Charting Science Fiction in Computer Science Literature

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Abstract. Studies concerning the usage of 'science fiction' in computer science research are scarce and rely mostly on anecdotal evidence and scattered oral accounts. For this reason, we present a content analysis of a random sample of 500 publications, retrieved from the IEEE *Xplore* Digital Library via a faceted, full-text search for 'science fiction'. We analyze the type of research paper and the contextual usage of the science fiction referral and show that science fiction, in the grand scheme of things, is a niche topic in computer science research. Furthermore, results demonstrate that science fiction referrals appear primarily in opinion-type contributions, largely with the purpose of drawing inspiration and innovation into the research paper. The implications of this study can guide computer scientists to consciously utilize science fiction in their research and scholarship and therefore, contribute to innovative HCI and computer science research and application.

Keywords: Science fiction · Human-computer interaction · Computer science · Science studies · Content analysis

1 Introduction

Both literary and audio-visual SF [22] propose important ethical questions and dilemmas to the general public—from the role and agency of technology in our lives, to the moral utilization of autonomous robots; or as well highlight the conflict zone of technology, privacy and security in the 21st century. Science Fiction (SF) and real-world technological development intersect in a variety of ways, and a bi-directional relationship between both domains seems not too far-fetched. Especially SF films and shows inevitable focus—to a lesser or larger extent—on yet-to-come Human-computer Interaction (HCI), speculative user interfaces, interactions and future human-machine integration. SF movies and shows can further provide visual use cases and compelling scenarios, allowing conjecture on technological foresight of, for instance, beneficial and detrimental technology outcomes of the society of the future.

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Commonly, depictions of advanced devices, innovative interactions and future technologies in SF are a regular topic in popular news and tech magazines. However, their usage in computer science research has not been comprehensively charted. Such investigations are critical to better understand the potential utility and latent shortcomings of SF for computing research and HCI innovation and, as such, through a content analysis of science communication, this study endeavors to shed light on the relationship between both domains.

2 Background

While still a nascent topic, distinct aspects of the mutual relationship and crossings of SF and HCI have been partially studied [31,40–42,55], including studies examining research indexed in the Association of Computing Machinery (ACM) Digital Library (DL), which:

- Investigated the patterns of use of SF in the CHI proceedings over three decades of computing research [24];
- Described the evolutionary usage of the popular SF franchise Star Trek [25];
- Assessed the utilization of 18 SF robots and AIs [45].

Related work concerning SF/HCI found a convergence of the depiction and real-world progress of computer technology [33]. More recently, researchers did delineate SF-based shape-changing interfaces [65] and hand gestures [16] from SF movies. In addition, catalogues of SF movies and shows, relevant to HCI research, have been made available recently [48,49,60]. In the larger arena of computer science research, the SF/real-world R&D link has been noted by many [11,14,15,21,62,63,69], including Kay and Dourish's [12] special issue on SF and ubiquitous computing.

SF can also stimulate creativity of students in computer science and a diversity of other STEM fields [67], such as computer-ethics [9,10] or -security [30], through an alternative viewpoint extending traditional technical foci in computing education. In fact, as early as in the 1970s, the value of SF literature for educational purposes has been discussed in, for example, Michalsky's essay [43] on the integration of SF into formal education, which presents an early notion of speculative fiction as a means to benefit student creativity. While the topic lately gained traction [3,4,20,37,54], SF in educational settings seems to be a double-edged sword, as has been viewed critically as well [46]; an indicator for a mindful integration of these materials in classroom and educational contexts in the time to come.

Furthermore, Aaron Marcus [40] has presented an overview detailing an HCI travelogue of Hollywood SF movies and shows, and has coordinated two Computer-Human Interaction (CHI) conference plenaries [41,42] on the topic. Similarly, Schmitz, Endres and Butz [58] surveyed various instances of a convergence of SF movies and HCI, outlining a collaboration scheme between researchers and filmmakers through a continuous, inspirational dialogue wherein

films (or filmmakers) are inspired by technology (or by scientists). David Kirby [26–29] speaks extensively about the impact of SF on both, the public perception and the Research and Development (R&D) of technology in his comprehensive, qualitative studies investigating the collaboration schemes of scientists and movie-makers. From a theoretical standpoint, hardly any models describe the relationship of SF and computer science research fully and comprehensively (e.g. [25,29,44,58]).

HCI researchers have as well followed up on the concept of design fiction, which has, since the 2010s, been popularized by a small number of design researchers and labs in HCI and computer science research [6–8,13,38,39,50,64]. Design fictions are closely related to film theory fundamentals, such as Kirby's [28] 'diegetic prototypes' or Frank's [17] notions of 'perceived and referential realities'. For example, Tanenbaum [64] refers to Kirby's [28] concept of diegetic prototypes and extends design fiction it into an emerging research and design method in HCI for innovative interface design research, which is currently used as i) a method to envision new futures and technologies, ii) a tool for communicating innovations to other researchers and the public and, iii) an inspirational and motivational vehicle to explore design affordances and constraints within fictional scenarios. Extending traditional academic research, the mutual relationship of SF/HCI is furthermore well recognized in applied settings, including Experience Professionals Association (UXPA) [66], Nature Careers [61] and the Los Angeles based Science and Entertainment Exchange [47].

Research Rationale. Notwithstanding the earlier introduced commonalities and existing body of research, Marcus [40] states that the history, relationship and synergy effects of of SF and HCI/computer science research, are poorly documented and insufficiently described. Thus far, no studies which explore the usage of SF in scientific publications, with a focus on computer science, are available up to this date with the existing work on the subject matter being:

- limited on specific aspects and applications of SF and computer science research, such as specific interaction types [16,65];
- having a selection bias (e.g. toward a specific subset of selected SF films) and lack accountable and longitudinal data to describe the relationship of SF and computer science research over time and across fields of computer science research [33,58];
- or using a limited sample size and restricted query (e.g. investigations for 20 SF films) without a focus on SF and computing research [34,35].

As a result, SF appears like a related, but yet uncharted topical domain in computer science research. Be that as it may, such investigations are important, as they highlight missed opportunities and future potentials of SF for computing research.

3 Method

Utilizing a methodological framework provided by [23–25,45,52], we present in the following procedure for a detailed, qualitative analysis and discussion of a large sample of computer science records, which refer to SF.

Research Questions. Our study is organized around the following research questions (RQ):

- RQ1: What are the metadata characteristics of computer science publications which reference SF?
- RQ2: What SF particulars co-occur in the context of computer science publications which reference general SF?
- RQ3: What is the purpose of references to SF, and SF particulars which co-occur in the context of SF references, in computer science publications?

Potential Repositories. Both, the ACM DL and Institute of Electrical and Electronics Engineers (IEEE) *Xplore* DL were identified as potential repositories. As an considerable body of research by [23,24,45] already analyzed records retrieved from the ACM DL, the decision was made to search in the IEEE *Xplore* DL for relevant publications which reference SF.

Metadata versus Full-text Retrieval. The question if a metadata, full-text or a hybrid search (e.g. full-text span retrievals) is the most effective method to generate relevant datasets in search and retrieval tasks is of substantial importance for the current study. Contrasting metadata and full-text searches, Beall [5] lists 25 disadvantages of full-text searches, including the failure to recognize abbreviations and acronyms (e.g. "science fiction" and "SF", "sci-fi", or "scifi") and synonyms.

On the other side, Salton and Harman [57] find common problems of metadata-based search and retrieval queries in digital collections, among those, the indexing qualification and individual expertise of those which generate the metadata of the records in the first place. It seems clear that both approaches stand in diametrical opposition to each other and research [19,36,68] shows that an integrated combination of both, metadata and full-text searches, can generate the best results with regards to the relevance of the retrieved documents in specific circumstances.

Comparative Queries. On Dec 30, 2017, a total of eight queries were conducted in the IEEE *Xplore* Digital Library. These initial searches—through the usage of synonyms and the instantiation of different search fields, Boolean operators, synonyms of SF and related concepts—increased in complexity. As a result, two potential candidate sets were identified, introduced next.

C_7 retrieved 353 records in the IEEE *Xplore* Digital Library for a metadata-based search for a variety of SF synonyms:

— *Displaying results 1-25 of 353 for ("science fiction" OR "science-fiction" OR "sciencefiction" OR "sci-fi" OR "scifi" OR "sci fi" OR "sf film" OR "sf movie" OR*

"sf show" OR "sf story" OR "sf author" OR "sf novel" OR "space fiction" OR "space fictions" OR "space opera")

C_4, a full-text search, over all fields of the records, returned at that date 2784 records for a search for the single search term "science fiction":

—Displaying results 1-25 of 2,784 for ("science fiction")

As RQ2 and RQ3 focus on the *contextual usage* of SF in computer science research publications, it can be reasoned that a full-text retrieval (which includes obvious SF referrals in the metadata) is the more fruitful and inclusive approach, especially if one aims to understand the usage of the concept *in situ* of the publication under scrutiny. Therefore, the authors agreed to move forward with C_4 for further analysis.

Facets and Sampling — C_4. Before the application of repository-specific facets (see Table 1), C_4 retrieved of a total of 2784 records (1262 Journals & Magazines, 1086 Conference Proceedings, 429 Books, 7 Early Access Articles) in the IEEE *Xplore* DL. After the application of the facets *My Subscribed Content*, *Content Type: Journals & Magazines*, *Conference Publications*, and *Early Access Articles*, C_4 is reduced to 1647 records—$C_{4(1647)}$.

Due to its notable size of 1647 research papers mentioning SF, $C_{4(1647)}$ was deemed unfeasible for a full qualitative review. Therefore, a random sample was drawn to create a subset called $C_{4(500)}$ representing about 30% of the records in $C_{4(1647)}$. Lastly, a random sample of 125 records was drawn from $C_{4(500)}$ and utilized for a subsequent Inter-rater Reliability (IRR) analysis of two interpretative variables. Table 1 shows the sampling process and step-wise reduction of records per set from the initial full-text retrieval as described in C_4.

Variable Overview. With regards to the variables and attributes reviewed for each record in $C_{4(500)}$, Table 2 presents the nine final variables, along with an abbreviation, the scale type they are measured on, the attribute per variable, data type, coding approach and the prevalence or absence of mutual exclusivity. From these nine variables, seven are reviewed solely by the leading author while the remaining two, the type of research contribution (Pub_{Type}) and the contextual usage of the SF referral (SF_{Cont}) were subjected to an independent, two-person IRR analysis.

Inter-rater Reliability — Pub_{Type} and SF_{Cont}. The lead author and Rater 1 (R1) randomly drew $C_{4(125)}$, as part of the random sample from $C_{4(500)}$, using a random number generator and proceeded to qualitatively review the publications for the variables in Table 2. After an independent coding by R1 of $C_{4(125)}$ for the two interpretative variables in this study—i) the type of research contribution (according to Wobbrock and Kientz [70]) and ii) the contextual usage of the SF referral—the initial coding scheme was established and $C_{4(125)}$ was made available to the second rater (R2).

Table 1. Reduction of C_4 via facets and sampling.

Set	Records	Sampling and reduction
$C_{4(2784)}$	2784	Initial full-text retrieval
$C_{4(1647)}$	1647	After application of facets
$C_{4(500)}$	500	Random sample of $C_{4(1647)}$
$C_{4(125)}$	125	Random sample of $C_{4(500)}$

Table 2. Variable overview.

#	Variable	Scale	Type	M.E.	Coding
1	Pub_{Year}	Interval	Quan	Yes	R1/in vivo
2	Pub_{Type}	Nominal	Qual	Yes	IRR
3	SF_{Freq}	Ratio	Quan	Yes	R1/in vivo
4	SF_{Loc}	Nominal	Qual	No	R1/in vivo
5	SF_{Cont}	Nominal	Qual	Yes	IRR
6	SF_{Auth}	Nominal	Qual	No	R1/in vivo
7	SF_{Books}	Nominal	Qual	No	R1/in vivo
8	SF_{Movies}	Nominal	Qual	No	R1/in vivo
9	SF_{Char}	Nominal	Qual	No	R1/in vivo

Following a general introduction to the coding scheme by R1 with a focus on the two interpretative variables—Pub_{Type} and SF_{Cont}—R2 coded independently $C_{4(125)}$ using the coding rubric for the two interpretative variables and attributes provided by R1. After R2 provided the assessment of $C_{4(125)}$, an IRR evaluation by means of cohen's κ (and Krippendorff's α as alternative) coefficient(s) was calculated. Two check-ins (one after R2 did code 50% of $C_{(4125)}$, one after R2 finished coding $C_{4(125)}$ by R1 served to resolve disagreements and finalize the final coding scheme. Specifically, R2 did indicate in 33 of the 125 records in $C_{4(125)}$ (36 of 250 possible codes) alternative codes for either, the type of research contribution, or the contextual usage of the SF referral. These 36 alternative codes were reviewed and consolidated between the raters, hence allowing R1 to proceed to code the remaining 375 records in $C_{4(500)}$.

Rater Background. Rater 1 is the lead researcher on this project and has been conducting research on SF and HCI/computer science research for the last 5 years. Rater 2 is a HCI and design innovation researcher and practitioner with 15+ years experience. Rater 2 volunteered her time and expertise to rate $C_{4(125)}$ for no compensation or reimbursement.

3.1 Coding the Type of Research Paper—$\mathbf{Pub_{Type}}$

In order to judge which type of research contribution is under scrutiny, the main contribution of the paper was coded along 7 mutually exclusive categories following Wobbrock and Kientz [40–43,70]. This variable is of categorical nature, mutually exclusive and has the following eight attributes:

1. **Empirical contributions**—e.g. experiments, user tests, field observations, interviews, surveys, focus groups, diaries, ethnographies, sensors, log files, quantitative lab experiments, crowdsourced study
2. **Artifact contributions**—e.g. input device, system, hardware toolkit, envisionment
3. **Methodological contributions**—e.g. method adaption, method application, method innovation, new measures, new instrument
4. **Theoretical contributions**—e.g. frameworks, conceptual models, design criteria, quantitative models
5. **Dataset contributions**—e.g. test corpi, benchmark results, repositories, datasets
6. **Survey contributions**—e.g. surveys on techniques, emerging topics, tools, domains and technologies, meta-analyses
7. **Opinion contributions**—e.g. arguments on specific research topics or a domain, for example, new prospects in evaluation, application or vision of the future
8. **Other contributions**[1]—e.g. Newsletters, Editor's Notes, Interviews, Readers Letters, Obituaries, Tutorials, Presentation Slides, Keynote Speaker Introductions, or Book Reviews, which do not fit in any of the other categories.

3.2 Coding the Contextual SF Referral—$\mathbf{SF_{Cont}}$

In order to classify the contextual usage[2] of the SF referral(s) in the publication(s) under review, a mutually exclusive variable called 'Contextual usage of the SF referral' with eight attributes was coded. These attributes did emerge from the prior introduced analysis of $C_{4(125)}$ and can be conceptually classified into three broader domains:

[1] This category has been added and is not listed as part of the original 7 categories from Wobbrock and Kientz [40–43,70]. In contrast to *opinion contributions*, these publications are coded as *other, non-research-focused contributions*, as they do not cite extensive, related research or work, commonly found in *opinion contributions*.

[2] In cases where multiple SF referrals occur in a publication, a judgment by the respective Rater across all referrals in the paper under review is made, therefore yielding one code for the overall usage of the SF referrals in the respective paper.

1. **SF Referrals, with a focus on drawing innovation from SF in the research paper:**
   (a) **Coming from SF**— This attribute sums up the usage of a SF referral to draw from a general SF concept, technology, device or idea, originating, as seen in or known from SF, and potentially inspiring research. Conceptually, this attribute describes references to SF, which in contrast to 1.(b) or 1.(c), refer to a known SF concept, but do neither stress the realization or impossibility of the concept.
   (b) **Making SF a Science Reality**— This attribute encapsulates a SF reference, which stresses the realization of a SF concept, technology, device, or idea (or approximation of), by crossing over into or being reality. Conceptually, this attribute describes SF references the authors use to stress that an innovation moved from SF into science. Conceptually, this attribute is a sub-attribute of 1.(a)
   (c) **Unreal SF**— This attribute describes a SF reference, which emphasizes a SF concept, technology, device or idea, as seen in, or known from SF, but, at the time of the publication, not possible in the real world. Conceptually, this attribute is a sub-attribute of 1.(a).
2. **SF referrals, with a focus on individuals, the scientific community and/or the general public:**
   (a) **SF and the Individual**—This attributes codes the contextual usage of a SF referral win regards to the relationship of the author, or another person (e.g. other researcher, SF author, or research participant), who is also involved with SF. Conceptually, this attribute encapsulates the usage of a SF referral with a focus on the external implications and consequences for people and communities. Conceptually, this attribute encapsulates the usage of a SF referral with a focus on specific individuals.
   (b) **SF and the Community or Public**—This attributes codes contextual usages of SF in reference to an the relationship of SF with the understanding, expectations, or imaginations of science in the public or research communities. Conceptually, this attribute encapsulates the usage of a SF referral with a focus on the external implications and consequences for general people and the larger community and society.
3. **SF referrals, integrated as part of the research paper**.
   (a) **SF and the Paper Research Method**—This attributes summarizes contextual usages of SF referrals in regards to the research background, method, objective, application, or outcome of the paper. Conceptually, this attribute encapsulates the usage of a SF reference with the purpose of the utilization within the research contribution itself.
   (b) **SF in the References**—In reference to SF reference, listed in the references section of a publication. Conceptually, this attribute reflects the usage of a SF referral in the references section of a research contribution.

3.3 Contextual SF Particulars—$\mathbf{SF_{Cont}}$

This variable represents explicit SF particulars, which co-occur in the publication which references SF in $C_{4(500)}$. This variable is of nominal nature and structured in the following sub-variables:

1. **SF Authors:** (e.g. Arthur C. Clarke or H.G. Wells)
2. **SF Books, Novels, Short Stories, Magazines**[3]: (e.g. Neuromancer or I, Robot)
3. **SF Movies or Shows:** (e.g. 2001: A Space Odyssey or Black Mirror)
4. **SF Characters:** (e.g. Mr. Data from Star Trek or HAL from 2001: A Space Odyssey)

Research Tools. With regard to the research tools, the author used Atlas.ti v8 to qualitatively code $C_{4(500)}$. In addition, Microsoft Excel was used to calculate descriptive measures of $C_{4(125)/(500)}$ and further utilized to create the graphs and figures for the data presentation in this paper. For the IRR analyis, IBM SPSS Statistics was used to calculate the IRR coefficients for cohen's κ, respectively, Krippendorff's α.

4 Results

In the remainder of this paper, only results pertaining to $C_{4(125)}$ and $C_{4(500)}$ will be presented. The IRR results were calculated using $C_{4(125)}$, the Publication Years results and Referral Frequency and Location results contrast both $C_{4(125)}$ and $C_{4(500)}$. All other results used $C_{4(500)}$.

Inter-rater Reliability (IRR). As all other variables are of non-interpretative nature and coded in vivo (see Table 2), only the variables Pub_{Type} and SF_{Cont} are subjected to an IRR assessment. The IRR coefficients of cohen's κ, respectively Krippendorff's α as an alternative measure, were calculated through IBM SPSS Statistics. The IRR analysis of the agreement of R1 and R2 with regards to the type of research paper (Pub_{Type}) of $C_{4(125)}$ showed a substantial agreement (κ between 0.61–0.80) between R1 and R2, with a κ of 0.71, respectively, resulted in an α coefficient of 0.71 ($\alpha \geq 0.667$ [32]) allowing for tentative conclusions to be drawn. The IRR analysis of the agreement of R1 and R2 with regards to the type of the contextual SF referral (SF_{Loc} in $C_{4(125)}$ showed a substantial agreement (κ between 0.61–0.80), with a κ of 0.65, respectively, resulted in an α coefficient of 0.68 ($\alpha \geq 0.667$ allowing for tentative conclusions to be drawn.

[3] There might be instances where it is not possible to identify if a specific SF referral is toward a movie or a book. Most SF media is rooted SF literature, however, in cases where it is not clear if an author refers to a specific SF book, or rather the equivalent SF film, a judgment by the Rater is conducted and either the *SF Books* or *SF Movies* categories is chosen.

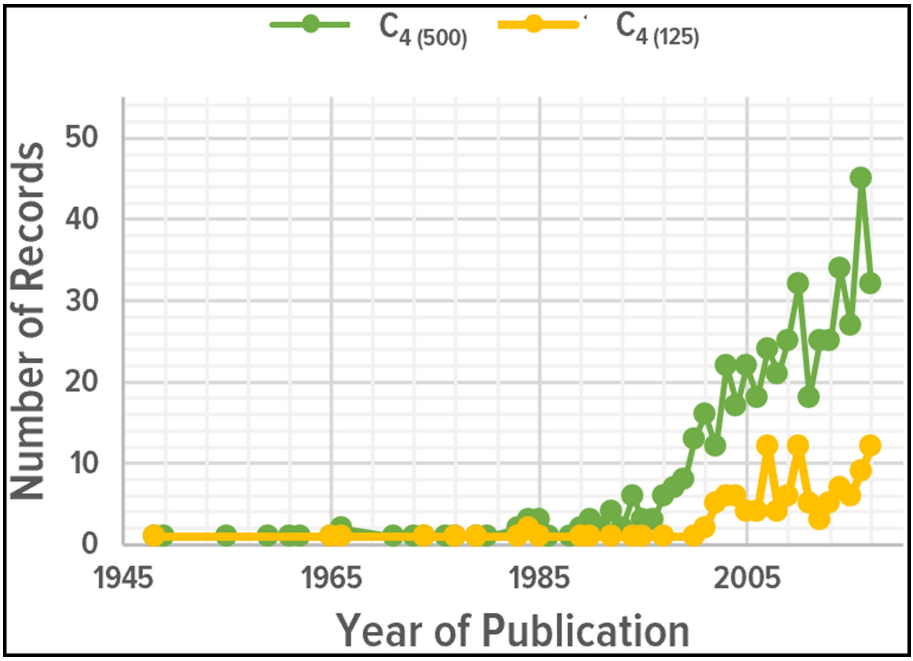

Fig. 1. Distribution of publication years: $C_{4(500)}$ and $C_{4(125)}$

Publication Years. Figure 1 shows the distribution of records per year of $C_{4(500)}$. The earliest record in $C_{4(500)}$ dates from 1948 while the most recent papers in $C_{4(500)}$ were published in 2017. Figure 1 also shows that 72 out of the 500 records (14%) in $C_{4(500)}$ were published before 2000, while the bulk of retrieved papers (n = 428, 86%) was published in the year 2000 or later. $C_{4(500)}$ is overall representative of the distribution patterns of publications years of records in comparison to the IRR Set $C_{4(125)}$.

SF Referral Frequency and Location. Table 3 shows the distribution of SF referrals in $C_{4(125)}$ and in $C_{4(500)}$.

In total, 899 referrals to 'science fiction' are identified with the vast majority of referrals (n = 761, 84.6%) being found in the body of the reviewed publications, n = 64 in the references, n = 49 in the abstracts, n = 21 in the titles and n = 4 in the footnotes. With a total of 899 SF referrals in 500 records, on average, every publication in $C_{4(500)}$ did refer 'science fiction' 1.55 times/record, with a maximum of 31 referrals in one single record. Table 4 shows that the majority of the records (380 out of 500 records, 76%) in $C_{4(500)}$ refer 'science fiction' one time. This frequency and location distribution re-ensembles closely the frequency and location distribution in $C_{4(125)}$.

Table 3. SF Referral frequency and location: $C_{4(125)}$ and $C_{4(500)}$.

SF_{Loc}	Records	% of $C_{4(500)}$	Records	% of $C_{4(125)}$
Title	21	2.3%	2	1%
Abstract	49	5.5%	12	6%
Body	761	84.6%	152	81%
Footnote	4	0.4%	2	1%
References	64	7.1%	19	10%
Total	**899**	**100%**	**187**	**100%**

Table 4. SF Referral frequency: $C_{4(500)}$ and $C_{4(125)}$.

SF_{Freq}	Records	% of $C_{4(500)}$	Records	% of $C_{4(125)}$
1	380	76.0%	98	78.4%
2	60	12.0%	15	12.0%
3	21	4.2%	3	2.4%
4	12	2.4%	4	3.2%
5	9	1.8%	2	1.6%
6	3	0.6%	1	0.8%
7	2	0.4%	1	0.8%
8	1	0.2%	—	—
10	2	0.4%	—	—
11	2	0.4%	1	0.8%
12	2	0.4%	—	—
15	1	0.2%	—	—
20	1	0.2%	—	—
22	1	0.2%	—	—
24	1	0.2%	—	—
25	1	0.2%	—	—
31	1	0.2%	—	—
Total	500	100%	125	100%

4.1 Type of Research Paper

Figure 2 shows the frequency distribution of the type of research paper across $C_{4(500)}$. With almost one out of three papers (n = 153, 31%), opinion research contributions represent the clear majority with regards to the publication type in $C_{4(500)}$. On the lower end of the spectrum, methodological contributions (n = 38, 8%) are found to be the least common type of research paper. Note that dataset contributions[4] (n = 0), as visualized in Fig. 2, were not found in $C_{4(500)}$.

[4] As dataset contributions are quasi non-existent in $C_{4(500)}$, this attribute of Pub_{Type} will be disregarded in the following analysis.

4.2 Contextual SF Referral

Figure 3 shows the frequency distribution of the context of the SF referral across $C_{4(500)}$.

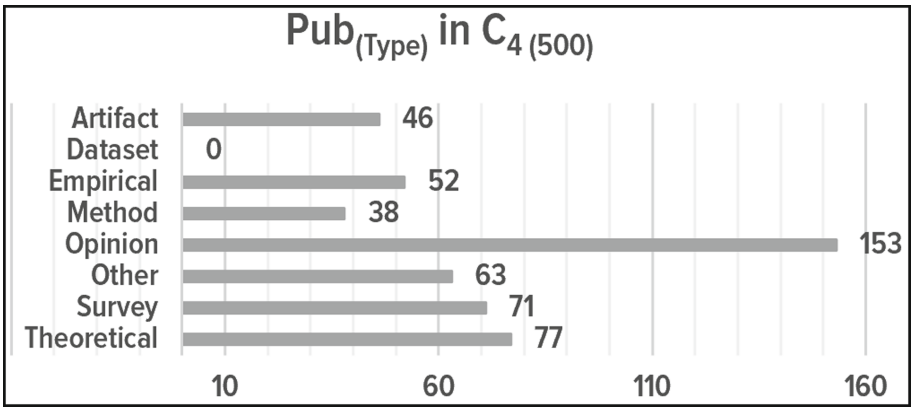

Fig. 2. Type of research paper: $C_{4(500)}$.

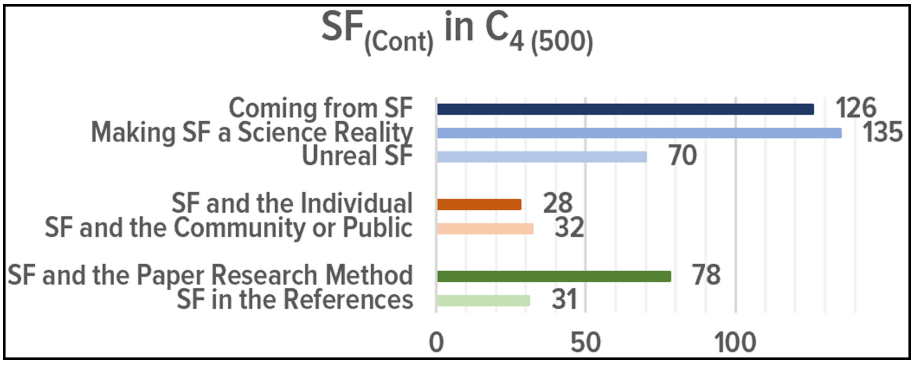

Fig. 3. Contextual SF referral: $C_{4(500)}$.

In $C_{4(500)}$, SF referrals are primarily used for two main reasons: First, in the context of introducing ideas, concepts, technologies, devices, or interactions originating in, seen in, or known from SF (n = 126, %25). Second, in the context of converting these ideas, concepts, technologies, devices, or interactions into reality (n = 135, %27), or an approximation thereof. Contrasting the three domains of the contextual usage of the SF referrals, it is clear that scientists primarily refer to SF with the purpose to draw innovation and inspiration from SF into the research contribution (331[5] out of 500 records, 66%).

[5] 331 = Coming from SF (n = 126) + Making SF a Science Reality(n = 135) + Unreal SF (n = 70).

4.3 Type of Research Paper/Contextual SF Referral

Figure 4 shows the frequency distribution of the type of research paper in relationship to the contextual usage of the SF referral (combination of Fig. 2 and Fig. 3).

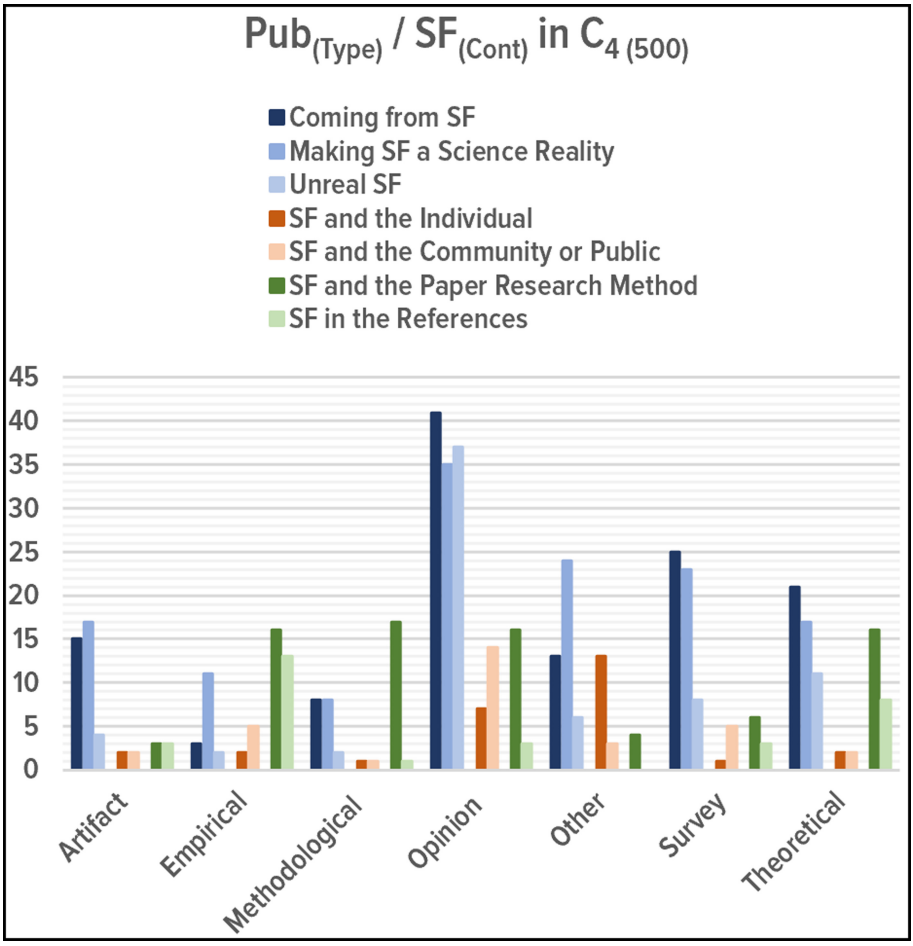

Fig. 4. Type of research paper/context of SF referral: $C_{4(500)}$.

An investigation of the most frequent contextual uses of SF references across all seven identified research paper types reveals that in three categories of contributions (Opinion, Survey, Theoretical), SF referrals are most often used to introduce concepts, originating in SF. In addition, SF referrals in the context of converting a SF concept into a reality are found most often in two categories of paper types (Artifact, Other).

The two remaining research contribution types (Empirical, Methodological) use SF referrals most frequently as an integrated part of the research paper introduction, background, application, method or discussion. These types of referrals (SF and the Paper Research Method) are also the third-most common type of referral in the Theoretical paper category. Furthermore, across the majority of all seven research contribution types in Fig. 4 (with Opinionated and Other paper types being the exception), SF referrals, with a focus on individuals, the scientific community and/or the general public are, - relative to all referrals within the individual category under review, the least common type of referrals.

4.4 SF Authors

A total of 72 unique SF authors, spread across 528 full-text referrals, in 201 records were identified in vivo in $C_{4(500)}$. Table 5 shows the partial results of this analysis by means of a cut-off for the 14 most frequent SF authors for binary counts[6].

Table 5. Most frequent SF Authors: $C_{4(500)}$.

	Author	bin. ref.	% of $C_{4(500)}$
1	Isaac Asimov	28	13.9%
2	Arthur C. Clarke	19	9.5%
3	William Gibson	15	7.5%
4	Robert Heinlein	9	4.5%
5	Jules Verne	7	3.5%
6	Karel Čapek	7	3.5%
7	Neal Stephenson	7	3.5%
8	Philip K. Dick	7	3.5%
9	John Brunner	5	2.5%
10	Vernor Vinge	5	2.5%
11	George Orwell	4	2.0%
12	Ray Bradbury	4	2.0%
13	Frank Herbert	3	1.5%
14	H. G. Wells	3	1.5%
	Subtotal	**123**	**61.2%**
...	...	...	...
72	William F. Nolan	1	0.2%
	Total records	**201**	**100%**

[6] The analysis of the binary counts in $C_{4(500)}$ disregards the coding frequency and counts the presence of a referral to a specific SF author as 'yes' if present, regardless how often, or 'no', if not present. This allows a differentiated analysis. For example, Norbert Wiener is the second most often mentioned SF author absolutely ($n = 80$), however only appears in $n = 3$ papers in the binary counting.

Herein, Issac Asimov (28 records, 13.9%) appears the most frequent in the research papers, followed by Arthur C. Clarke (19 records, 9.5%) and William Gibson (15 records, 7.5%). The fourteen SF authors who appear the most often in research papers in Table 5 account for the majority (123 records, 61.2%) of the 201 records in $C_{4(500)}$, which mention at least one of the 72 SF authors identified.

4.5 SF Writings

A total of 162 unique SF books, novels, short stories and magazines, spread across 328 full-text referrals, in 224 records were identified in vivo in the random sample of 500 records in $C_{4(500)}$. Table 6 shows the partial results of this analysis by means of a cut-off for the 14 most frequent books and short stories, by binary count.

The binary frequency analysis in Table 6 shows that Neuromancer (10 records, 4.5%) appears the most frequent in the research papers in $C_{4(500)}$, followed by references to Astounding Science Fiction (7 records, 3.1%) and Runaround (7 records, 3.1%). The 14 SF novels which appear the most often in research papers (binary counting) in Table 6 account for a little less than a third (65 records, 29%) of the 224 records in $C_{4(500)}$, which mention at least one of the 162 unique SF books, novels, short stories or magazines.

4.6 SF Movies and Shows

A total of 103 unique SF shows and movies, spread across 429 full-text referrals, in 205 records were identified in vivo in the random sample of 500 records in $C_{4(500)}$. Table 7 shows the partial results of this analysis by means of a cut-off for the 14 most frequent SF movies and shows, by binary count.

The analysis shows that Star Trek (28 records, 13.7%) appears the most frequent in the research papers in $C_{4(500)}$, followed by 2001: A Space Odyssey (23 records, 11.2%) and the movie The Terminator (13, 6.3%). The 14 SF movies and shows which appear the most often in research papers (binary counting) in Table 7 account for more than $\frac{2}{3}$ (141 records, 68.8%) of the 205 records in $C_{4(500)}$, which mention at least one of the 103 unique SF movies or shows.

4.7 SF Characters

A total of 38 unique SF characters (humans, robots, androids, computers), spread across 100 full-text referrals, in 55 records were identified in vivo in the random sample of 500 records in $C_{4(500)}$. Table 8 shows the partial results of this analysis by means of a cut-off for the 14 most frequent books and short stories, as a binary count.

The analysis shows that HAL 9000 (11 records, 20%) appears the most frequent in the research papers in $C_{4(500)}$, followed by R2-D2 (3 records, 5.5%) and Dick Tracey (3 records, 5.5%). Accordingly, the 14 SF characters which appear the most often in research papers (binary counting) in Table 8 account for more than half (31 records, 56.4%) of the 55 records in $C_{4(500)}$, which mention at least one of the 38 unique SF characters.

5 Discussion

SF Referral Frequency and Location. The study outcome demonstrates that SF referrals occur in the majority of cases one single time in the full-text of a publication (i.p 78% in $C_{4(125)}$, respectively 77% in $C_{4(500)}$). In addition, the results indicate that SF referrals occur the most often in the body of the reviewed records (i.p. 81% in $C_{4(125)}$, respectively 84.6% in $C_{4(500)}$). This suggests that the majority of scientific authors who refer to SF do not focus ultimately on SF in their research contributions per se, but instead most often introduce, draw, refer, discuss or exemplify, a general or specific aspect of a SF idea, concept, device or technology in the context of the individual research contribution. From a frequency and referral location analysis point-of-view, it can be reasoned that

Table 6. Most frequent SF writings: $C_{4(500)}$.

	Books, Novels, Short stories	bin. ref.	% of $C_{4(500)}$
1	Neuromancer	10	4.5%
2	Astounding Science Fiction	7	3.1%
3	Runaround	7	3.1%
4	Snow Crash	6	2.7%
5	HH Guide to the Galaxy	4	1.8%
6	The Shockwave Rider	4	1.8%
7	R.U.R.	4	1.8%
8	Do Andr. Dream of E. Sheep?	4	1.8%
9	I, Robot	4	1.8%
10	True Names	3	1.3%
11	From the Earth to the Moon	3	1.3%
12	Nineteen Eighty-Four	3	1.3%
13	The Diamond Age	3	1.3%
14	2001: A Space Odyssey	3	1.3%
	Subtotal	**65**	**29%**
...	...	...	...
162	Young Lady's Ill. Primer	1	0.4%
	Total records	**224**	**100%**

Table 7. Most frequent SF movies and shows: $C_{4(500)}$.

	Movies, Shows	bin. ref.	% of $C_{4(500)}$
1	Star trek	28	13.7%
2	2001: A Space Odyssey	23	11.2%
3	The Terminator	13	6.3%
4	Minority Report	12	5.9%
5	Star Wars	11	5.4%
6	The Matrix	9	4.4%
7	I, Robot	9	4.4%
8	Fantastic Voyage	8	3.9%
9	Star Trek: TNG	7	3.4%
10	Blade Runner	7	3.4%
11	Gattaca	4	2.0%
12	Metropolis	4	2.0%
13	Forbidden Planet	3	1.5%
14	Battlestar Galactica	3	1.5%
	Subtotal	**137**	**68.8%**
...	...	...	...
103	Westworld	1	0.5%
	Total records	**205**	**100%**

Table 8. Most frequent SF Characters: $C_{4(500)}$.

	Movies, Shows	bin. ref.	% of $C_{4(500)}$
1	HAL 9000	11	20.0%
2	R2-D2	3	5.5%
3	Dick Tracy	3	5.5%
4	Captain Kirk	2	3.6%
5	Borg	2	3.6%
6	C-3PO	2	3.6%
7	Wintermute	1	1.8%
8	Princess Leia	1	1.8%
9	Waldo	1	1.8%
10	David	1	1.8%
11	Dr. Frankenstein	1	1.8%
12	Mr. Data	1	1.8%
13	Terminator (robot)	1	1.8%
14	Agent Smith	1	1.8%
	Subtotal	**31**	**56.4%**
...	...	...	...
38	Victor Frankenstein	1	1,.8%
	Total records	**55**	**100%**

SF rather often acts as a 'supportive vehicle' in computer science research. This interpretation is supported by the analysis of the usage of SF in the paper types, in context. Furthermore, this finding supports results found by [24], where the majority of the reviewed records in the ACM DL (30%) did as well refer one single time, one (of six possible) SF search term(s).

Type of Research Paper. In cases where researchers refer to SF, the analysis shows clearly that opinion research papers are *the* preferred outlet of research contributions for (computer) scientists who publish in the IEEE *Xplore* DL. This finding confirms work by [45], which identified philosophical and opinion papers as the most frequent category of research contribution type when searching for SF robots.

Unsurprisingly, this dominance of opinion research contributions stems from the fact that SF—etymologically and historically—is a powerful mediator, effectively bridging the arts and technical fields. In this study, SF was often utilized via its main intended function, a commentary and envisionment on future, socio-technical possibilities.

It is therefore likely that SF appears the most frequently in research papers which are placed in that niche of opinion research papers, essays and philosophical arguments. A remarkable result, however, is that SF references occor in opinion research contributions (n = 153 records) twice as much as they do in the second most frequent category, theoretical papers (n = 77 records).

In addition, methodological papers – after dataset papers with n = 0 referrals – are the least frequent type of research paper in which references to SF appear. This may be due to the fact that the contextual SF referral in methodological papers typically involves a practical integration of SF into the research method or application, for example as a method to recommend entertainment content among SF movies. In other words, SF in methodological-type papers is not often used to introduce innovation, creativity, or reflection into the research paper or study, despite that being the ample opportunity SF offers in the first place.

Putting aside both extremes, opinion (n = 153 records) and dataset contributions (n = 0), another interesting observation is the more-or-less even distribution of the remaining five paper research contribution types, ranging between = =38–77 records per category. Perhaps this indicates that SF referrals can serve as a 'jack-of-all-trades', as scientists utilize them in a broad range of research settings, from empirical studies to theoretical/conceptual research papers, from artifact and interface contexts, to surveys/overviews on emerging research topics.

This broad and almost universal applicability of SF, as a source of inspiration, as part of a research method, or as a vehicle to assess future developments in the realm of technology and society allows a selective utilization of preferred aspects of SF across different types of research. For example, theoretical and survey articles on the topic of smart, autonomous drones (e.g.[1,2]) outline the proliferation and beneficial technology outcomes of as the coming-of-age of SF dreams. Barfield [2],[810], based on Asimov, introduces three laws of robotics for drones, which he calls 'flyborgs', including navigational heuristics for a strategic airspace. The laws call for a protection of first, 'friendlies' and second, 'protection

of its own existence', in order to avoid in-air collisions with other drones or manned aircraft. However, what laws or heuristics are relevant for autonomous drones, which share an airspace with 'hostiles' are not presented, nor any sort of explanation what would happen in such case. As a reminder, Issac Asimov's original laws did mention in fact 'humans' instead of 'friendlies' and 'hostiles'. On the other hand, these important ethical questions and concerns seem to be addressed in opinion-and other-type research papers (e.g. [18,59]), who do in fact warn, that scientists are on the verge of crossing the Rubicon to create 'Killer Robots', but seem less relevant in methodological-, theoretical- or survey-based research contributions.

While the above-mentioned efforts are noteworthy and important, one main function of SF is to actually show the public the broad range of potential outcomes of technologies as part of our lives, positive and negative. The *unintended consequences* of this rapid transition and transformation toward the information society are in fact barely understood, and even more difficult to predict. SF can provide either, an admonition or commendation of these forthcoming changes – scientists should consider both equally and critically.

Contextual SF Referral. The analysis of the contextual usage of the SF referrals in this dataset shows that four specific attributes, from two conceptual domains, are utilized the most often:

The group of SF referrals, with a focus on drawing innovation from SF in the research paper emerges as the preferred utilization of SF across paper types . SF is most often referenced in the context of a fictional idea, concept or technology crossing over from fantasy to reality (Making SF a Science Reality, $n = 135$). Also, SF references which emphasize the origin, inspiration, acknowledgment or linkage to a SF writing or movie represent the second most-frequent category with 126 referrals. The fourth most often contextual SF referrals are associations with far-fetched, unrealistic or impossible SF concepts ($n = 70$).

From the domain of SF referrals, integrated as part of the research paper and representing the third most-often utilized category overall, 78 referrals are utilized as part of the research method application, implementation or evaluation. This attribute reflects a SF reference as a integrated component of a method, an empirical evaluation or study, rather than e.g., a vehicle for inspiration or blueprint of a future technology. For instance, SF referrals in the context of user preferences in the evaluation of a movie recommendation system or as part of a content analysis of an online community are found in this category. It should be noted that a subset of records in this category reflects papers, which utilize SF in i) traditional engineering and computer science education, ii) in the context of design research via SF prototyping and, iii) SF as a means to forecast future technological developments.

These results show that SF in scientific articles is abundantly utilized by scientists as an inspiration, a blueprint, an envisionment and pacemaker of past, present and future technological developments, across usage contexts. SF references herein range from innovative medical devices to the SF depiction of AI and robotics, from new interaction modalities through gesture and speech to utopian

visions of teleportation, light speed travel and space elevators. The three categories of this domain – providing inspiration and innovation through SF for the research paper – account for a total of 331 out of 500 SF referrals in our dataset. This is both a remarkable result and a powerful display of the inherent strength and advantage SF can provide to scientists. This diversity of SF imaginations can be traced back to the search strategy in this study, an inclusive retrieval of a full-text search for 'science fiction', instead of a focus on a specific SF author, book or movie or concept.

SF Authors and Writings. The analysis of the SF particulars, i.e. the presence and frequency of referrals to SF authors and writings, reveals interesting, although anticipated trends.

With regards to the SF authors, Issac Asimov is referenced in 28 records in $C_{4(500)}$ and succeeded by Arthur C. Clarke (n = 19 binary referrals) and William Gibson (n = 15 binary referrals). Suitably, the works of the most frequent SF authors are reflected in the distribution of the most popular SF novels per record accordingly, with William Gibson's Neuromancer being the most often (n = 10 binary referrals) cited SF writing in $C_{4(500)}$. Issac Asimov's short story I, Robot (n = 4 binary referrals) originally appeared in Astounding Science Fiction, n = 7 binary referrals) is the second most often referred SF writing. As such, the analysis of the referred SF authors and books complements itself – the most frequent works of the most often mentioned SF authors are both found in $C_{4(500)}$. It is well known that Isaac Asimov, Arthur C. Clarke, and Robert Heinlein held a 'SF triumvirate' in the first golden age of SF [51],[81] which:

> *"[...] largely dominated American (and, though to a lesser extent, Anglo-American) science fiction during the 1940s, the 1950s and well into the 1960s [...].*

In this study, the analysis of the SF authors in $C_{4(500)}$ places the these three SF authors – informally referred to as the 'Big Three' – in the Top 4 most often named SF authors per record. Interestingly, Roberts [31,53] finds that:

> *"[...] the so-called 'Golden Age' of science fiction, from the late 1930s through to the early 1960s [...] referred to a particular body of texts that were, specifically, founded in science and the extrapolation of science into the future."*

As this study explores the utilization of SF in computer science, it can be reasoned that these influential SF authors, including their works from the first golden age of SF, are the preferred choices of scientists, expressed by their explicit referrals in the publications in $C_{4(500)}$. Although negligible in the larger context of all records in the full collection of the IEEE *Xplore* Digital Library, the specific analysis of $C_{4(500)}$ shows a clear manifestation of this first golden age of SF in scientific research, a remarkable reflection of influential pop-culture in science communication. This is an overall plausible conjecture supported by anecdotal

evidence, for instance, by Carl Sagan, who stated in a New York Times essay in 1973 [56] that SF had been a seminal factor and forerunner to pursue his scientific career as astronomer, science communicator and SF author.

5.1 SF Movies, Shows and Characters

With regards to the referrals of specific SF movies and characters, the study results show that the Star Trek (n=28 binary referrals) and Star Wars (n=11 binary referrals) franchises, as well as the SF films 2001: A Space Odyssey (n=23 binary referrals), The Terminator (n=13 binary referrals) and Minority report represent the top SF franchises and films in $C_{4(500)}$. The density of Star Trek referrals, including spin-offs of the franchise (e.g. Star Trek: TNG and others, see Table 7), was anticipated due to work by conducted by [23], who investigated exclusively Star Trek references in the ACM Digital Library.

Yet another interesting discovery is that the 38 SF characters, referenced in $C_{4(500)}$, are more often 'robots/AIs' than 'human characters', with the most frequent SF character, HAL 9000 from 2001: A Space Odyssey, accounting for 20% of all binary referrals. This indicates that scientists preferably resort to SF robots and depictions of an AI, instead of the human counterparts found in SF stories and movies and more importantly, introduces a speculation space for such rationale.

An obvious explanation could be that fictional robots and AIs, through the utilization of a bandwidth of technologies, from speech interfaces to sentient systems, can serve as both ways—as utopian imaginations of future human-robot cooperation or dystopian horrors of technological disobedience and men-versus-machine scenarios, either-ways, providing full-fledged examples, highly relevant to computer science research. for instance, work by [45] did not only identify 18 SF robots in a different repository, the ACM Digital Library, but also confirmed that the contextual referrals of these robots was mostly to communicate (SF) concepts to the readers.

6 Limitations

First of all, we acknowledge that the IRR coefficients for both interpretative variables, Pub_{Type} and SF_{Cont}, were acceptable but did not reach the desired levels of agreement. With regards to the type of research contribution, Wobbrock and Kientz [70] state that very often, multiple primary contribution types might co-occur in a single publication, complicating a one-dimensional, mutually exclusive coding. With regards to the contextual usage of the SF referral, the above-average IRR results can be explained due to the fact, that the mutually exclusive seven attributes chosen for this variable were not perfectly defined and hence did partially overlap. This is an expected result, especially in consideration that an emerging coding approach was utilized, which generated the coding scheme from $C_{4(125)}$, and not $C_{4(500)}$.

As a second limitation we acknowledge is the deliberate choice to use a singular search/query term—"science fiction"—for a full-text search in the IEEE *Xplore* DL. This choice might have affected the results as it can not be reasonably assumed that every record, which discusses SF, will use *this* search query term, instead of, for instance, an appropriate synonym, such as "SF" or "sci-fi". Nevertheless, the query for "science fiction" in C_4 does represent an inclusive, full-text retrieval returning the largest cache of records while minimizing Type 1 Errors and false-positive retrievals, effectively establishing high precision and recall.

As mentioned earlier, the records in $C_{4(500)}$ are retrieved for a full-text search for 'science fiction' in the IEEE *Xplore* Digital Library. One drawback for such an inclusive search in a large technical repository is that of institutional subscription limitations. As a consequence, the initial set of records $C_{4(2784)}$ was not fully accessible for a retrieval. Therefore, facets were applied, among those, the filter 'subscribed content only'. This reduced the potential set of records for analysis to $C_{4(1647)}$, effectively decreasing the initial retrieval cache by 40%. As the initial body of retrieved records, $C_{4(1647)}$, was deemed unfeasible for a full qualitative review by the author, due to its massive size, a random sampling was conducted to review about 30% of records in $C_{4(500)}$. While this was a necessary reduction of the retrieval cache at hand for simple study feasibility, this sampling might, in contrast, not necessarily be representative of $C_{4(1647)}$. However, a comparative publication year analysis of all C_4 sets did show a distribution of records of $C_{4(500)}$, which did principally re-ensemble the distributions of records per year in both, $C_{4(1647)}$ and $C_{4(2784)}$.

7 Conclusions

This work provides a broad and in-depth investigation analysis of records, which discuss SF in the IEEE *Xplore* DL. Although, SF is clearly a niche topic in the overall IEEE *Xplore*, which lists about 4.5 million records, its influence is explored and established in specific types or research contributions and contextual usages, i.p. by means of researchers resorting to SF concepts, ideas, technologies, devices or interfaces in mostly opinionated research contributions. Therefore, future researchers, professionals and educators in computer science and HCI research might be able to use this work to recognize the potentials and opportunities, as well as the challenges and limitations, SF can provide them with, including their peers, their students, their research and ultimately, their future work. The SF particulars (authors, books, movies and characters) identified in this study show that researchers predominately resort to Western SF, with a clear minority of SF references stemming from Non-Western materials. This leads to believe that personal cultural upbringings and influences play a significant role in the context of researcher creativity, motivation, objectivity and ultimately, bias.

7.1 Future Work

Supplementing the data and results in the presented content analysis with empirical data (i.p. interviews with researchers) seems like a logical, next step to better comprehend the link of SF and computer science/HCI research. Such studies could shed light on the reasons scientists write, or do not write, about SF in their publications. This then could lead to the exploration of the influence of popular culture on the works of researchers. For instance, the analysis of $C_{4(500)}$ revealed multiple instances where scientists stated to be inspired to begin a research career, based on past exposure to a SF novel or movie. Additional potential directions to extend the presented work would be to investigate if the most frequent SF particulars, found in this study, are representative of the distribution when searching directly for them. Such a study could then be cross-referenced with the presented results and, as a consequence, provide further support or further extend the results of this research.

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