of Modern Physics	1.1991	1.9773
Astrophysical Journal	1.6553	1.1845
Physical Review E – Statistical, Nonlinear, and Soft Matter Physics	0.7177	2.7244
Physics and Fluids	1.0810	0.8383
Mean	1.414508	1.370608

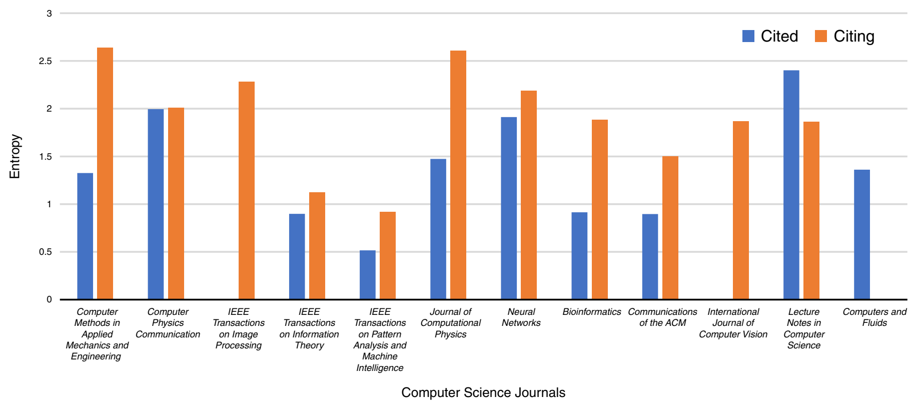

Figure 1.
Entropy of computer science journals

all journals. *Journal of Applied Physics* has almost the same cited and citing entropy, it cites knowledge from computer science as well as is cited by computer science journals. Figure 2 gives a graphical representation of physics journals.

4.2 Results of citations outside category

The statistics of specialty, inter-specialty, inter-disciplinarity index of both disciplines are presented in Tables VII and VIII along with the journal outdegree.

According to the results shown in Figures 3 and 4, the seven computer science journals, namely, *Computer Methods in Applied Mechanics and Engineering*, *IEEE Transactions on Information Theory*, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *Journal of Computational Physics*, *Neural Networks*, *Communications of the ACM*, *International Journal of Computer Vision* have high specialty than their inter-specialty and inter-disciplinarity index. These cite more information in the same specialty or same journal, whereas *Computer Physics Communication*, *IEEE Transactions on Image Processing* and *Bioinformatics* have the highest inter-disciplinarity index for the stated number of references referring more diversity and overlap toward physics domain and *IEEE Transactions on Information Theory* and *Journal of Computational Physics* have inter-disciplinarity index greater than its specialty. The former

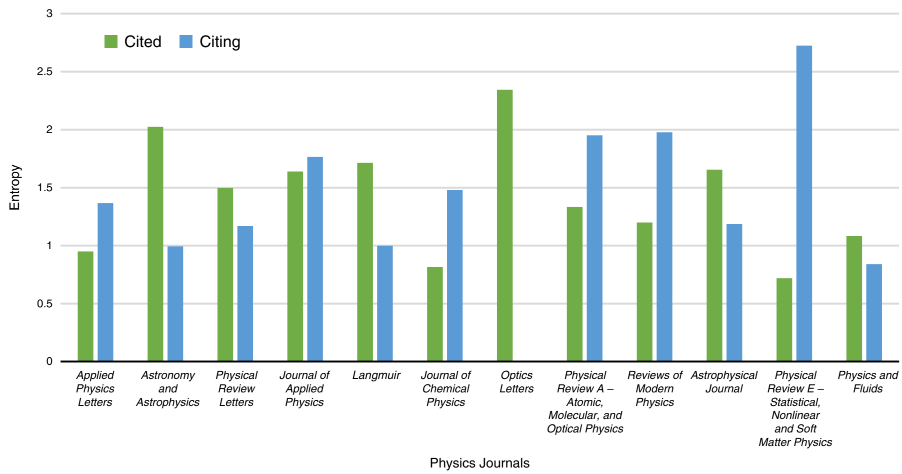

Figure 2.
Entropy of physics journals

Table VII.
Statistics of COC of computer science journals

Computer science journal	Outdegree	Specialty	Inter-specialty	Inter-disciplinarity index
Computer Methods in Applied Mechanics and Engineering	6,168	14	2.9	1.21
Computer Physics Communication	10,302	12	1.8	17
IEEE Transactions on Image Processing	19,994	2	6.5	15
IEEE Transactions on Information Theory	9,559	29	0.61	1.39
IEEE Transactions on Pattern Analysis and Machine Intelligence	2,018	90	28	0.15
Journal of Computational Physics	9,368	24	1.6	3.45
Neural Networks	12,697	12	2.37	0.61
Bioinformatics	2,225	12	0.94	71
Communications of the ACM	2,557	4	1.25	0.15
International Journal of Computer Vision	10,556	7	20	0.25
Lecture notes in Computer Science	13,481	4.68	2.85	0.16
Computers and Fluids	1,401	3.27	0.14	0.21
Mean	8,360.5	17.82917	5.746667	9.215

Table VIII.
Statistics of COC of physics journals

Physics journals	Outdegree	Specialty	Inter-specialty	Inter-disciplinarity Index
Applied Physics Letters	165,159	21	23	0.06
Astronomy and AstroPhysics	15,210	0.09	2	0.13
Astrophysical Journal	74,593	2.07	3.42	0.12
Journal of Applied Physics	174,754	24	43	0.11
Journal of Chemical Physics	144,581	26	35	0.63
Langmuir	2,263	13	19	0.08
Optics Letters	361	14	38	0
Physical Review A – Atomic, Molecular, and Optical Physics	26,345	22	54	0.26
Physical Review Letters	97,011	21	32	0.48
Reviews of Modern Physics	40,539	2	30	0.27
Physical Review E – Statistical, Nonlinear, and Soft Matter Physics	14,333	3.2	25	0.38
Physics of Fluids	26,330	14	8	2.5
Mean	65,123.25	13.53	26.035	0.418333

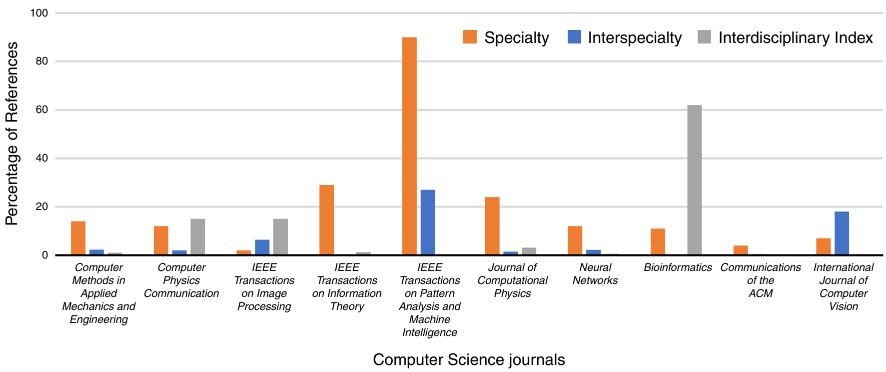

Figure 3.
COC of computer science journals

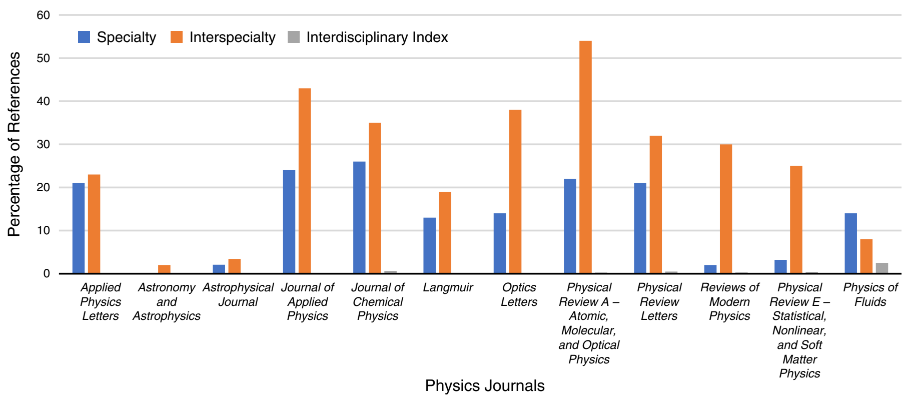

Figure 4.
COC of physics journals

three journals are more diverse in diffusing or getting knowledge from physics discipline. The latter two journals get more knowledge from physics than computer science.

Looking at the COC indicator of physics journals, all journals have high specialty index except for the two journals *Astronomy and AstroPhysics* and *Reviews of Modern Physics*. These two have high inter-specialty index than specialty means they cite more knowledge from their discipline instead of getting knowledge only from the same journals. On the other side, all journals have the lowest inter-disciplinarity index than their specialty and inter-specialty index shows they share and spread knowledge in the in-line field.

Looking at the other side, *Journal of Chemical Physics*, *Physical Review Letters*, *Review of Modern Physics*, *Physical Review A – Atomic, Molecular, and Optical Physics*, *Physical Review E – Statistical, Nonlinear, and Soft Matter Physics* and *Physics of Fluids* have much high inter-disciplinarity index than other journals.

Comparing this situation with that of computer science, one can say that more knowledge is transferred from computer science to physics. The journals of computer science exhibit more diffusion toward physics as compared to diffusion of knowledge from physics journals to computer science.

4.3 Diversity of research keywords

The selected keywords are furthest widespread in extensive research fields, nevertheless, they are not described with equal dynamics of influence. The topic correlation dissemination patterns present weak or robust inter or intra-relationships and are obtained for both directions among selected disciplines.

Figures 5 and 6 show the influence of both disciplines, computer science and physics, within and across the disciplines. Along y-axis is the probability of influence and x-axis is the name of research keywords. In general, for both disciplines, intra-relationship is higher than inter-relationship. Intra-relationship is the relation within the discipline and inter-relationship is the relationship across the two domains.

Inter-relationship and intra-relationship. The inter-relationship and intra-relationships show the following four trends in general (words relationship and influence are used interchangeably in the following description):

(1) high inter-influence;

(2) high intra-influence;

(3) same intra-influence as inter-influence; and

(4) high intra-influence than inter-influence.

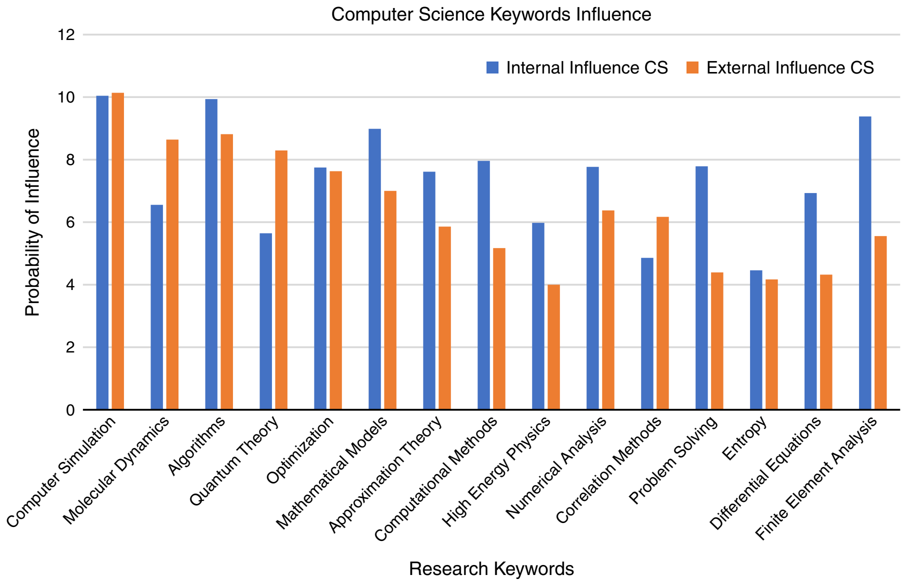

Figure 5.
Influence of both disciplines on computer science

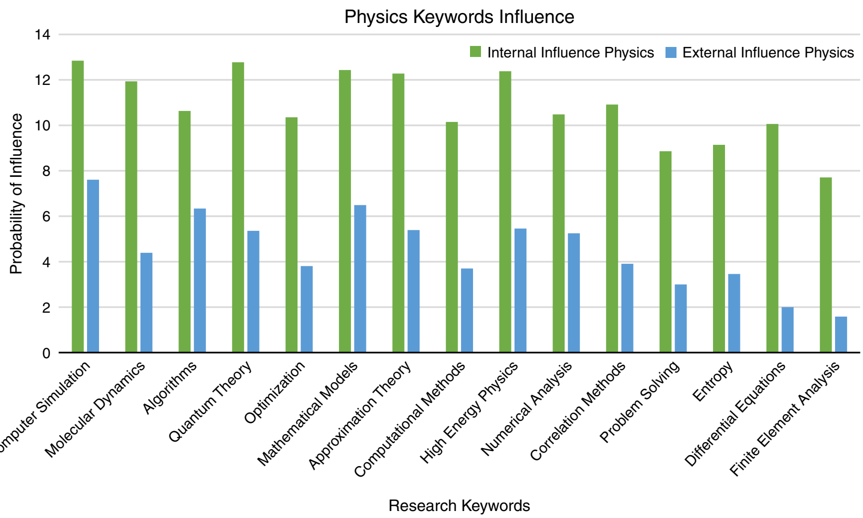

Figure 6.
Influence of both disciplines on computer science

Computer science shows strong inter-relationships, while physics shows stronger intra-relationship.

Computer science is influenced by physics for the research keywords “Computer Simulation,” “Molecular Dynamics,” “Quantum Theory,” “Correlation methods,” “Optimization,” “Approximation theory” and “High Energy Physics.”

Research keywords “Computer Simulation,” “Optimization” and “Entropy” show inter-influence as much as intra-influence.

Computer science shows the stronger intra-relationship for the keyword “Computer Simulation,” “Algorithms,” “Mathematical Models,” “Numerical Analysis,” “Problem Solving” and “Finite Element Analysis.”

The keywords “Computer Simulation,” “Molecular Dynamics,” “Correlation Method” and “Quantum Theory” reveal stronger inter-relationship on computer science than intra-relationship.

Physics exhibits strong intra-relationship for “Computer simulation,” “Approximation theory,” “High Energy Physics,” “Mathematical Models” and “ Quantum Theory.”

Physics is strongly influenced by computer science for the keywords “Computer Simulation,” “Algorithms,” “Mathematical models,” “Approximation theory,” “High Energy Physics” and “Numerical Analysis.” while the keyword “Finite Element Analysis” shows weak inter-influence on physics.

The inter-relationship of journals shows the role of the individual journal in diffusing knowledge across both disciplines. Almost all computer science journals have interaction with each physics journal. The inter-relationships of computer science journals show that among the 12 journals “*Computer Methods in Applied Mechanics and Engineering*” and “*Computer Physics Communications*” import knowledge from all the 12 journals. That shows these two journals have a key role in diffusing knowledge across disciplines. *Journal of Computational Physics*, *Neural Networks* show connection the top 9 journals playing a significant role in transferring knowledge from physics to computer science.

All physics journals import knowledge from *Computer Physics Communications*, *Journal of Computational Physics* and *IEEE Transactions on Information Theory*. It exports knowledge to the top 10 journals. *Physical Review E – Statistical, Nonlinear, Biological, and Soft Matter Physics* only exports knowledge from *Bioinformatics*, *Lecture Notes in Computer Science* and *Computers and Fluids* while *Physics of Fluids* is not influenced by any computer science journal.

Computer Physics Communication focuses on computational method, numerical analysis, hardware and software development in support of physics and physical chemistry. It plays an important role as knowledge exporter and importer between physics and computer science. It shows strong intra-relationship with *Physical Review Letters* and *Applied Physics Letters*.

The *Journal of Computational Physics* is strong knowledge importer and exporter that focuses on computational aspects of physical problems. *Astronomy and Astrophysics*, *Journal of Applied Physics* and *Astrophysical Journal* import knowledge from *Journal of Computational Physics* among all the 12 journals. Seven physics journals are influenced by the research work of *IEEE Transaction on Information Theory*. *Review of Modern Physics* largely exports knowledge from it.

5. Conclusions and future work

Knowledge diffusion is the process of sharing knowledge between scientific disciplines, organizations and individuals. The purpose of this study is to find and interpret the micro level diffusion trends among computer science and physics publications at the journal level via Shannon Entropy, COC and research keywords and illustrate how these indicators evaluate the diffusion patterns. This study focusses on diffusion by citations to examine patterns of information flow between computer science and physics top 12 journals. The study determines the role of each journal in the diffusion of knowledge across these two domains. The computer science journals have higher citing entropy as compared to their citing entropy means they are referring more knowledge from physics while the reverse is the case for physics journals. *Computer Physics Communication* and *Journal of Computational Physics* are highly contributing to the literature of physics. On the other

Physical Review Letters, *Journal of Chemical Physics* are most cited by computer science journals. Computer science journals show a higher average specialty index as compared to their inter-specialty and inter-disciplinarity index. Thus, they have a higher trend of citing articles from the same journal. They have a higher average inter-disciplinarity index as compared to their inter-specialty index. Physics journals have a very high average inter-specialty index as compared to their specialty index and inter-disciplinarity index. They are diffusing more knowledge within the domain and pay less attention to computer science. In general, the predictable diffusion trends from both methods are comparable to each other in terms of the strength and directionality of influence but with diverse viewpoints on diffusion. The findings of knowledge diffusion drawn in this study are comparable to previous work.

The disciplines of computer science and physics are not silent on the matter of information diffusion. Physics is now utterly computational; the publications of physics are more useful or interesting to computer scientists. Research in so many areas is becoming computational one can say that "All science is Computer Science." In the future, we are interested to examine the diffusion patterns at the macro-level (subareas of the disciplines). Covering a whole set of journals and conferences can also give a more consistent picture of collaboration between disciplines. We can also further explore the study using other inter-disciplinarity indicators. We are also interested in uncovering the diffusion trends at the conference level along with a collection of longitudinal data and advanced statistical methods.

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