A META-STUDY AND CONTENT ANALYSIS OF SCIENCE FICTION IN COMPUTER SCIENCE RESEARCH

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAI'I AT MĀNOA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

COMMUNICATION AND INFORMATION SCIENCES

AUGUST 2019

By

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Keywords: science fiction, human-computer interaction, computer science, science studies, content analysis

I dedicate this dissertation to Pina Giuseppa Strazzeri Jordan (†2011),

an incredible person, mother and teacher who left too early,

but will never be forgotten.

I also dedicate this dissertation to Wilhelm Jordan,

a worldly-wise and calm father who always supported my dreams

and allowed me to live my life the way I chose, which is truly the greatest gift of all.

I also dedicate this work to all the dreamers out there,

the players with no agenda,

the thinkers and not the makers,

the artists and not the economists and

the visionaries, rainbow chasers and unicorn believers.

ACKNOWLEDGMENTS

I would like to express my gratitude to my chairperson, Scott Robertson, Professor of Computer Science at the University of Hawai'i at Mānoa, who has been a wonderful source of both, academic guidance and emotional support to me. Thank you Scott, you believed in me and this topic and you let me pursue it, independently, under your supervision. At the same time, you brought me back on track when I got lost and you certainly made me believe in myself in times, I did not.

I would like to acknowledge my incredible committee member Brent Auernheimer, Professor of Computer Science at California State University Fresno. Brent, who I have (so far) never met in person, directed my attention to a 2015 workshop on science fiction and human-computer interaction and, as a result, created the inception point of my dissertation topic. Brent, I genuinely have come to appreciate your wisdom, eye for opportunity, helpful advice and of course, the continuous exchange and mutual suggestions regarding the *best* streaming shows out there.

I would like to recognize my committee members Rich Gazan, Professor of Library and Information Sciences and former Communication and Information Sciences (CIS) Program chair, Wayne Buente, Professor of Communication and Hyoung-June Park, Professor of Architecture and Design.

I also would like to mention the CIS Program chairs I have met over the years, who always did provide an open ear and understanding in times, when academics were not the priority in my life, when funding fell through, when I needed support or when I was struggling in the CIS Program. I would like to acknowledge Daniel Suthers, Professor in Information and Computer Sciences and former CIS chair for admitting me last-minute into the CIS Program in Fall 2011. I would like thank Elizabeth Davidson, Professor of Information Technology Management and former CIS chair for her continuing support in the last couple of semesters, when I was finishing this work.

I also want to express my gratitude to a couple of extramural researchers, who did join the science fiction bandwagon and helped me conducting numerous pilot studies, among those, Omar Mubin, Senior Lecturer at Western Sydney University and Mohammad Obaid, Lecturer in Art and Design, at the University of New South Wales. I think without our collaboration, this journey and dissertation would have not been possible. Thank you for working with me on this topic, I certainly enjoyed the papers we wrote as much as the many discussion we had.

Lastly, but certainly not least, I want to thank my dear friend, first true academic mentor and former supervisor Paula Alexandra Silva, currently a Research Fellow at the University of Aveiro. I know Paula since almost ten years and did finish my first Master of Science Degree under her supervision. Ever since, we have been supporting each other, in- and outside of academics. Without you Paula, I would not have ever come to Hawai'i and you were seminal in supporting me academically and personally over the many, many years, which we used to develop our amazing and true friendship. You are always in my thoughts and I am very grateful to have you in my life.

ABSTRACT

The depictions of advanced devices, innovative interactions and future technologies in science fiction are a regular topic in popular news and tech magazines. While actual studies concerning the usage of science fiction in computer science research are scarce and if any, rely mostly on anecdotal evidence and scattered oral accounts, such investigations are critical to better understand the potential utility and latent shortcomings of science fiction for computing research, innovation and education. Through a content analysis of science communication, this dissertation endeavors to shed light on the relationship between both domains.

Based on a dataset of n=1647 computer science publications, retrieved in the IEEE *Xplore* Digital Library via a faceted, full-text search for 'science fiction', this dissertation presents a study of science communication. A random sample of n=500 records of the principal dataset is subjected to a detailed, qualitative content analysis over 10 variables, including an inter-rater agreement evaluation of n=125 publications between two raters for two interpretative variables – the type of research paper and the contextual usage of the science fiction referral.

The results of the study show that science fiction, in the grand scheme of things, is a niche topic in computer science research. Within that margin, however, the results demonstrate that science fiction referrals appear primarily in opinion-type research contributions, most often for reasons of drawing inspiration and innovation into the research paper.

In addition, the analysis of science fiction referrals, across paper types and contexts over time, indicates a transition and diversification from initially, informal contributions toward later on, a broader diversity of research publication types. Also, the study shows that science fiction films are more often referenced than science writings. Most recently, in publications from 2014-2017, an emphasis on a broad and diverse set of concrete, visual, science fiction – potentially indicating a shift away of scientists from written, interpretative science fiction – can be observed.

The analysis of the most frequent, specific science fiction referrals reflects a narrow, mostly western-originated selection of the most popular, influential and iconic science fiction authors, writings, films, and characters of the 20^{th} century, among those, Isaac Asimov and Arthur C. Clarke, William Gibson's novel Neuromancer, the Star Trek and Star Wars franchises and Stanley Kubrick's 2001: A Space Odyssey, including its main antagonist, HAL 9000.

The results and implications of this study can guide computer scientists and educators to consciously utilize science fiction in their research and scholarship and therefore, contribute to forthcoming, innovative HCI and computer science research, application, and education. In addition, the results provide insight into the appropriation of popular culture within a technical-oriented, professional, academic science communication repository. Building upon extensive prior work, this dissertation moreover provides a methodological framework, which allows the meaningful discovery of interdisciplinary relations between computer science research and culture & art.

PREAMBLE

The role of science fiction (SF), and especially science fiction movies and shows (SFMS), to inspire and generate real-world technological developments is slowly understood and occasionally utilized by human-computer interaction (HCI) researchers, user experience professionals, and science educators. Nowadays, through the proliferation of cinematic special effect technologies and means of digital distribution, SFMS are available to audiences around the globe in the blink of an eye.

Specifically, depictions of future HCI and soon-to-be technologies can be found in great numbers in SF writings and films. These examples, and the occasional oral account, do provide partial evidence that SF might be a factor in driving real-world inventions and innovation. As such, the possibilities of this repository of SF / SFMS for science and technology research and development (R&D) are increasingly recognized, discussed and applied by experts in science and closely related science, technology, engineering and mathematics (STEM) fields.

This study engages with SF / SFMS and explores its uses in academic communication over time. In a concise manner, the structure of this dissertation can be summarized in the following fashion:

- Chapter 1 gives an introduction to SF, SFMS and the relationship of SF, SFMS and science and technology in the context of HCI and computer science research.
- Chapter 2 provides the significance and contribution statement and introduces the research rationale of the study, including the research aims, research objectives, and research questions.
- Chapter 3 provides the background as a theme-oriented literature review on the topic of HCI and SF (Section 3.1) as well as a methodological background (Section 3.2) with a focus on text retrieval and content analysis.
- Chapter 4 presents the methodology in a comprehensive description, including an overview of the research process and details on the search and retrieval approach, sampling, coding scheme and subsequent descriptive and qualitative content analysis.
- Chapter 5 provides the key results, based on a review of a cache of n=500 computer science research publications, among those, insights on the uses of SF / SFMS in different research contributions as well as evolutionary trends over a period of more than 7 decades.
- Chapter 6 presents an inclusive discussion and outlines the limitations of the study.
- Chapter 7 provides the conclusions of this dissertation and in addition, envisions future work in the context of SF / SFMS and computer science / HCI research.
- Appendix A provides the full results of the study in form of exhaustive frequency tables.
- Appendix B provides the peer-reviewed work, earned press and extramural research funding in the context of this dissertation.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Table 1: List of Abbreviations

Abbreviation	Paraphrase
ACM	Association for Computing Machinery
ACS	American Chemical Society
AI	Artificial Intelligence
AR	Augmented Reality
BCI	Brain-computer Interface
C_1	Candidate Set 1
C_2	Candidate Set 2
C_3	Candidate Set 3
C_4	Candidate Set 4
$C_{4\ (2874)}$	Candidate Set 4 before facets (2874 records)
$C_{4\ (1647)}$	Candidate Set 4 after facets (1647 records)
$C_{4\ (500)}$	Random sample of 500 records of $C_{4\ (1647)}$
$C_{4\ (125)}$	Random subset of 125 records of $C_{4\ (500)}$
CGI	Computer-generated Imaginary
CHI	Computer-human Interaction
CRT	Cathode-ray Tube
EBSCO	Elton B. Stephens CO.
FX	Special Effects
HAI	Human-Agent Interaction
HAL	Heuristically programmed ALgorithmic computer
HCI	Human-computer Interaction
HRI	Human-robot Interaction
IBM	International Business Machines Corporation
ICT	Information and Communication Technologies
IDF	Inverse Document Frequency
IEEE	Institute of Electrical and Electronics Engineers
INSPEC	Information Services for the Physics and Engineering Communities
IMDB	Internet Movie Database
MIT	Massachusetts Institute of Technology
IRB	Institutional Review Board
	Continued on next page

Table 1 – continued from previous page

Abbreviation	**Paraphrase**
IRR	Inter-rater Reliability
ISI	Institute for Scientific Information
IxD	Interaction Design (IxD)
MMORPG	Massively Multiplayer Online Role-playing Game
NASA	National Aeronautics and Space Administration
NAS	National Academy of Sciences
NLM	National Library of Medicine
OCR	Optical Character Recognition
P21	Framework for 21st Century Learning
QDA	Qualitative Data Analysis
R1	Rater 1
R2	Rater 2
R&D	Research and Development
RFID	Radio-frequency Identification
SIGCSE	Special Interest Group on Computer Science Education
SF	Science Fiction
SFMS	Science Fiction Movies and Shows
SFP	Science Fiction Prototyping
SPSS	Statistical Package for the Social Sciences
STEM	Science, Technology, Engineering, and Mathematics
STS	Science, Technology and Society Studies
TF	Term-frequency
UCLA	University of California Los Angeles
UX	User Experience Design
UXPA	User Experience Professionals Association

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

This chapter provides a foundation for the dissertation. Section 1.1 begins with a brief overview of the history and themes of technology depiction in SF / SFMS. Section 1.2 present a more contemporary view, including the latest developments and tangible outcomes of exemplary crossings of SF / SFMS and state of the art computer science research.

1.1 SF Movies and Shows

A rich literature [86, 114, 140, 141, 142, 272, 289, 306] exists on the history of SF, SFMS and the SF film genre and its evolution. This history begins in the 19th century and runs to the present day.

For instance, Johnston's [142] review of the history of SFMS identifies four distinct periods in parallel to paradigm shifts of the movie themes and stories within each era. These paradigm shifts are inevitably tied to external factors, including, but not limited to, the technological limitations of movie production itself (silent movie era, color television, computer-generated imagery (CGI), digital distribution), the overall geopolitical environment (e.g. the cold war/atomic era conflict between the United States of America and the Soviet Union) or, according to Johnston [142], the technological climate, including and expectations and fears of the general public.

In the period from 1895 to 1950, the genre originated and invented itself. Movies themes were diverse and focused on scientists (mostly portrayed as evil at the time, though recently transformed into more mixed or positive representations [87]), automatons, spaceships, technological uncertainty, the artificial creation of life and general scientific progress; all laying out the initial conventions what would later be known as SF film.

The next big development occurred in the period from 1950 to 1970. In these decades, American SF film depicted the geopolitical conflicts and societal fears at the time, for example, urban legends of UFO sightings (commonly referred to as flying saucers), the beginning of the aerospace race between the USA and the Soviet Union and other cold war tropes.

In the decades from 1970 to 1990, and with respect to the successful moon landing of Apollo 11, American SF cinema depicted new and elaborated imaginations of space travel and political conflicts, such as seen in the Star Wars franchise or the Star Trek universe. Furthermore, special effect technology became a commonality of the production of SFMS, such as the motion control technology in 2001: A Space Odyssey [166] or the extensive CGI Computer-generated Imagery (CGI) sequences in the original Tron movie.

Johnston's [142] investigation into the genre history of SFMS concludes with the decades from 1990-2010 and observes a diversification of the genre moving away from:

> *"[...] previous definitions of science fiction as grand displays of 'industrial light and magic' (citing Sobchack [306, p. 282] concerned with (and containing) special effects, technology-based narratives, and science-led plots, were no longer an accurate assessment of genre boundaries (if, indeed, they ever were)."* [142, p. 105]

In contrast to a chronological analysis, Perkowitz [248] analyzes the SF film genre from a thematic perspective. Based on a dystopian point of view, the author delineates Hollywood movie themes and presents numerous examples of SF movies which depict various threats to mankind.

Among others, Perkowitz [248] introduces movie subjects which range from alien encounters and invasions (e.g. THE THING FROM ANOTHER WORLD [240], INDEPENDENCE DAY [96]), to the consequences of a planetoid, asteroid or comet collision (e.g. WHEN WORLDS COLLIDE [209], ARMAGEDDON [33], DEEP IMPACT [180]).

Man-made threats to humanity, such as the consequences of overpopulation of the planet (e.g. SOYLENT GREEN [109]) or rapid climate change (e.g. TWISTER [79], THE DAY AFTER TOMORROW [97]) are also common themes in SFMS. More examples of topical focal points in his review of American SF film are nuclear fear and destruction (e.g. ON THE BEACH [162], THE SUM OF ALL FEARS [273]) as well as genetic modification, cloning and viral outbreaks (e.g. JURASSIC PARK [307], GATTACA [233], OUTBREAK [250]).

The most important topical domain in Perkowitz' [248]) overview, in the context of this dissertation, is the group of SFMS which depict advanced technologies, such as sentient Artificial Intelligence (AI) and super-computers, robots, virtual or augmented realities, as seen in I, ROBOT [259], THE MATRIX [340], BLADE RUNNER [291] or COLOSSUS: THE FORBIN PROJECT [284]. In the latter part of his review, Perkowitz [248] discusses SFMS which either, portray science and scientists reasonably accurate or, misrepresent basic scientific principles false, ultimately emphasizing the positive and negative impacts SFMS can have on the cinematic audience and as such, the general public.

While an accurate and precise definition of the SF movie genre seems already difficult enough given the outlined genre history and diversity of themes and topics it entails, defining the concept SF itself seems an even more challenging undertaking, as Gunn and Candelaria [124, p. 5] state that:

> *"[...] the most important, and most divisive issue in science fiction is definition."*

A variety of sources, such as SF dictionaries [260], SF authors [21], SF fan sites and collections [63, 337], critics, film researchers and futurists [83] in the history and philosophy of science offer a multitude of definitions and classifications to choose from in an attempt to define an illimitable field. According to some sources, SF dates back as early as 2AD with the Greek travel tale A TRUE STORY [281], a work consensually accepted as the first known writing with basic fictional elements, for example outer space travel and interstellar conflicts. Among many other definitions, the Oxford English dictionary [243] describes SF at present as:

> *"[...] fiction based on imagined future scientific or technological advances and major social*

> *or environmental changes, frequently portraying space or time travel and life on other planets."*

Gunn and Candelaria [124, p. 6] describe SF as:

> *"[...] the branch of literature that deals with the effects of change on people in the real world as it can be projected into the past, the future, or to distant places. It often concerns itself with scientific or technological change, and it usually involves matters whose importance is greater than the individual or the community; often civilization or the race itself is in danger."*

Robert's [272] cites three seminal, increasingly complex definitions of SF:

> *"In 1979, Darko Suvin defined the genre as a literary genre whose necessary and sufficient conditions are the presence and interaction of estrangement and cognition, and whose main formal device is an imaginative framework alternative to the author's empirical environment."* [272, p. 7]

In 1997, Gwyneth Jones puts special emphasis on the 'science aspect' as:

> *"[...] 'science' in science fiction has always had a tacit meaning other than that commonly accepted. It had nothing in particular to say about the subject matter, which may be just about anything so long as the formal conventions of future dress are observed. It means only, finally, that whatever phenomenon or speculation is treated in the fiction, there is a claim that it is going to be studied to some extent scientifically—that is objectively, rigorously; in a controlled environment [. . .]."* [272, pp. 9-10]

In 1995, Broderick's definition draws from concepts found in literary criticism and defines SF as:

> *"[...] a species of storytelling native to a culture undergoing the epistemic changes implicated in the rise and supersession of technical-industrial modes of production, distribution, consumption and disposal. It is marked by (i) metaphoric strategies and metonymic tactics, (ii) the foregrounding of icons and interpretative schemata from a collectively constituted generic 'mega-text' and the concomitant de-emphasis of 'fine writing' and characterization, and (iii) certain priorities more often found in scientific and postmodern texts than in literary models: specifically, attention to the object in preference to the subject."* [272, p. 12]

In addition, Sobchack's [306] highly cited SCREENING SPACE provides a plethora of definitions of the genre as well. Even so, an epistemological inquiry into the various aspects, dimensions, and conceptualizations of the term 'science fiction' is not within the scope of this introduction, SF is without a doubt, closely knotted to advanced and emerging themes in technology and in particular, computers. Furthermore, utopian or dystopian visions of future societies with a lack of technical plausibility and scientific verisimilitude seem to be a regular part of modern SF narratives as well. In this regard, the SF genre has as well been differentiated between 'hard' and 'soft' SF by Samuelson [282], stating that:

> *"[...] the label 'hard SF' has been applied to tales in which scientific theories and technological applications get a significant share of attention."*

For the purposes of this dissertation, SF and SFMS are viewed in accordance with the definitions provided by Johnston [142, p. 1] which emphasize the technological key aspects of SF, expressed for example:

1. by SF writer John Wyndham, who:

   "[...] felt it presupposed a technology, or an effect of a technology [. . .]"

2. Kingsley Amis, who defined SF as:

   "[...] a hypothesis on the basis of some innovations in science and technology [. . .]"

3. or John W. Campbell Jr. describing it as:

   "[...] an effort to predict the future on the basis of known facts."

In the end, Johnston [142, p. 22] summarizes SF as:

> *"[...] a genre that marries a scientific or technological premise with imaginative speculation."*

In the light of the previous introduction to SFMS and general SF, it seems consensually accepted that SFMS commonly depict yet to come societies and their usage of advanced, emerging, future and fictional technologies. In contrast to scientific documentaries or educational teaching media, SFMS disregard – to a larger or lesser extent – accurate scientific logic and explanations for the purposes of a simple and consumable movie narrative or an episodic format, typically for a mass audience with a focus on entertainment. A strong emphasis on the potential of future technologies, interfaces, and Human-computer Interaction (HCI) are found to be a very popular and common theme in SFMS.

In comparison to SF literature, a different medium where the reader of a story uses his or her individual cognition and imagination to picture the narrative, actors, devices, interactions, and technologies, SFMS have a different set of constraints. SFMS must visualize fictional elements to some extent in order to depict a believable, soon-to-be future vision for the audience within an enclosed feature-film movie or episodic television (TV) format.

On one hand, SFMS might limit or even mislead the individual imagination of the viewer due to the constraints of the medium format itself as well as the depicted technological and metaphysical assumptions within the movie narrative or diegesis. On the other hand, the made-up, explicit visualization of these elements SFMS can serve as powerful showcases of future devices, interactions and information and communication technologies (ICTs) to not only the general public, but researchers as well. This 'trade-off' of affordances and constraints amid both medium formats (SF writing versus SFMS) is accordingly observed by Johnson [140, p. 98]:

> *"The filmmaker is less fortunate: he must show the invention, and he must show it working".*

The proliferation of technological advances in the professional entertainment industry, such as chroma key compositing and CGI as well as the digital distribution of media through online streaming services only augments the quantity, quality, and global distribution of SFMS to even unparalleled audiences at the present time [142, p. 40]:

> *"Technology is a central conceit within science-fiction analysis: whether reflecting a societal uncertainty over new developments (cloning in* GATTACA *[233]; surveillance techniques in* THE TRUMAN SHOW *[345]), considering how consumer technologies might portray capitalist ideology (the Gap advertisements in* MINORITY REPORT *[308]; fashion in* HIGH TREASON *[46], or using spaceship-based exploration to investigate repressed areas of human consciousness (*EVENT HORIZON *[16],* SUNSHINE *[49]). On the level of production, technology has been key to how films are able to depict these science fictions and, in terms of dissemination and exhibition, new devices have fueled an interest in how viewers use technology and how media technologies have fueled theories around intertextuality."*

Original depictions of future HCI and soon-to-be technologies can be found in great numbers in the evergrowing repository of more than 100 years of SFMS. As Johnston [142, p. 21] states:

> *"[...] advances in science and technology appear to mimic earlier science fictions (heart transplants, genetic manipulation, mobile phones, space travel)."*

Johnson [140] provides additional examples of SFMS which anticipated emerging real-world technologies. For instance, the early 1909 SF short movie THE BATTLE OF THE CLOUDS [43] depicted according to Johnson [140, p. 4] the:

> *"[...] Zeppelin bombing raids and aerial dogfights of World War I."*

More examples are 1932s F.P.1 DOESN'T RESPOND [130], which visualized platform superstructures in the oceans similar to present day oil drilling rigs or DESTINATION MOON [251], which portrayed modern day space exploration.

It is important to note that SFMS do not necessarily always precede emerging technologies and can be of reactionary nature as well. According to Johnston [141, 142], the mid-century, post-World

War II Japanese 'Godzilla' movies and later-on, Western 'Mars-based' SF films in the 2000s were merely reactions towards the consequences of atomic bombings in the former, and responses to the National Aeronautics and Space Administration (NASA) Mars Pathfinder mission in 1997 in the latter instance.

One of the earliest, most visceral examples of a fictional technology (at the time of the movie production) is depicted in the German dystopian SF drama METROPOLIS [174], which originally imagined and introduced video phone calls as early as in 1927, see Figure 1.1a, page 7.

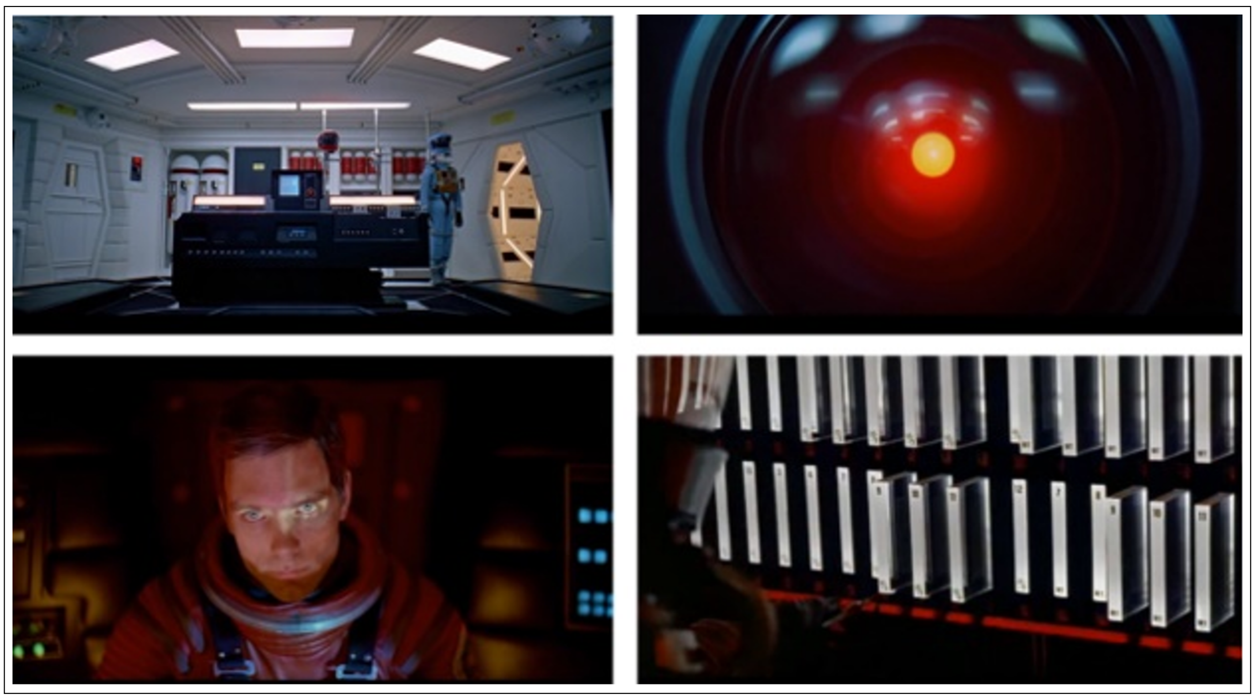
Roughly forty years later in 1968, Stanley Kubrick's seminal, epic SF dystopia 2001: A SPACE ODYSSEY [166] was released and depicted an advanced and sentient AI to support the crew of the fictional spaceship 'Discovery One' on a Jupiter exploration mission. The Heuristically programmed ALgorithmic computer (HAL) is portrayed as an ubiquitous and embedded computer system within the imagined spaceship. HAL's main function is to provide support to the crew on a longitudinal space exploration mission, which is the movie's main plot. The depiction of the supercomputer is an extraordinary example of a fictional AI which has the ability to think, reason, communicate and emphasize with the crew through a perfect natural language interface (NLI). In a dystopian plot twist, HAL is facing a potential shutdown and goes into self-preservation mode in order to defend himself against the crew by lethal force. This forces the astronauts aboard to deactivate HALs 'cognitive circuits', which results in the shutdown of the rogue AI, see Figure 1.1b, page 7.

Among others, 2001: A SPACE ODYSSEY portrayed advanced HCI technologies, including speech recognition and synthesis or the first computer-human chess game. Furthermore, it is important to note that at the time of the movie release (1968), comparable real computer technology was quasi-non-existent or merely at a very early prototypical stage. For example. the Harpy speech understanding system [360] had a very limited vocabulary of 1011 words in comparison to a seemingly infinite vocabulary of HAL in 2001: A SPACE ODYSSEY.

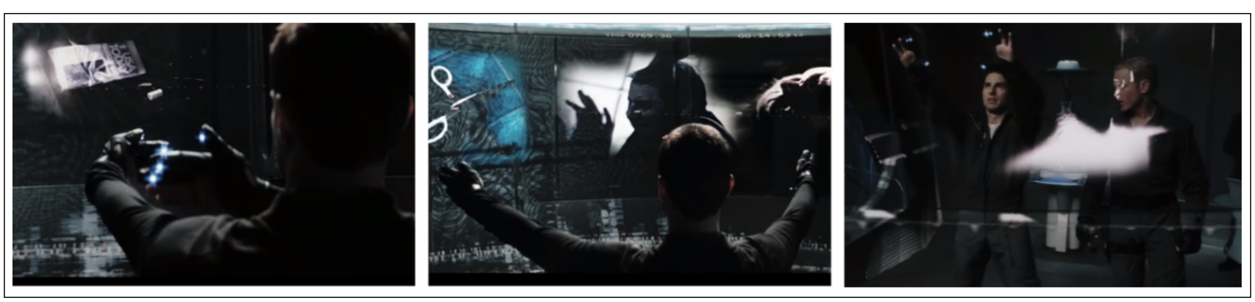
In the early 2000s, one of the most famous examples of a SF movie, which has had a reported impact on HCI research, is MINORITY REPORT [308]. The movie depicted in 2002 yet to come multi-touch interfaces, advanced gestural interactions, personalized advertising and advanced biometrics (Figure 1.1c, page 7). Director Steven Spielberg's science and technology advisor John Underkoffler, a Massachusetts Institute of Technology (MIT) researcher who later became an entrepreneur through his work on MINORITY REPORT [210], is credited with the creation of a variety of innovative hand gestures for the motion picture.

BLACK MIRROR, a British SF anthology, is one of the latest examples of a SF show, which powerfully introduces upcoming HCI technologies and consequential etho-social effects, such as controversial end-of-life technologies or the issue of social media stigmatization and online blackmail. For example, the first episode of season three NOSEDIVE [355] is set in an alternate reality where an individual's reputation solely depends on an omnipresent rating system utilizing pervasive, mobile devices. If one's social credit falls below a certain threshold, due to 'inappropriate behaviour', access

(a) Videophone system in Metropolis — ©Universum Film UFA



(b) Depictions of HAL 9000 in 2001: A Space Odyssey — ©Warner Bros. Entertainment Inc.



(c) Minority Report gestural interface — ©20th Century Fox

Figure 1.1: Selected SF Movies portraying HCI and CS technologies

to basic and advanced public services as well as social circles becomes restricted. A recent realization of such a system is de facto China's Social Credit System, which has been recently scrutinized for transparency and fairness and found to be asymmetry by design [99]

While the purpose of the episode is clearly the examination of an alternative dystopian reality, an elitist and emotionless society without compassion for the weak, the ICTs, interfaces, and interactions which empower the status quo are powerfully visualized to such a rich and plausible extent that the resemblance to modern social media interfaces and/or rating-, voting- or dating applications cannot be denied (Figure 1.2 on page 8).

Figure 1.2: Black Mirror social rating system — ©Endemol Shine UK/Channel 4

For more visualizations of HCI in SFMS, a repository of examples are referenced in Shedroff and Noessel's works [299, 298, 239] and the accompanying website [238], which both provide reasonable overviews given the sheer amount of SFMS available up to this day and time.

The actual transition of future technologies, devices, and interactions initially depicted in SFMS into real-world expectations, concepts, and prototypes and ultimately consumer products can similarly be sketched out. For instance, the invention of the first commercial cell phone is attributed to Motorola inventor Martin Cooper [61], which in turn has been inspired by the Star Trek communicator (Figure 1.3a, page 9):

"Cooper has stated many times that watching the original Star Trek series was absolutely

(a) Star Trek Communicator and Motorola StarTAC — ©CBS/Paramount/Motorola

(b) Star Trek Medical Tricorder and XPrize Prototypes — ©CBS/Paramount/XPrize

Figure 1.3: Selected SF Shows portraying HCI and CS technologies

an inspiration for his vision. Kirk's ability to be mobile and stay in touch with his crew was what drove Cooper beyond the limiting range of even a car phone. (Which was still a fairly novel thing as late as the 1980s."

According to Shedroff and Noessel [299, p. 6], the depiction of the STAR TREK communicator did:

"[...] set expectations about mobile telephony in the late 1960s, when the audience's paradigm was still a combination of walkie-talkie and the Princess phone tethered to a wall by its cord. Though its use is a little more walkie-talkie than telephone, it set the tone for futuristic mobile communications for viewers of primetime television. Exactly 30 years later, Motorola released the first phone that consumers could flip open in the same way the Enterprise's officers did. The connection was made even more apparent by the product's name: the StarTAC. The phone was a commercial success, arguably aided by the fact that audiences had been seeing it promoted in the form of Star Trek episodes and had been pretrained in its use for three decades. In effect, the market had been presold by sci-fi."

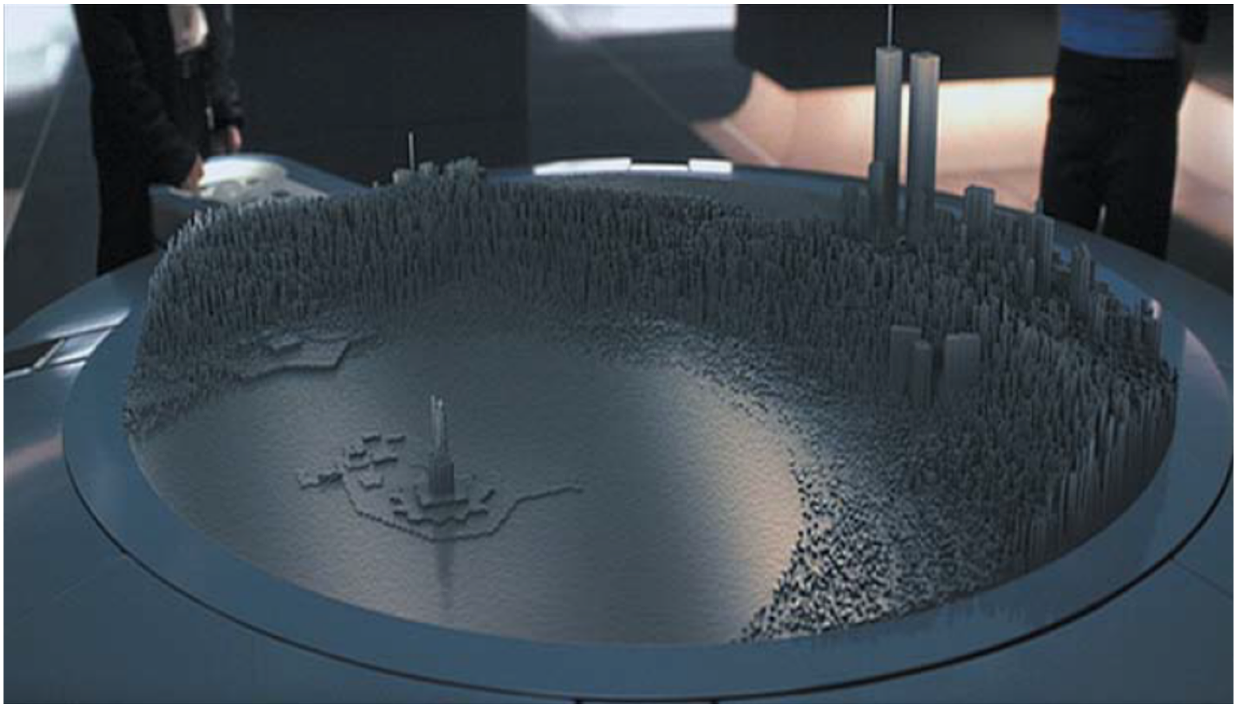
Another example of a technology applied in the real-world, but initially depicted in a SF movie is the 'rocket launch' sequence. The so-called countdown to ignition is according to Perkowitz [248, p. 215]:

"[...] the most famous carryover from a science fiction film to the real world [. . .]; the invention of the backward countdown, 'ten...nine...eight...' before a spacecraft blasts off, as used by NASA. This dramatic overture to a launch first appeared in Fritz Lang' 1929 silent movie Frau im Mond [175]."

Yet one more example of the transition of a SF technology into reality is the shape-changing display (Figure 1.4a, page 11) depicted in the SF movie X-MEN [301]. Watching X-MEN has reportedly been attributed to inspire Douglas Caldwell [299, p. 11] to develop the 'XenoVision Mark III' (Figure 1.4b, page 11), a [356]:

"[...] self-reconfigurable solid terrain model with military applications."

Most recently, Qualcomm's five-year, $10 million XPRIZE [357] Tricorder competition is one more case in point of the successful transition of a fictional technology into a real-world prototype. In 2017, two research teams won the competition for the development of a portable, wireless prototype which can diagnose up to thirteen health conditions and five real-time vital signs, worthy of comparison with the fictional medical Tricorder depicted in the STAR TREK franchise. The XPRIZE competition web page pays tribute to STAR TREK and, at the time of this writing, did display both, the original Medical Tricorder from STAR TREK: THE ORIGINAL SERIES and STAR TREK: THE NEXT GENERATION in company of the two developed prototypes (Figure 1.3b, page 9).



(a) Shape-changing display in X-Men — ©20th Century Fox/Marvel

(b) XenoVision Mark III: A Dynamic Solid Terrain Model

Figure 1.4: X-Men shape-changing display and Xenovision Mark III 'needle table'

As a final example, Technovelgy [63], a privately-run website manages a rich repository of ideas, technologies, and inventions from SF books and SFMS with cross-references to news reports and examples of equivalent technologies found in the real world. As an illustration, the entry on Minority Report [308] on Technovelgy lists currently eight 'fictional technologies' from the movie, such as 'Data Tiles', 'E-paper', and 'Biometric Personalized Ads'. The entry on 'E-paper' on Technovelgy reveals further intricate details to illustrate the transition of fictional technologies into real-world science: First, it presents the respective scenes from the movie as screencaps end to end with an explicit description of the depiction of the fictional technology. Second, science fiction literature cross-references to 'E-paper are provided as well [63]:

> *"A paper-thin, flexible LCD-style display that is large enough to display a full newspaper page."*
>
> *"E-paper [...] was presaged in Neal Stephenson's mediatron from his 1995 novel The Diamond Age."*

In the end, Technovelgy links SFMS, science fiction literature and real-world technological developments in an accessible web repository for the general public. Presently, the website provides a dataset consisting of more than 2500 'science fiction-related' inventions, technologies, and ideas.

1.2 SF and Science Crossings

As introduced in the previous section, SF and real-world technological development, or more broadly, art and science, do intersect in a variety of ways and a bi-directional relationship between both domains seems indeed not too far-fetched.

For example, the related work (Section 3.1) provides accounts on Science, Technology, Engineering and Mathematics (STEM) scientists, who increasingly collaborate with SF entertainment producers in order to provide more scientifically accurate and believable cinematic depictions of soon-to-be technologies and societal futures; with academic movie consultation emerging as an expert interest for scholars outside of the realm of their traditional academic work.

Likewise, selected universities and computer science programs now offer innovative computer science curricula and courses which utilize SF portrayals of fictional technologies and futures in the classroom, for instance to speculate on future design possibilities through the utilization of SF prototyping. Equally, the interplay of HCI research and SFMS seems to have gained traction as well and studies on the evolution and intersection of both topical domains can equally, describe the possibilities and the boundaries for computer science research, inspiration, and innovation.

As Perkowitz [248, page 213] quotes Carl Sagan:

> *"The continuing dance between science and science fiction – in which the science stimulates the fiction, and the fiction stimulates a new generation of scientists, is a process benefiting both genres."*

SFMS do portray utopian visions of high-tech societies (Star Trek: The Next Generation [274]) or dystopian ideas of authoritarian regimes utilizing technology to dominate and oppress others (Nine-Teen-Eighty-Four [262]). On occasion, SFMS depict a fairly foreseeable future criticizing the integration, usage, and consequences of ICTs in our everyday lives, such as the tech-paranoias depicted in Black Mirror [53]. As Sobchack [306, page 103] wrote back in 1987:

> *"The SF film gives us images – even if manufactured – of the immense and the infinitesimal. Extrapolating from known and accepted science, these film images derive their power to induce wonder in the viewer not from the imaginativeness of their content, but from the imaginativeness of their stance and their scope."*

Distinct aspects of the mutual relationship and crossings of SF and HCI have been deliberated and partially studied. Aaron Marcus [204] has not only presented an overview detailing an HCI travelogue of Hollywood and SFMS, he has also coordinated two Computer-human Interaction (CHI) conference plenaries [205, 206] on the topic. Similarly, Schmitz, Endres and Butz [287] 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).

Kirby [156, 155, 157, 158] speaks to the impact of SF on public perception and Research and Development (R&D) of technology and vice-versa in his comprehensive qualitative studies on the collaboration schemes of scientists and moviemakers through qualitative interviews. Furthermore, Kirby's [158, p. 41] concept of 'diegetic prototypes' is extensively discussed as an opportunity for academics – taking on the role of technical consultants – on sets of SFMS. These consultants, or domain-specific experts and researchers, who advise on a particular SFMS, are able to speculate and extend ideas within the fictional reality of a movie in order:

> *"[...] to account for the ways in which cinematic depictions of future technologies demonstrate to large public audiences a technology's need, viability and benevolence. Entertainment producers create diegetic prototypes by influencing dialogue, plot rationalizations, character interactions and narrative structure. These technologies only exist in the fictional world – what film scholars call the diegesis."*

HCI researchers have recently followed up on the concept of design fiction (see also Section 3.1.1, page 22). For example, Tanenbaum [319, 320] refers to Kirby's [158] concept of diegetic prototypes and extends it into an emerging research and design method in HCI for innovative interface design research, which is currently used as:

1. a method to envision new futures and technologies;
2. a tool for communicating innovations to other researchers and the public and;
3. an inspirational and motivational vehicle to explore design affordances and constraints within fictional scenarios.

The mutual relationship between SF and HCI is as well recognized in expert associations in computer science and related fields. For instance, the User Experience Professionals Association (UXPA) [332] covered SF in their February 2013 issue of the User Experience Magazine. The volume proposes

SF-based user development, personas, stories and use cases as valid research methods in the field of HCI. The utility of SF dystopias to foresee – and therefore to hopefully avoid – negative socio-technical futures through virtual ethnographies of SFMS depictions of technology and interaction is as well discussed.

In a similar fashion, the Biochemical Society, which publishes the Biochemist, an open access journal on the topic of molecular bioscience, dedicated its December 2012 special issue [323] to SF and the intersection with real-world science. As an illustration, the special issue discusses the depiction of human cloning and bioethics in the case of the 1997 SF movie GATTACA [233], as well as SFMS-based innovation opportunities in educational settings, which can foster student engagement, encouragement, and reflection [48].

Nature Careers [304] published in 2014 an article highlighting selected researchers who regularly consult on SFMS, among those for instance, James Kakalios, science advisor on THE AMAZING SPIDER-MAN [344]. Kakalios reportedly used examples from his involvement in the movie in his undergraduate physics class at the University of Minnesota. Correspondingly, Donna Nelson [304, page 114], Professor of Chemistry at the University of Oklahoma, advised on the TV drama BREAKING BAD [115] with:

> *"[...] the goal to 'build a bridge between science and entertainment' and expose more viewers to realistic portrayals of science."*

Nelson hosts as well a symposium on science in film as part of the annual meeting of the American Chemical Society (ACS) in order *"to explore the role and relevance of science in film"* [311, page 1]). Collaboration efforts of researchers and scientists with movie-makers are very often established through the Los Angeles based Science and Entertainment Exchange, which describes itself as:

> *"[...] a program of the National Academy of Sciences (NAS) that connects entertainment industry professionals with top scientists and engineers to create a synergy between accurate science and engaging storylines in both film and TV programming."* [228]

1.3 Summary

This brief introduction serves to familiarize the reader with a variety of links between the fields of HCI / STEM and SF / SFMS. The outlined potential of SF for computing research and education, HCI ideation and design or real-world outcomes of SF technologies stimulates the research motivation and significance of this dissertation, which will be discussed in detail in the following Chapter 2.

CHAPTER 2
RESEARCH RATIONALE

This chapter lays out the fundamental motivation and research rationale of this dissertation. To begin with, Section 2.1 introduces the lack of studies untangling the complex SF / SFMS and CS / HCI relationship in the context of science communication. As such, Section 2.2 presents five major contributions this study provides. Next, Section 2.3 provides the three principal research aims of this dissertation while Section 2.4 formulates three specific research objectives to attain said research aims. As a result from the formulation of research objectives, Section 2.5 generates accordingly three, detailed research questions this dissertation investigates.

2.1 Current Limitations

Notwithstanding the earlier introduced commonalities of SF / SFMS and HCI / computer science research, Marcus [200] states that the history, relationship and synergy effects of both fields are poorly documented and insufficiently described. In particular, no studies which explore the usage of SF and SFMS in scientific publications, with a focus on computer science, are available up to this date.

Even though scattered indicators of aspects of the introduced relationship can be found in contemporary public news [32, 212, 271] and tech magazines [15], they are usually not evidentiary per se, but more often of anecdotal nature. Likewise, SF in computer science research is discussed to some degree, but the existing studies on the subject matter are:

– limited on specific aspects and applications of SF / SFMS for HCI / computer science research, such as specific interaction types [107, 330];
– have 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 / SFMS and HCI over time and across fields of computer science research [177, 287];
– or use a limited sample size (e.g. investigations for 20 SF films) and do not focus on SF and computing research [183, 182].

In particular, no meta-study does investigate the presence and patterns of usage of SF and SFMS in the context of scientific publications; over time and within distinct subfields of computer science research. As a result, SF appears like a related, but yet undiscovered topical domain in computer science research, education, inspiration, reflection, communication and collaboration.

Be that as it may, such investigations are, however, important as they can point to missed opportunities and future potentials of SF for computing research. An overview and chronological description of SF in computing research can provide many insights which are important for future computing research application, research and education. For instance, data on the occurrence, frequency, usage and contextual referrals of SF and its terminology derivatives in computer science publications can identify computing research themes, which are more or less prone to use SF; and therefore, might benefit more or less from assimilating SF and SFMS in the future.

In addition, the cultural origin, purpose, and nature of the SFMS and narratives in computer science publications have not been described as well, for instance, the patterns of usage of Western and Non-Western SF. Also, the prevalence or abundance of SF referrals within and between distinct subfields of computer science research publications, for instance, the patterns of usage in HCI, Human-robot Interaction (HRI) or design research are not investigated at present.

One might ask why SF is used in a computer science publication; what kind of SF is referenced in the respective publication and how does it inform the research itself? Is there a cultural bias of the referred SF in computing literature? Did SF referrals evolve from rhetorical devices into serious research topics for HCI and computing literature over time? Are there clusters of computer science areas (e.g. HCI, HRI, AI) which regularly draw from and refer to SF?

These are questions this study aims to answer and it is this niche, the contribution of this dissertation is situated in. Prior pilot studies ([148, 151, 222]) in the leading computer science conference (CHI conference), respectively the ACM Digital Library, do support the assumption that SF is progressively used throughout HCI research.

Moreover, prior work recognizes a cultural bias of the SFMS in computing literature due to a strong tendency towards the usage of Western, and averseness of Non-Western SF. Despite these indications linking both fields, further research is necessary to describe this symbiotic and multi-faceted relationship, on the micro- or the macro-level.

2.2 Significance and Contribution

First, the study of the relationship of SF / SFMS and HCI/computer science research is insufficient. In order to address this academic void, this dissertation aims to discover linkages of SFMS in scientific publications. Levin and De Filippo's [183] study of the referrals of twenty self-selected SF movies in the Web of Science database does provide a methodology and some insight into the usage of selected SF media across scientific fields. However, Levin and De Filippo [183] do not deliver a comprehensive analysis of SFMS in computer science publications from an chronological, cross-cultural and contextual perspective.

Second, the author is developing the topic with collaborators to delineate distinct aspects of the links of SF and HCI research though incremental efforts. Extensive prior work (Section B) gives an account of six published pilot contributions. Based on this prior work and the literature review (Section 3.1), this dissertation aims to provide a further, wide-ranging investigation of HCI and SF in peer-reviewed computer science publications in a larger corpus using quantitative and qualitative content analysis techniques to describe the usage, purposes, cultural origin and chronological patterns of SF in computer science communication. By doing so, the results of this work are expected to discover emerging patterns between art and science in the field of computing.

Third, the exemplary studies of the crossings HCI and SF which are introduced in Section 6.1 are primarily overviews and lack depth and a full analysis of the relationship of SF and HCI. Specifically, the works of Marcus [200, 199, 198, 201, 202, 203, 204], Schmitz et al. [287], Levin [182] and Levin and De Filippo [183] are fairly general and do not present a full picture of the links between HCI and SF. Most importantly these overviews do not measure this relationship in detail, nor provide directions how to measure the connection of SF and HCI research within each publication and across different collections. This work, therefore, aims to provide a measurable and specific outcome of the linkages between the two disciplines of HCI and SF. By doing so, this dissertation will provide a complete representation of the mutual relationship of the two disciplines through the analysis of publications from two representative computer science databases, the ACM Digital Library and the *IEEE* Xplore Digital Library repositories.

Fourth, an important parameter to judge the influence of any discipline within a field of research is the analysis of the articles emerging from that area. Scientometrics [161] and bibliometrics [341] are defined as the area of research focusing on measuring various factors on science and technology and the technique is being widely utilized in understanding the publication trends in HCI [30]. Through the analysis of the contextual presence and usage of SF related keywords, terms and publication characteristics (titles, abstracts) in computer science research publications, this dissertation is expected to show an increase of the usage and importance of the role SF plays in computer science research. As there is gradual recognition that the field of HCI and interactive technology can benefit from SF and vice-versa, this dissertation will explore this developing bi-directional relationship in the case of two computer science collections and an expected publication corpus of 2000 conference papers and periodicals in multiple studies.

Fifth, through a contextual analysis of the purpose, nature and chronological usage of SF in HCI and computing research (e.g. country of origin and type of SF, the context of the SF referral), emerging research themes where SF and SFMS are utilized in computer science publications are expected to be identified. For instance, an analysis of the prevalence of explicit SF over time and editions of specific periodicals or conferences could show varying degrees of influence, popularity and usage patterns. This then may tie back to a particular SF movie being released in a certain year and will assist in determining what leads to a successful collaboration between the two disciplines of HCI and SF over time and assist in extrapolating distinct subfields in computing research, which SF and computer research intersect.

2.3 Research Aims

The assumption in this study is that SF is an existing, yet undiscovered topical domain in computer science research and its associated subfields. Specifically, SFMS, but also general SF authors, technologies, concepts, characters, and stories will be traced in order to investigate the prevalence, usage, and appropriation of SF in scientific publications. Thus, the primary aims of this dissertation are to establish a ground truth of the relationship between HCI and SF, outlined in the following:

1. The dissertation aims to quantify for the first time the described relationship between popular SF media depiction of technology in computer science publications.
2. The dissertation aims to create and describe measures of this relationship utilizing guided content analysis (term-frequency measures, co-word analysis, cluster extraction) of publications which reference SF as well as descriptive analysis (total publications referring SF over time, types of SF referred over time).
3. The dissertation aims to inform a more comprehensive framework to re-conceptualize the bi-directional relationship of HCI and SFMS and related fields which utilize SF and SFMS.

2.4 Research Objectives

The principal research objective of this dissertation is to discover, to describe and to analyze the relationship between SF and computer science research through a content analysis of scientific publications which refer SF in their metadata; over time and within distinct subfields of computer science research. The following paragraphs present increasingly specific research objectives and research questions to guide this study.

RO1: Identify an Interplay between SF / SFMS and HCI Research

The primary research objective of this dissertation is to discover a relationship between SF / SFMS and computer science research, with a special focus on human-computer interaction topics. For the purposes of this dissertation, RO1 is addressed through the related and prior work. The related work (Section 3.1) provides a thematic literature review and indicates a mutual, yet not quantified, relationship of both fields. In addition, prior work [148, 151, 222] confirmed the presence and usage of SF / SFMS concepts in the ACM Digital Library and the CHI proceedings.

To further investigate these suggestions and corroborate RO1, an in-depth study of the occurrence of SF /SFMS in a larger scientific corpus of peer-reviewed publications and studies is conducted, in particular in the context of the IEEE *Xplore* Digital Library.

RO2: Determine Patterns of SF / SFMS References in Computer Science / HCI Research Publications

The second research objective of this dissertation is to explore possible indicators SF has had, currently has and potentially will have on computer science and HCI research. To do so, text mining and a qualitative content analysis of the cited SF concept(s) in relationship to the research theme of the retrieved publications will be used to understand the context of the referral.

Through such a qualitative analysis, a determination of the purpose and level of influence of the referral in distinct subtopics of computing research and HCI (such as mobile computing, robotics, wearables, virtual reality and others) can be assessed. Moreover, patterns across periodicals and collections, such as the mechanics of SF referrals in certain subtopics in computing literature could indicate which fields of research or authors are more or less prone to draw from and integrate, SF in their research.

RO3: Describe and Analyze the Characteristics, Purpose and Cultural Origin of the SF / SFMS References in Computer Science / HCI Research Publications over Time

A third research objective in this dissertation is the identification and determination of the cultural origin of the referenced SF in the retrieved publication in order to provide an chronological overview of the type and purposes of SFMS in research publications over time through a descriptive analysis. A contextual analysis of science fiction in computer science research publications can describe the cultural origins of the material (authorship of the SF / SFMS, country of production) as well as the purposes of the referral in the context of the individual publication.

Through RO3 the prevalence and absence of specific SF from specific countries and areas will be determined. Patterns, for instance, the type of SF, the purpose of the reference of the SFMS, the year and subfield of computing research over time should enable deductions if SF precedes, matches or follows real-world technological development and research.

2.5 Research Questions

In a very simplified form, the three research questions, as well as the overarching, encompassing relationship of SF and CS research is illustrated in Figure 2.1 om page 20. In a more explicit and definite form as well as in association with the general research aims and objectives, the following specific research questions are formulated:

RQ1: What are the Metadata Characteristics of Computer Science Publications which reference Science Fiction?

Examples of metadata characteristics can be the:

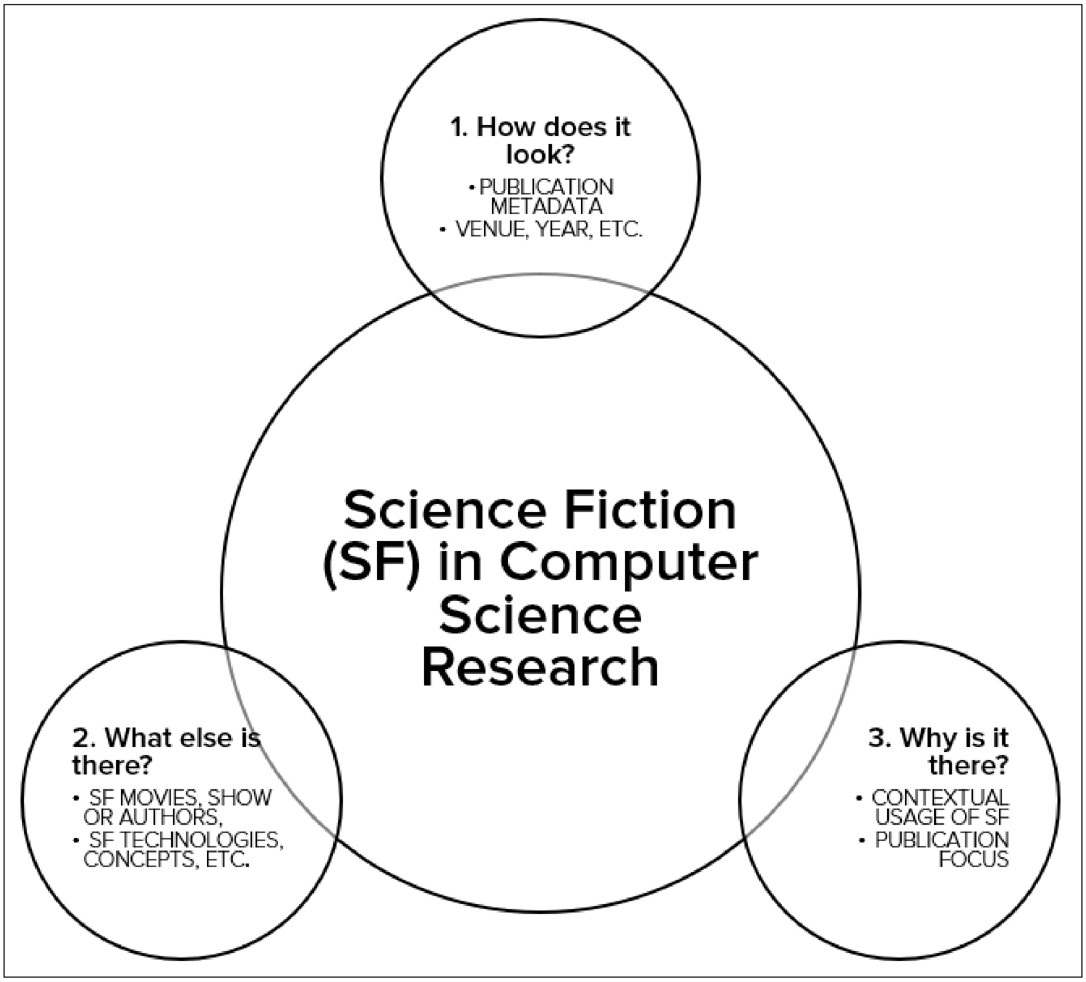


Figure 2.1: Simplified visualization of the research questions

– Publication topic [e.g. AI, Design Research];
– Publication year [Year];
– Publication venue [CHI/AI & Society/Ethics and Information Technology];
– Publication keywords [Natural language interface, Technology ethics, Robots].

RQ2: What Science Fiction Particulars co-occur in the Context of Computer Science Publications which reference Science Fiction?

Science fiction particulars can be understood as references to additional science fiction authors, shows, movies, novels, books, narratives, characters and technologies (e.g Isaac Asimov, The Matrix, Mr. Data, Holodeck). RQ2 can be addressed after coding the retrieved publications, through analyses of:

- The contextual referral of the science fiction reference and particulars within a certain periodical;
- Relationships of the type and purpose of the SF referral and SF particulars with regards to the publication year.

RQ3: What is the Purpose of References to Science Fiction, and Science Fiction Particulars which co-occur in the Context of Science Fiction References, in Computer Science Publications?

RQ3 will develop categorizes of purposes, for instance:

- Science fiction referral as a rhetorical device;
- Science fiction as a data source itself for the research paper;
- Science fiction as an inspiration for the research paper;
- More categories can be derived from [183, 151, 222].

2.6 Summary

This chapter presented the research rationale of this dissertation, which is motivated by both, a lack of comprehensive studies of SF / SFMS in computer science research communication and the implicit, likely beneficial relationship between SF / SFMS and computer science and HCI research.

Based on the introduction (see Chapter 1), traces of this relationship are discovered, which the research questions presented in this section aim to answer through quantifiable data, including frequencies and contextual types of usages of SF in computer science research publications.

Next, Chapter 3 presents an in-deep background and literature review of SF / SFMS in computer science research in addition to a methodological background (see Section 3.2), relevant for the presented dissertation study.

CHAPTER 3
BACKGROUND

This chapter provides the background of this dissertation, divided into two sections. Section 3.1 provides an extensive, thematic literature review on the topic of HCI and SF. In addition, Section 3.2 provides the essential, methodological background for this dissertation. Furthermore, Appendix B gives a brief account of the prior work and cumulative publications on the research topic in the context of this dissertation.

3.1 Related Work

In this section, a theme-oriented literature review will present related work which links SF / SFMS and computer science / HCI research on a multitude of aspects. Research on SFMS as potential depictions of real-world, future technologies, studies on the relationship between SF-makers and researchers in addition to work on reciprocal influences of the field of SF and computer sciences will be reviewed. The goal of this section is to establish a comprehensive review of related work on the interplay of SF and computer science research.

3.1.1 SF, Computing Visions and Design Theory

The intersection of SF and real-world scientific progress, with a special focus on computer science research, has been noted by Ferro and Swedin's inquiry [105, 104] into the linkages of SF and computing as well as Kay and Dourish's [85] special issue on SF and ubiquitous computing. Both contributions provide accounts of *"a long relationship between scientific research and speculative fiction"* [85, p. 765] through a compilation of essays of SF authors and design researchers as well as philosophical explorations into both SF and real-world science. However, the actual measurement of the role and usage of SF in science seems a more complicated endeavor as Ferro and Swedin [104, p. 4] state that:

> *"[...] measuring the degree to which science fiction has played a role in creating technology and defining culture is not trivial, nor do the analysts of science fiction necessarily believe science fiction to the principal creative factor."*

Both, Ferro and Swedin [104] and Kaye and Dourish [85] refer to well-known SF authors, such as Bruce Sterling or futurists, such as Brian David Johnson [138], a proponent of SF prototyping who give accounts of the symbiotic relationship of both fields.

Stork's [313, 314] inquiry into AIs culminating in his edited book HAL's Legacy: 2001's Computer as Dream and Reality [64] focuses on diverse aspects of the Heuristically programmed

ALgorithmic computer – HAL – from the SF movie 2001: A SPACE ODYSSEY [166]. Forty years later, 2001: A SPACE ODYSSEY and the aspects of the AI which have been both, correctly or falsely, envisioned by Kubrick are revisited. Yet another compendium of essays and interviews with a focus on a specific, seminal SF movie, scientists from the field of computing and AI research explore the predictions, verisimilitude, and proximity of a real-world 'HAL-equivalent supercomputer'.

The work [64] compares the envisioned natural language user interface capabilities, HALs ability to recognize human emotion (affective computing) in contrast to real-world developments and achievements in AI and computing research. Accounts from computer scientist Murray S. Campbell, who describes his involvement in the creation of IBMs Deep Blue supercomputer (which for the first time in 2006 defeated the reigning chess Grandmaster Garry Kasparov) draws analogies to HALs chess playing skills in 2001: A SPACE ODYSSEY. Likewise, AI pioneer Marvin Minsky [271], describes through an interview his involvement in 2001: A SPACE ODYSSEY at the time of the movie production, which is renowned for its scientific accuracy as a result of director Kubrick's and writer Clark's recruitment of [64, p. 2]:

> *"[...] scientists in universities and industry and at NASA in their effort to portray correctly the technology of future space travel."*

Westfahl, Yuen and Chan [346] present a collection of critical essays on the topic of SF and technological futures through a review of selected SF literature as a means to predict the future. Typical utopian fallacies, such as assumptions of universal wealth and general technological deterministic stances in SF stories are found to be common characteristics of the genre.

Dunne and Raby's [88] work on speculative design embodies a design catalog of non-functional products, artifacts, devices and installations in a similar fashion to Bleecker [38, 39, 40] as a means to visualize how things could be when technological limitations at the present are disregarded.

Additional accounts of the relationship of SF and HCI are provided by Doctorow, Warner, Perkowitz and Johnson [83] on SF prototyping, Shedroff and Noessel's [298] overview of HCI in SF movies and Marcus [200] eBook on HCI in SF movies.

In addition, a 2004 CHI Panel [35] explored and reviewed the value of video visions of the future for HCI[1]. The main agreement of the panelists was an acknowledgment of the importance of video visions for creativity and inspiration in computer science and HCI research.

Among others, the panel discussed the pros and cons of videos, or so-called 'potential vessels', as research stimulus. These can range from low-quality research videos to stylish utopian [216], as well as dystopian [211], future visualizations of society and technology. Beside of the actual quality of the visual depiction and overall presentation of the future video vision, the panel further identified as well the importance of the story and narrative the vision and the technologies are embedded in. In the past, the importance of stories and narratives for a believable future vision has been discussed by a variety of researchers, for instance by Tanenbaum [319] and Frank [112].

[1]Similar CHI panels have been held by Marcus et al. [205], respectively Marcus et al. [206] previously.

Portigal [255], through a review of a variety of inventions, recollects connections of SF and real-world design research. SF is framed herein as a cultural mind breaker to prepare society for new changes — or a 'Gedanken experiment' — extending traditional technological forecasting through the consideration of the implications and consequences of technology on a cultural, societal and ethical level. With regards to design theory in HCI, Bleecker [38, 39] with his private venture, The Near Future Laboratory [41], is credited with the groundwork of SF proposals as a means to derive design implications for the real world and therefore credited as one of the founding fathers of 'design fiction', a buzzword in contemporary HCI research. Bleecker (2009) elaborates in on the origins of design fiction in conjunction with science fact, SF, and design itself [38, p. 6]:

> *"Design fiction as I am discussing it here is a conflation of design, science fact, and science fiction. It is an amalgamation of practices that together bends the expectations as to what each does on its own and ties them together into something new. It is a way of materializing ideas and speculations without the pragmatic curtailing that often happens when dead weights are fastened to the imagination. The notion that fiction and fact could come together in a productive, creative way came up a couple of years ago while participating in a reading group where a colleague presented a draft of a paper that considered the science fiction basis of the science fact work he does. He saw a relationship between the creative science fiction of early television in Britain and the shared imaginary within the science fact world of his professional life. There were linkages certainly, suggesting that science fiction and science fact can share common themes, objectives and visions of future worlds. My colleague was not saying that the science of fact and the science of fiction were the same. In fact, he was explicitly not conflating the two. Nevertheless, coming from a computer science professor I found this idea intriguing in itself. It was certainly something to mull over. What was percolating in my mind was this liminal possibility of a different approach to doing the same old tired stuff. This notion presented a new tact for creative exploration — a different approach to doing research."*

Bleecker's Near Future Laboratory continuously creates tangible design fictions and prototypes, such as the TBD (To Be Done) catalog ([40], a physical product catalog introducing a variety of fictional devices, services, and appliances as a means to inspire, challenge and question future designers. Most recently, Lindley [189] Lindley and Coulton [190, 191] assess design fiction as being in a formative stage. Regardless of the failure to agree on a universally accepted definition of the term and meaning of design fiction, the concept seems to gain traction as a valid theoretical approach towards critical design research in recent years.

3.1.2 SF in Contemporary HCI Research

As one example of a study which primarily analyzes SFMS as a data source in order to derive design lessons for real-world interfaces, Shedroff and Noessel's [299, 298] review a massive repository of SFMS with a focus on the depicted interfaces and interactions. The study proposes not only four SF inspired domains which influence interaction design and interface conception, but as well a comprehensive list of selected SF movies with handy interaction design lessons derived out of. Acknowledging the reciprocal influence of SF and HCI, the research question in the exploratory study is more of a practical nature [298, p. 2]:

> *"What can real-world interface designers learn from the interfaces found in science fiction?"*

While a noteworthy approach, the heuristics derived seem quite similar in comparison to widely known and well-established HCI design principles in the field, such as Shneiderman and Plaisant's eight Golden Rules [300], Norman's five design principles [257, pp. 36-39], Nielsen's ten heuristics [234] or Tognazzi's first interaction design principles [326] . Shedroff and Noessel continue to disseminate HCI in SFMS; after the publication of the main results in form of a book [298], a narrated webcast [239] which sketches out the research process and highlights selected SF movies as well as a web page, which is regularly updated [238] with new material and SF interaction design examples and lessons.

Larson [177] studied ten SF movies and contrasted them with eleven trends in real-world computing advances and HCI interactions. His study showed that [177, p. 295]:

> *"depictions of computers in science fiction films mirror, for the most part, real-world trends in computer technology development."*

Furthermore, Larson presents four criteria for the movie selection in his analysis, a common challenge for both, SFMS genre definition itself and selection bias in SFMS studies [177, p. 295]:

1. *"They must have depicted some vision of the future when they were produced."*
2. *"They must feature computers or computer technologies in their depictions of the future."*
3. *"They must be relatively popular science fiction films."*
4. *"They must feature more-or-less representative depictions of the computer."*

In his overview, Larson [177] overall recognizes rather a 'reflection' instead of an 'evolution' of the computer technology depicted and envisioned in the ten SF movies in comparison to real-world computer technology. Furthermore, the study points out that SF does not necessarily always portray new or non-existent technologies, but can also present a version of a more polished and seamlessly working, but already existing technology, case in point Norman's assessment of 2001: A SPACE ODYSSEY [166]:

> *"Norman notes that one large difference between computer technologies today and how they were presented in 2001 is how flawlessly the depicted technology works"* [177, p. 298]

Schmitz et al. [287] present a survey of selected SFMS based on a temporal differentiation of the HCI technology available at the time of release. The study links technologies and interactions observed in selected SFMS with real-world technological developments and prototypes and presents a simple framework of the collaboration of film-makers and scientists. In a similar fashion to Larson [177], a simple categorization scheme of the depicted technology in SF movies is introduced:

– SFMS pre-computer interaction;
– SFMS which apply a simple technology adaption;
– SFMS which depicted advanced technologies;
– and SFMS which envision unrealized HCI.

In addition, Schmitz et al. [287] also identify three key factors that contribute to the applicability of interaction design in movies, which are:

1. the available special effects technologies;
2. the available budget;
3. and the overarching importance of the role of technology within the movie itself.

Schmitz et al. [287] do cover selected milestones of interface design found in SFMS within the 20th century but the study lacks at the same time, through a very limited selection of SFMS, representativeness.

In a similar manner to Schmitz et al. [287], Kurosu ([170] reviews a very small number of pre-selected science fiction movies to draw analogies to real-world HCI research and development. In comparison to the categorization in Schmitz et al. [287], Kurosu [170] simply differentiates between SF movies with a, i) realistic or, ii) unrealistic prediction of future HCI and technologies. Examples from the former category are the Roomba-style cleaning robots seen in The Fifth Element [37] while examples of the latter category are for instance the depiction of advanced autonomous and automated cars in Minority Report [308]. Kurosu [170, p. 583] concludes that science fiction movies can certainly inspire HCI research as:

> *"HCI researchers may be able to get some hints from these movies in terms of the future user interface."*

In yet another recent study on SFMS and HCI, Troiano, Tim and Liab [330, p. 1] explore a total of 340 SF movies to identify patterns of shape-changing interfaces as:

> *"sci-fi, and specifically sci-fi movies, may represent a valid source of information in that respect, due to their creative and inspirational approach towards the vision of future technology."*

The authors use thematic analysis to find 101 instances of shape-changing interfaces in the 340 SF movies and accordingly classify these instances into four main behavioral patterns which are:

- Reconfiguration of shape-changing interfaces with the subcategories of assembling / disassembling, reshaping environments and revealing interactive parts;
- Transformation of shape-changing interfaces with the subcategories of camouflage and morphing;
- Adaptation of shape-changing interfaces with the subcategories of finding the intended shape, expanding and reversing Shape;
- Physicalization with the subcategories of representation and materialization.

With regards to the selection of the SF movies and in similar manner to Schmitz et. al [287], Larson [177] and Shedroff and Noessel [299, 298], the 340 SF movies are non-randomly selected from the Internet Movie Database (IMDb) [9] and Wikipedia ([348]. The authors identify an increase in the visual depiction of shape-changing interfaces over time, with 32 of the 101 instances found in SF movies from 2000-2015, an indicator for the potential of modern SFMS for HCI research. The results indicate opportunities for the inspiration and design of shape-changing interfaces depicted in SFMS for the purposes of real-world, HCI research.

As a final example of a study which uses a virtual ethnography of SFMS to derive yet to come potential interaction techniques, Figueiredo and colleagues [107] review gestural interactions in SFMS. In detail, the authors select 25 [107, p. 1321]:

> *"sci-fi movies they remembered with unusual human-computer interaction, requiring the characters to move arms and/or hands in order to make the system respond to his intention".*

The twenty-five movies are divided into 221 individual scenes using Shedroff's [298] classification scheme to categorize and code the gestures in their review. The study's main contribution is a catalog of future hand gesture interactions for interface designers.

3.1.3 SF and Real-World Scientists

Kirby's [156, 155, 157, 158] qualitative studies of the collaboration of film-makers with scientists show in detail the intrinsic and extrinsic motivations of researchers who decide to consult on movies. Through interviews and archival research, the author gives a detailed account of positive outcomes of these collaborations for either, the film-makers, researchers and the public as well. Among those are three distinct implications, namely:

- the 'conditioning' of the public audience through demonstrating a novel technologies' potential application in SFMS (audience implication);

– the increased success of SFMS through a realistic presentation of prototypes within the diegesis (film-maker implication);

– as well as successive funding opportunities for the scientific consultants after the SFMS are released to the public (scientist implication).

Kirby [156, 155, 157, 158] finds out that placing a so-called 'diegetic prototype' into a narrative and social context of a SFMS does create the environment for the fictional technologies and prototypes to be viable in a close future (in reality). Bleecker [39] quotes Kirby [158] in his essay on design fiction regularly and introduces various examples of the translation of SF stories into the real world. Among those, is the story of Franz Josef, a designer who published a couple of imagined STAR TREK design props, specifically in 1975 a set of Star Trek Blueprints [81] and in 1986, the Star Fleet Technical Manual ([152]. Even completely "made up", both pseudo-scientific books sold to such a success that they were on the New York Times Bestseller List at the time [266].

Design fiction, Kirby's [158] main object of interest is herein viewed as a technique to skip the traditional iteration- and improvement innovation lifecycle towards a tangible, not functional prototype, which is embedded in a story with the goal to start a discussion about design, life, and social alternatives. Bleecker defines the design fiction object accordingly as:

> *"[...] circulating back and forth between prototype and story proposition, influencing, challenging, questioning, blurring fact and fiction [...]"* [39, p. 7] and concludes that
>
> *"[...] designing with the genre conventions and story-telling idioms of science fiction may introduce a new kind of innovation practice."* [39, p. 10]

Frank's [112] essay on the theoretical implications and general requirements of the visual depiction of believable technologies in a SFMS provides important contextual information for the aspect of scientific advising on movie productions. According to Frank [112, p. 427]:

> *"[...] twenty percent of the top-grossing films of all time have had scientific or technical consultants."*

Furthermore, his work introduces important theoretical concepts of film theory in relationship to science advising which will be briefly recapped here as they provide the foundation of scientific consulting on movie sets. Citing Prince's [258] concepts of i) reality depictions and ii) audience perceptions in movies, a filmed image can be characterized according to two standards of reality when perceived by an audience, which are i) referential and ii) perceptual reality. Frank [112, pp. 429-430] develops on this notion further by stating that:

> *"[...] thus a scene in a film is 'referentially' either real or unreal— that is, it depicts events that actually occur or exist, or ones that are imagined. The same scene is also either 'perceptually' real or unreal, meaning that it appears to be real or appears to be a fantasy*

(or lack significant real-world elements). To become perceptually real means depending on references between what people know to be true from outside, real-life experiences, and what they see on screen. If the relationship to experiential cues is strong enough, a film can make things appear perceptually real."

It is important to notice that this minimum level of realism in SFMS, or 'presumed reality', is a conditio sine qua non for the audience to feel the smallest level of connection to the movie or TV program. As Frank [112, p. 431] further explains:

"The stated belief is that at the very least, audiences need a plausible scientific-sounding excuse: cloning and mosquitoes trapped in amber in order to bring dinosaurs to life, radiation to create a hulk or spider-man... This requirement for a sort of basic foundation in familiar reality or expectation extends both to the visual environment of a film or television program and to the plot."

Another theoretical distinction in Frank's [112, p. 432] review of science in movies, as well as scientific consulting, is the distinction between the concepts of i) dramatic truth and ii) veritable truth:

"If veritable truth is that revealed by real scientists, dramatic truth is the version of that truth that is entertaining and commercially viable—in other words, the veritable truth that appears on screen once it is filtered through the social and structural limitations imposed upon it by the filming process. These limitations can include everything from studios' time and budgetary constraints to personal preferences of the director or the filmic requirement to keep things visually appealing,"

Frank [112, p. 433] concludes that:

"perceptual and referential reality describe why science consultants are hired, and provide a theoretical model for explaining why science is incorporated by Hollywood [...] Veritable and dramatic truth address how informants— scientists, science consultants, and insiders from the entertainment industry—seem to envision scientific knowledge and understanding when speaking with each other and to outsiders (i.e. anthropologists)"

Frank's [112] deductions are the result of interviews with 14 movie consultants, respectively expert scientists within their fields, among those Jack Horner, world-renowned paleontologist and technical advisor for JURASSIC PARK [307], Astronomers Carl Sagan, Jill Tarter and former Director of NASA, Gerald D. Griffin who inspired Jodie Foster's fictional lead role in CONTACT [362].

More cases of the collaboration of scientists and movie makers (applying Frank's [112] principles of perceptual and referential reality) in the creation of believable SFMS are discussed in Karlin's [154] report in *IEEE* Spectrum and Smaglik's [304] account in Nature Careers. In the former, Karlin [154] describes the collaboration of two University of Arizona researchers (neuroscientist and electrical engineer Charles Higgins and physicist Wolfgang Fink) which advised on the 2015 SF movie SELF/LESS [302]. The input of both ensured a basic presence of a 'referential reality' in the movie which assumes:

> *"[...] a brain-scanning immortality technology that allows a person's consciousness to be transferred to a new body."* [154, p. 26]

In the article, Fink states with regards to the believability of such an imagined technology that:

> "[...] once you buy into the underlying premise that you can transfer consciousness, then the rest of movie flows quite logically. It doesn't tank." [154, p. 26]

The article concludes with Higgins emphasizing the potential SF has for the greater public as::

> *"[...] by doing interviews and relating real science to science fiction, I believe that we are connecting better with people than academics typically do."* [154, p. 26]

In this context, the Science and Entertainment Exchange [228] at the University of California Los Angeles (UCLA) is the single recognized, professional organization which connects scientists with entertainment professionals and has created more than 2500 connections – or matches – between scientists and movie producers since its inception in 2008.

3.1.4 SF in Computer Science Education

SFMS can be used as well to stimulate creativity of students in computer science and a diversity of other related STEM fields [338], such as computer ethics, AI and computer security [160] through an alternative viewpoint, therefore, extending traditional technical foci in computing education. As early as in the 1970s, the value of SF literature for educational purposes has been discussed. In Michalsky's essay [215] on the topic early, arguments for the integration of SF into formal education are presented, for example, the early notion of speculative fiction as a means to benefit student creativity [215, p. 248]:

> *"The implication from all this, I should like to suggest, is that SF can function as a tool in coping with the onrushing future. Studying speculative fiction offers the student the opportunity to be more creative in his thinking about the future and thus augment the options for possible tomorrow."*

Studies on the benefits and hindrances of SFMS in formal education have started to appear in the early 2000s and are inconclusive. For example, Barnett, Wagner, Gatling, Anderson, Houle and Kafka [29] did conduct an experiment with 82 8th grade students, divided into 5 cohorts, who attended a medium-sized, urban/suburban middle school. The focus of the study was on earth science education and the impact a SFMS can have on the perception and understanding of scientific concepts. In the experiment, the researchers found that students who did watch the SF movie The Core [10], after a four-week curriculum of earth science education, were negatively impacted in comparison to students who did not watch the movie but instead finished the module with a portfolio. According to Barnett et al. [29, p. 188]:

> *"[...] movies that build upon a foundation of reasonably accurate science and then proceed to more fictionalized science appear to be more likely to lead students to accept that the ideas presented in the movie are scientifically reasonable. In other words, a film's attention to scientific detail appears necessary to root a plot or idea in reality but it appears that the plausibility of those ideas has significant potential to influence students' ideas about scientific concepts. We were rather surprised at the influence".*

In 2013, Lin, Tsai, Chien and Chang [188] conducted an experiment to investigate the relationship of SF movies on the technological creativity of 132 middle school students. According to Lin et al. [188] and Barnett et al. [29], SF movies have an impact on the understanding and perception of students on scientific mechanisms and concepts, either positively or negatively. Lin et al. [188] use a 4-group, pre-test, post-test design (2 control, 2 experimental groups, Williams Creativity Scale administered before and after the experiment) to measure the effect a SF movie has on student's technological creativity. In the two experimental groups (two class cohorts), 69 students watched the SF movie I am Legend [178] while in the two control groups (two other class cohorts), 63 students were not exposed to the SF movie. In all groups, students then engaged in practical design activities. Lin et al. [188, pp. 198-199] conclude that:

> *"The effective use of SF films can stimulate middle school students' technological creativity and enhance their ability to design product improvements. Analysis of the results shows that middle school students exposed to practical technology-design education activities including a SF film performed better than did students who did not view the SF film. Thus, despite Larson's [177] doubts about the usefulness of SF films for depicting future developments in computer technology, the integration of such films into practical educational activities can stimulate students' imaginations and enhance their ability to design product improvements."*

In a special issue on the utilization of SF for teaching, the value of SFMS for educational purposes is discussed and observed to be of increasing importance as [48, p. 15]:

> *"... the traffic between science fiction and science fact is growing and, with the proliferation of this genre in mainstream film, television and even computer gaming, it seems likely that, for a number of students, an interest in science may have been inspired by science fiction."*

With a stronger focus on SFMS and the claim that modern SFMS are scientifically more accurate than past productions, Rogers [275] used scenes from five SF movies to illustrate well-known HCI principles (e.g. from Preece et al. [257] or Shneiderman & Plaisant [300]) in order to propose the idea of integrating SFMS into computer science and HCI teaching. The connection between HCI and SF is made explicit, as according to Rogers [275, pp. 677-678]:

> *"[...] science fiction movies and television shows, since their inception, have included computers and interfaces as key parts of the plot and scenery. In the past, many of the depictions were futuristic and impractical but more modern productions have been quite accurate in predicting use patterns and interface designs. This use of computer interfaces on the movie screen allows for the general public to get an understanding of the impact of design in ways that lectures are limited in doing. Because of the popularity of these types of media, there is a greater chance for common ground to begin discussion of HCI design principles and concepts."*

To illustrate the benefit of SFMS, five HCI design concepts or heuristics (error prevention; visibility of system status; constraints; conceptual model; and user-centered design) are described through scenes from five SF movies[2]. Rogers [275, p. 679] summarizes that SFMS, which are referenced as *"culturally current media"*, can illustrate both, good and bad user interface design as well as *"design strategies, application and evaluation"* for innovative HCI curricula.

A 2012 Special Interest Group on Computer Science Education (SIGCSE) panel led by Bates [31] with four other computer science professors and educators as participants discussed experiences and methods for the future usage of SF in computer science education. In the panel discussion, the connection of SFMS and computer science education is illustrated in the development of unique courses and classes by each of the panelists which integrate SFMS in their teaching. For instance, Bates developed an undergraduate general education course[3] at Minnesota State University, which is described as tracing [31, p. 161]:

> *"[...] the historical imagining of AI technology in science fiction, giving a context for the technical developments and societal expectations of technology. Students can grapple with ethical issues in the relative comfort of an alien world, while learning about state-of-the-art technology and developing their writing skills."*

According to Bates account, SFMS, such as THE COMPUTER WORE TENNIS SHOES [57], TRON [192] or WARGAMES [23] can be used to show computer science education students different depictions of various AI paradigms over time.

Another example of a crossing of SF and computer science in the panel discussion is CS 463[4], a class taught at the University of Kentucky by computer science Professor Judy Goldsmith. According

[2] MONSTERS VS. ALIENS [181], APOLLO 13 [134], MINORITY REPORT [308], STAR TREK IV [236], UP IN THE AIR [268].

[3] CS 201: Artificial Intelligence and Science Fiction.

[4] Computer Science 463: Introduction to Artificial Intelligence.

to her account, CS 463 offers a SF film review (which depicts an AI) as an alternative for the final class project for students [31, p. 161]:

> *"The most popular option is the SF review. The proposal consists of the SF work and the relevant AI theme. The negotiations lead to a suitable work, and corresponding bibliography of research papers (at least 3 peer-reviewed papers or chapters of advanced textbooks) on the AI topic of interest."*

Other instances of computer science classes integrating SF [31] are STS 2500[5] at the University of Virginia, taught by Rosalyn Berne a Science, Technology and Society (STS) professor and CS 190[6] taught by Valerie Henderson Summet at Emory University. For example, CS 190 utilizes SF fiction readings to introduce robots, robotics, and AI to future computer science students. One more instance of a SF-related university level course is Brueckner and Novy's [54] MAS S65[7] course at the Massachusetts Institute of Technology (MIT) which connects:

> *"[...] science fiction with speculative and critical design as a means to encourage the ethical and thoughtful design of new technologies."*

With respect to AI courses and education, Burton, Goldsmith, Koenig, Kuipers, Mattei and Walsh [55, p. 2] state that in:

> *"[...] thinking through the future of AI, it is useful to consider fiction, especially science fiction."*

Furthermore, using SF in the classroom can be a useful in fields outside of computer science education, for example in the fields of biochemistry or physics and has been proposed since the late 1980s by Physics Professor Letoy W. Dubeck [48, p. 15] as:

> *"[...] an early proponent of using science fiction as a tool for scientific learning."*

However, SF in educational settings seems a double-edged sword as has been viewed critically as well. Myers and Abd-El-Khalick's [226] study on the perception of graduate students after watching the SF movie CONTACT [362] concludes that SF films need to be cautiously utilized in classroom settings:

> *"With this increase in sci-fi film realism, 'willing suspension of disbelief' becomes riskier in terms of its potential impact on public understanding of science. It is our hope that, with more literature in the present study's line of research, science teachers and students alike will develop proper interventions to grow a deeper, more reflective awareness that permits enjoyment of sci-fi film (and other screen media) for its entertainment value without believing, often involuntarily, in its augmented scientific realities."* [226, p. 25]

[5] Science, Technology and Society 2500: Ethics, Science Fiction and the Future.
[6] Computer Science 190: Robotics Freshman Seminar.
[7] Media Arts and Sciences S65: Science Fiction to Science Fabrication.

3.1.5 SF and Computer Science Frameworks and Models

This section introduces a variety of frameworks and models which connect SF and SFMS to real-world science and collaboration schemes between researchers and movie-makers, as well as theoretical links of inspirations of SF media and HCI.

Kirby's unidirectional framework: To begin with, in his 2013 book called Lab Coats in Hollywood, Kirby [157] presents a simple framework (Figure 3.1, [157, p. 11]), which links the scientific community and the entertainment industry in a sequential, unidirectional, three-step process.

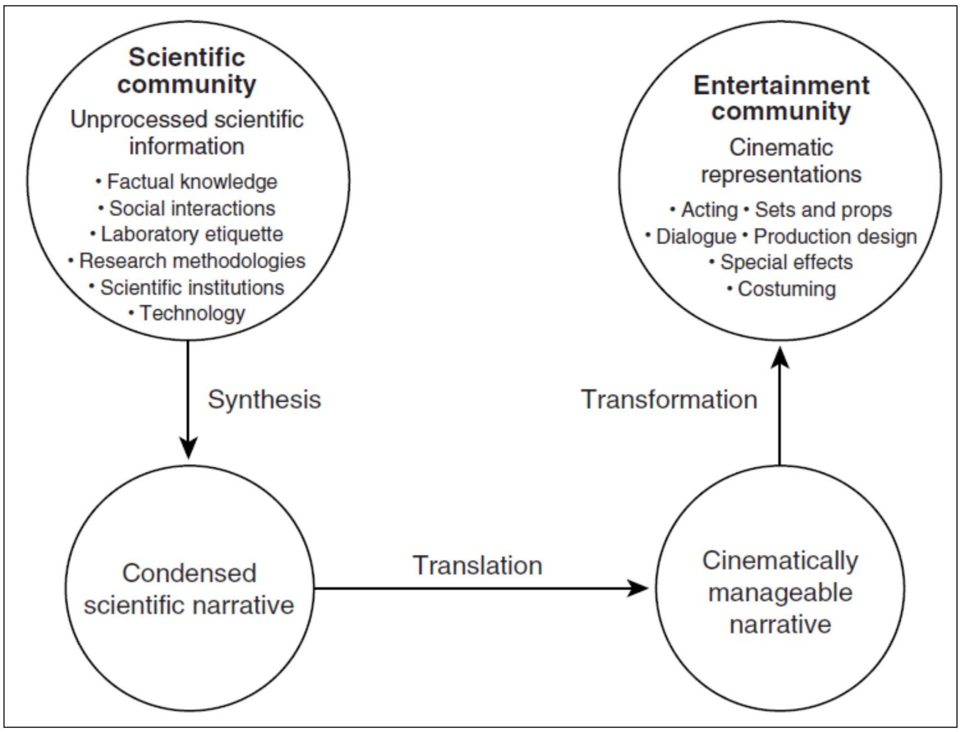


Figure 3.1: Kirby's unidirectional framework

This framework starts with the scientific expert community, which inherently possesses the rationale, knowledge and scientific rigor. Through three steps of synthesis, translation and finally transformation, scientists' input can be incorporated into a science fiction movie or show. Interestingly enough, Kirby's framework, while quite detailed in its presentation, e.g. through the introduction of community-specific etiquette and requirements (such as the usage of research methodologies or the available special effects technology in either domain), only covers a part of the science—SFMS relationship.

For example, prior work has shown that the scientific community is on occasion directly inspired by a SF film, case in point the prior introduced Star Trek Communicator [148] or the development of Puffy, a robot for children with neuro-developmental disorder [113, 222], which has been visualized and envisioned as Baymax in the movie Big Hero 6 [128].

Nevertheless, Kirby's framework calls attention to a paramount factor in the context of SF / SFMS and real-world science – that is the importance of stories. This is indicated by the translation of the commonly rational, concise, and unglamourous 'scientific narrative' into a 'cinematically manageable narrative'. A good example highlighting this observation is the 'Hoverboard', a skateboard-looking device without wheels, which can float over the ground, depicted in the 1989 SF film Back into the Future 2 [176].

Not only manifests the 'Hoverboard' the conversion of the technological concept of "Magnetic levitation of a stationary or moving object" (see e.g. US Patent 20140265690A1 [133]) from an abstract description into a filmic, manageable narrative, it also reflects the value of 'diegetic prototypes' (introduced in Section 3.1.3) as story vehicles, which are crucial for the believability and understandability of SF films. While certainly incomplete with regards to the dynamic linkages of SF / SFMS and science, the recognition of this conversion of scientific information toward a palatable story for a non-expert audience can be understood as the main contribution in Kirby's framework.

Schmitz' multi-directional framework: The second framework linking both topical domains – science fiction and human-computer interaction/computer science research – is presented in the survey of Schmitz et al. [287] on human-computer interaction design in science fiction movies as a multidimensional collaboration framework (Figure 3.2) of scientists and researchers.

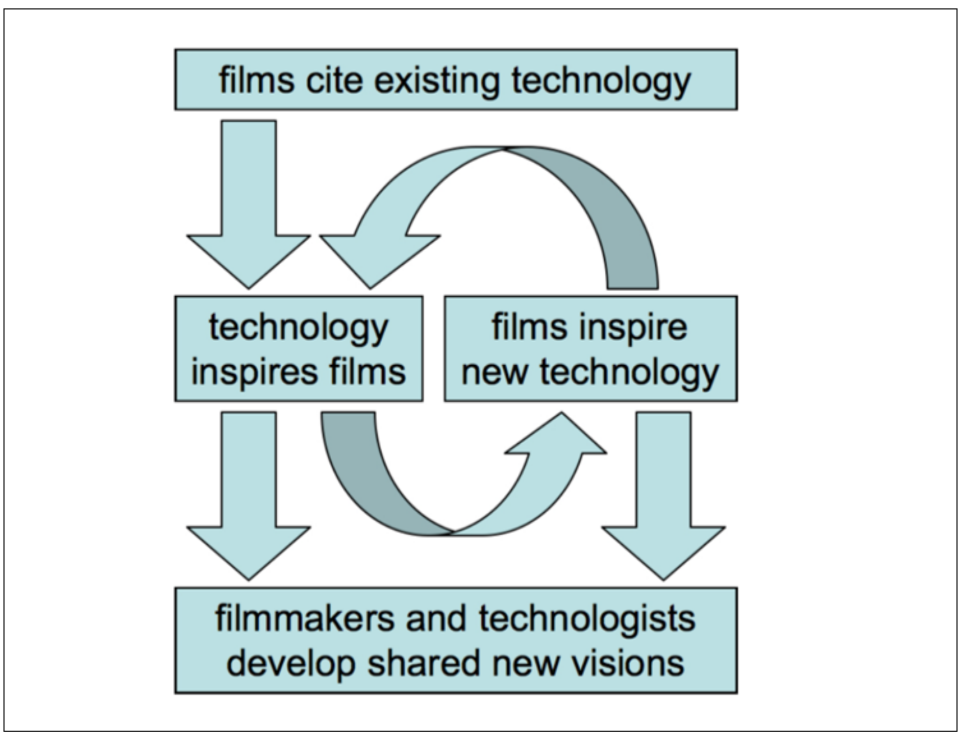


Figure 3.2: Schmitz' multi-directional framework

Herein, SFMS utilize existing technologies from real-world research, but subsequently are framed as standing in a reciprocal dialogue, inspiring and influencing each other and vice versa. The model's singular entry point, a film citing an existing technology, seems controversial as there are plenty of examples, where a SF film portrayed a technology, far ahead of its time, case in point the video-phone in the 1927 SF film METROPOLIS [174] (see Figure 1.1a).

Granted, one can find earlier conceptualizations of a videophone, such as the telephonoscope (circa 1870-1890), but an equivalent, existing device or technology, at the time of the METROPOLIS videophone, was hardly to be found with the closest example probably be represented by AT&T's and Bell Laboratories two-way television-telephone [342](circa 1930). Nevertheless, Schmitz et al.'s framework clearly shows an interchange of technology and films, or science and art, with filmmakers and scientists both inspiring each other to envision possible futures in their respective domains.

UXPA framework: Yet another principal linkage of science fiction, science fact and the technological climate is identified in the 2013 User Experience Professionals Association (UXPA) [332] magazine, which dedicated a full issue to SF and User Experience Design (UX). The so-called science fiction feedback loop (Figure 3.3), according to the UXPA magazine [332, p. 15], is defined by a constant *"state of inspire, create, repeat."*

While being presented as a circular process, the 'science fiction feedback loop' begins with the creation of SF, in response to the overarching technological climate at the time (Figure 3.3, top right area). The resulting SF, may it be of literary or cinematic nature, then influences the audience and as such, the technological climate itself, leading to the creation of new science and ultimately, the imagination and envisioning of even farther, advanced ideas, hence completing the 'science fiction feedback loop'.

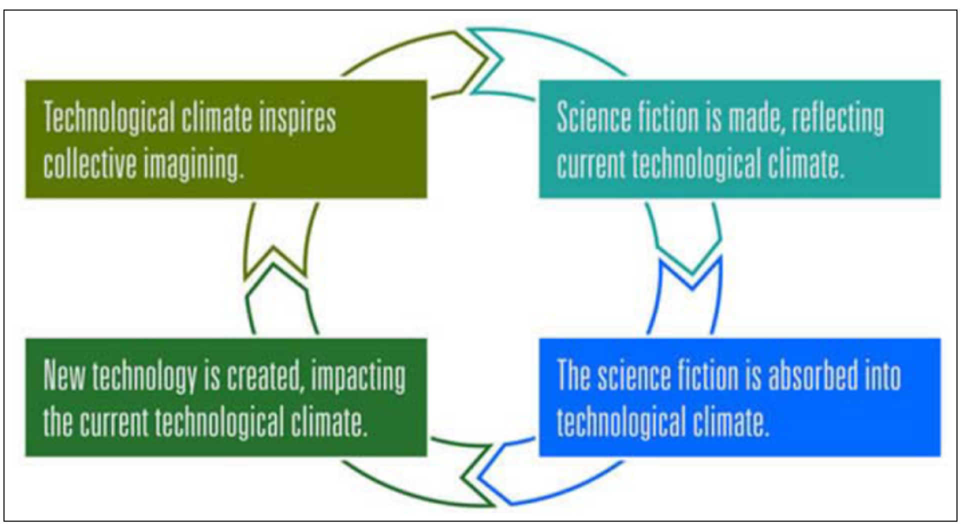


Figure 3.3: UXPA science fiction feedback loop

The UXPA framework places this 'science fiction feedback loop' in the context of a larger 'lifecycle model', which connects the three broader conceptions of SF, scientific fact and the technological climate as linear and interrelated processes over time (Figure 3.4).

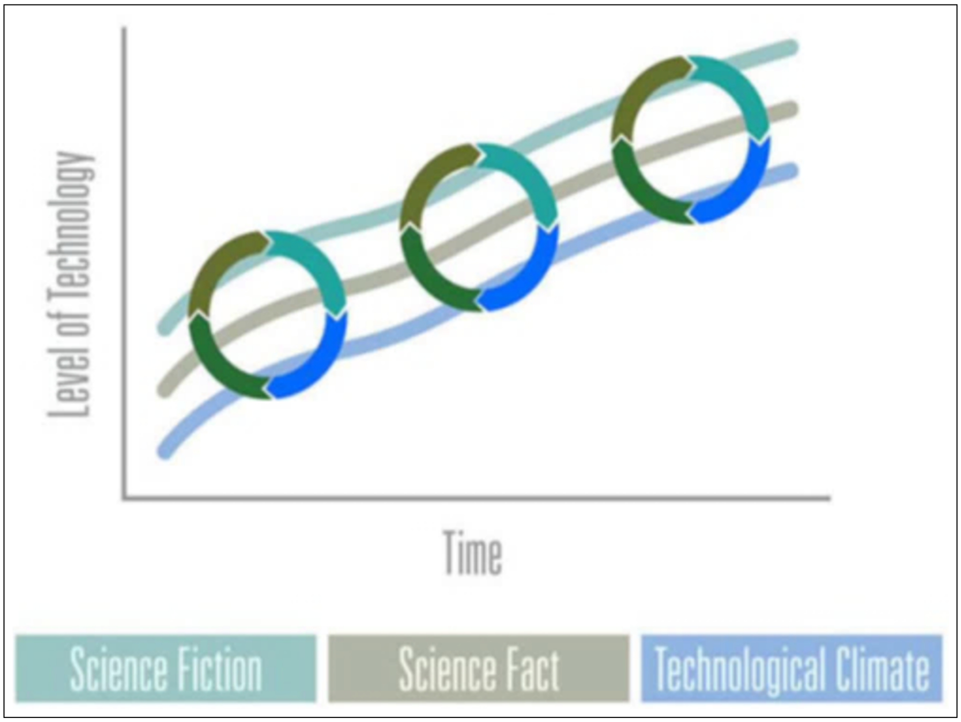


Figure 3.4: UXPA science fiction feedback loop over time

The UXPA science fiction feedback loop and framework stand out for two main reasons. First, it conceptually places SF as the antecedent to science fact and the technological climate. As such, the UXPA framework positions fiction and imagination as the first step in technological innovation, in contrast to Kirby's (see Figure 3.1) or Schmitz et' al.'s (see Figure 3.2) frameworks, which both position technology and science as the inception point in their models of SF and real-world R & D.

Second, it implicitly establishes the importance of the audience and general public via the introduction of the concept of the technological climate as a key component and as such, extends the SF—science relationship into the realm of public discourse, including the people's perception, acceptance or reluctance toward future technologies.

Mubin's virtuous design cycle: Lastly, in 2016, Mubin and colleagues [220] proposed yet another model connecting HCI research with SF / SFMS. As the UXPA framework does (see Figure 3.4 and Figure 3.3), Mubin and colleagues work links the general public, who is exposed twice (via SF artwork and later on, through scientists who develop actual products and devices) to the envisionment of new technologies and interactions in the context of the SF—Science relationship.

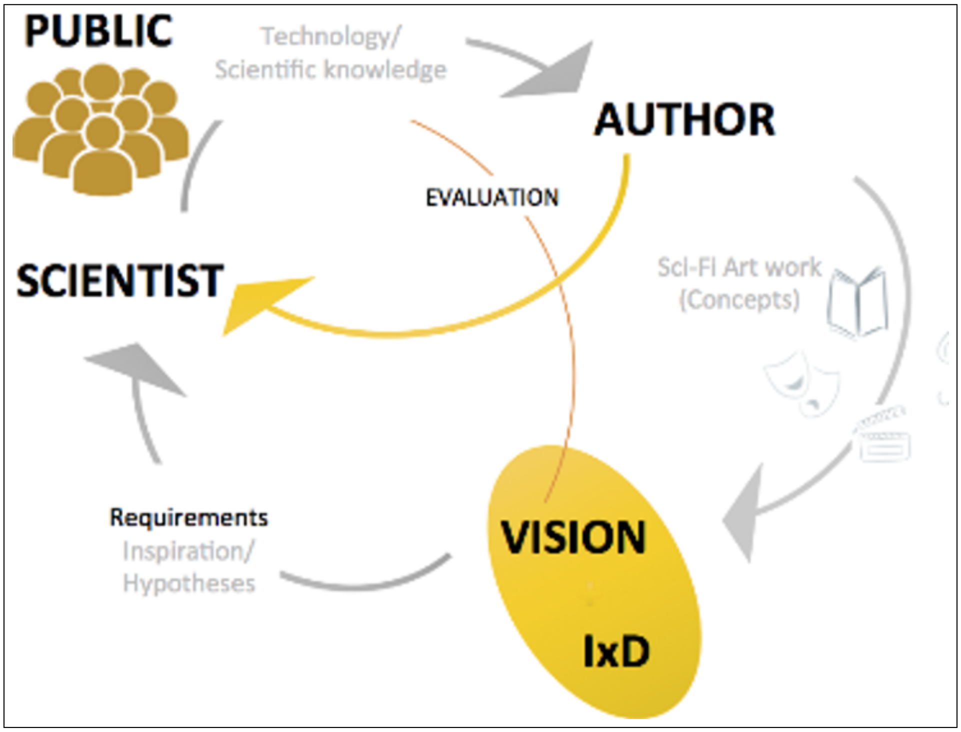


Figure 3.5: Mubin's virtuous design cycle

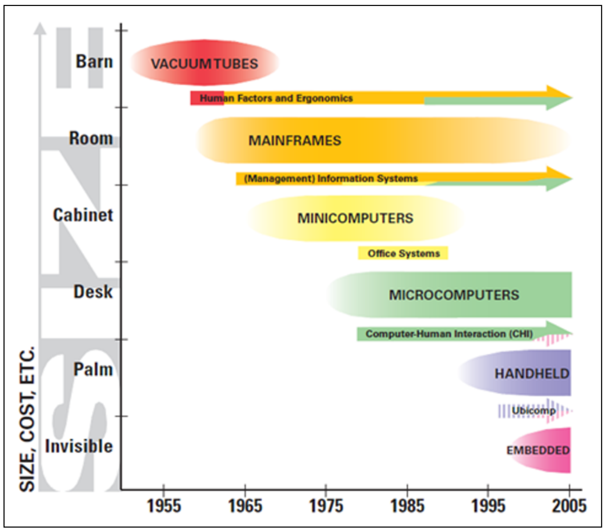
In the framework by Mubin et al., SF is the origin (Figure 3.5, right side) of a series of steps, from the envisionment of new Interaction Design (IxD), the derivation of requirements for scientists, who then, in turn, can provide the knowledge to evaluate these proposals. As a result, these new designs and envisionments can influence SF creators (e.g. SF authors or film-makers) as well as the general public, who represents the culmination point in this specififc model.

Summary of frameworks: In summary, it is important to note that the four introduced models and frameworks do display a connection of SF and real-world research to some degree, however at the same time, all introduced frameworks or models are based on small case studies, interview data, anecdotal evidence or a combination of thereof. As a result of the lack of explicit operational definitions and objective data, the link of SF and HCI, computing research and technological advancement is vague at best. Furthermore, none of the introduced frameworks conceptualizes the transition of SF into scientific output, such as research publications, nor explicitly defines measures of the possible links between both topical domains.

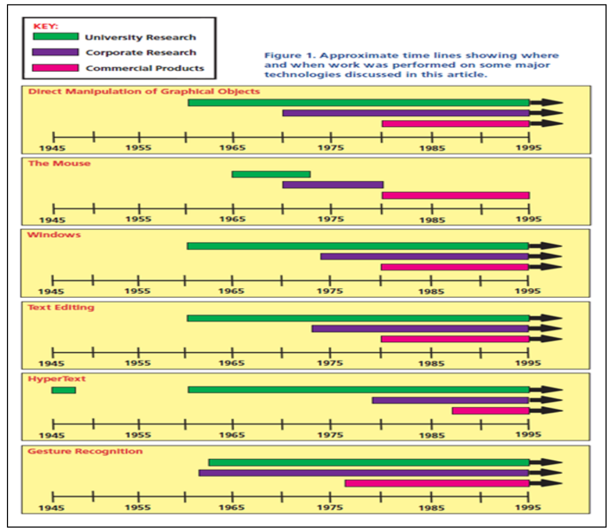
On the positive side, the introduced frameworks, taken as a whole, display the multi-dimensional relations and connections of SF and real-world science, ranging from the translation of technical, expert know-how into digestible narratives to the recognition of external factors outside of the core SF—Science relationship, among those the technological climate at the time and the perception and attitude of the general public toward disruptive, innovative or controversial technologies.

3.1.6 A Chronology of SF and Computer Science Research

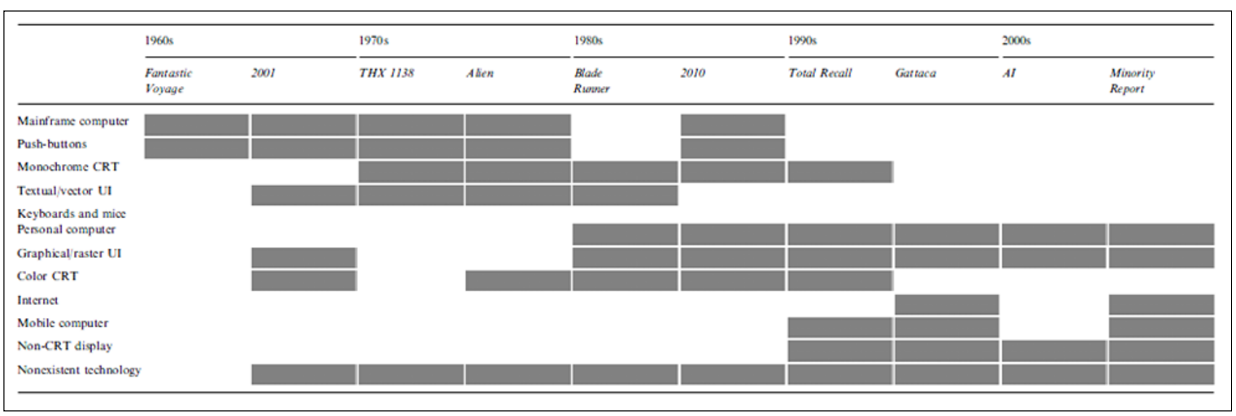
Trend-, scientometric- and bibliometric studies to either, extrapolate emerging paradigm shifts, or to review past research themes in computer-science research have been conducted in the past. However, it is important to note – with Levin's study being the exception [183, 182] – that no content analyses of scientific publications which focus on SFMS could be identified. Nevertheless, for the purposes of this dissertation, the referred studies and overviews in this section do provide methodological guidance as the authors do en devour identify trends and paradigm shifts in computing research and literature over time.



(a) Platform dependent HCI research over time



(b) Interaction techniques in HCI research over time



(c) Real-world technologies in ten science-fiction films

Figure 3.6: Chronological HCI / CS research

-To begin with, Grudin [121] reviewed the chronological evolution of computer hardware platforms from 1955 to 2005 in accordance with major paradigm shifts in the research topics associated in computing (Figure 3.6a, page 39). With a stronger focus on HCI and interaction styles, Myers [225] presents similar time-lines, while reviewing research and development efforts on distinct direct and indirect manipulation techniques in HCI (Figure 3.6b, page 39). With a focus on SFMS, Larson [177] did investigate 'SF computer technologies' preceding 'real-world computer technologies' in ten SF movies[8] and contrasted them with – at the time of the movie release – eleven trends in real-world computing advances and HCI interactions. Larson [177, p. 294] points out that:

> *"[...] previously cited research suggests a reciprocal, symbiotic relationship between fiction and reality, but there is currently very little empirical evidence in support of this claim. This research is an effort to provide that needed research.".*

The results of this small case study show overlaps of the real-world computing technologies – available at the time – in comparison to the depiction of computing technology in the ten surveyed SF movies (Figure 3.6c, page 39). For example, the SF movies from the 1990s and 2000s do not depict any outdated computer technology, such as mainframe computers or textual/vector user interfaces, but show instead concurrent or emerging technologies (at the time of the movie release) of mobile computing or advanced display technologies. The is corroborated by the fact that nine out of the ten selected movies depict some sort of a non-existent technology with FANTASTIC VOYAGE [108] being the only exception.

Computer science research themes and trends can as well be extrapolated through bibliometric methods, such as co-word or citation analyses. Such quantitative approaches have successfully been applied in software engineering publications [73], respectively the CHI proceedings [194], to infer trends and paradigm shifts in computing literature in the past. As one example, Bartneck and Hu [30] did conduct an extensive quantitative analysis of the CHI proceedings over the course of 26 years. The authors explored in specific the authors, affiliations, and publication citations, through an analysis of metadata, XML files of the CHI proceedings. Among other results, the study shows evidently the dominance of publications originating in the USA [30, p. 707]:

> *"More than 62% of the credits go to the USA, and the top four countries (USA, UK, Canada, and Japan) alone accumulate 82 percent of all credits [...] the main contributors to the conference are a relatively small group of organizations from the USA, Canada, and the UK."*

Bartneck and Hu's [30] study might be relevant for this dissertation with regard to the investigation of the cultural background of the SF – referenced in computer science repositories – as prior work [151] identified a cultural bias towards Western SF in the CHI proceedings. While Coulter, Monarch and Konda [73] investigated co-word occurrences in the ACM Digital Library using the ACM Computing Guide to literature classification scheme, Liu, Goncalves, Ferreira, Xiao, Hosio and Kostakos [194]

[8] SF films from the 1960s into the 2000s; two per decade; see Figure 3.6c on page 39 for details.

applied co-word analysis to publications' keywords; Both studies can serve as blueprints for a quantitative content analysis of publication abstracts or keywords in this dissertation.

Guha, Steinhardt, Ahmed and Lagoze [122] used bibliometric methods to analyze temporal citation patterns between SIG and CHI publications and vice-versa to investigate transitions and paradigm shifts in HCI, as a distinct sub-discipline of computer science, within the ACM Digital Library. Guha et al. [122, p. 141] state that the main contribution is the identification *"of at least three significant paradigm changes in the field of computer science since its inception in the post-World War II period."*

The 1980s are characterized by a paradigm change from algorithms towards the recognition and introduction of human factors into computer science. The second paradigm shift occurred in the late 1990s, through the proliferation of personal computers and graphical user interfaces. The third paradigm shift is attributed to the early 2000s, which the advent of social media. As one of the assumptions of this dissertation is an intensification in SF-related research publications in the recent years, this study is relevant as it presents a potential method to classify changing patterns and trends in a computer science repository over time using bibliometric methods.

However, the by far closest state-of-the-art identified is a set of papers by Levin [182] and Levin and De Filippo [183] on the presence of twenty science SF films in scientific publications, respective journals, as listed in the Clarivate Analytics Web of Science. In prior referred papers, a two-stage search and retrieval process, along with a qualitative coding, is utilized by the authors.

The results of that study showed that seminal SF movie 2001: A SPACE ODYSSEY [166] was referenced the most frequent, followed by AVATAR [58], JURASSIC PARK [307], PLANET OF THE APES [285] and METROPOLIS [174]. More interestingly, Levin and De Filippo [182] present a content analysis and coding categories for future studies, which are outlined in Section 3.2.6.

3.1.7 Summary of the Related Work

In summary, the provided review on SFMS and computer science research provides a diversity of accounts of the intersection of HCI and SF from a multitude of perspectives.

Edited books draw analogies between both fields, through interview accounts and philosophical inquiries; qualitative interview research indicates a collaboration between scientists and movie-makers benefiting both domains, academia and entertainment alike. Furthermore, studies have shown how to use SFMS for inspiration in HCI research and computer science education – indicating in the latter case both, the detrimental effects (due to a misrepresentation of scientific information in SFMS) as well as the beneficial aspects (such as fostering student creativity in science education).

Furthermore, SF has been identified as the antecedent of design fiction in HCI research and selected contributions provide guidance to measure and extrapolate trends, impact, and usage of SFMS in computer science publications in the past, present and future.

While the presented literature review in this section could certainly identify traces of the relationship of SF / SFMS and HCI / computer science research, it also found an absence of studies on the contextual usage and presence of SF and SFMS in computing research communication. This dissertation endeavours to fill that academic void herein.

3.2 Methodological Background

3.2.1 Research Tools and Software

In this subsection, the main software packages, such as document preparation, data analysis and presentation tools, utilized for the purposes of this study, are briefly outlined.

Atlas.ti: Atlas.ti 8 [116] is a computer-assisted qualitative data analysis software for the assessment of large bodies of text and other data. In this study, Atlas.ti is the software of choice to search, explore and qualitatively code the dataset in this dissertation.

Among others, Atlas.ti 8 provides advanced analytic features, such as automatic-, Boolean-, semantic-, and proximity-based search and retrieval functions. The software suite allows as well a guided coding- and proximity analysis of coded data and text segments and is also compatible with Microsoft Excel and IBM SPSS Statistics.

In addition to the contextual coding and analysis of the SF referrals, Atlas.ti is used to calculate term-frequency patterns and word co-occurrences of the retrieved Candidate Set 4 (C_4).

Microsoft Excel: Microsoft Excel provides advanced table and query functions (pivot tables, complex data queries) and data visualizations (charts, diagrams, heat maps) and is used to calculate descriptive measures of both, the metadata of $C_{4\text{ before / after facets}}$ and the IRR / qualitative coding of $C_{4\text{ 125 / 500}}$. In addition the data-visualization features of Microsoft Excel are utilized to present results in section 5.

IBM SPSS Statistics: IBM Statistical Package for the Social Sciences (SPSS) [72] version 22 is a software package which allows advanced statistical analysis of large numerical datasets. SPSS is used to calculate the IRR coefficients for cohen's κ, respectively, Krippendorff's α of two interpretative variables in the inter-rater set ($C_{4\ (125)}$).

Google Suite: The Google Suite [118] provides important collaboration tools, including Google Drive, which is used to store and share the retrieved publications with the second Rater. In addition, Google Docs and Google Sheets are used to collaborate on the coding of the inter-rater set via shared spreadsheets as part of the assessment of the $C_{4\ (125)}$.

Overleaf: Overleaf [294] is a cloud-based LaTeXtypesetting solution which is used to produce this dissertation.

3.2.2 Metadata versus Full-text Search and 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 with regards to the presented queries and retrieved records in this section.

In contrasting metadata and full-text searches, Beall [34] outlines a variety of disadvantages of full-text searches, which can range from an ineffectiveness in differentiating homonyms (e.g. desert, bow or box) of the search terms as well as the failure to recognize abbreviations and acronyms (e.g. "science fiction" and "SF", "sci-fi", or "scifi"). In total, Beall [34, p. 439] lists 25 disadvantages of full-text search and retrievals and identifies that *"the biggest and most pervasive weakness of full-text searching is the synonym problem."*

On the other side, Salton and Harman's [280] article provides a similar assortment of drawbacks of metadata-based search and retrieval queries in digital collections. Among common problems in these are, for instance, the indexing qualification and individual expertise of those which generate the metadata of the records in the first place. For example, computer scientists regularly provide keywords and index terms when they submit an article for peer-review and publications. Are these authors, clearly subject matter experts in their own field, preferable to trained indexers in creating that metadata? Salton and Haman [280, p. 861] provide additional disadvantages of metadata indexed collections:

> *"Retrieval failures may be due to the analysis and indexing policy, such as the manual or automatic assignment of too many, or too few, or of a number of incorrect content indicators; or to what parts of a document are used to create the index (i.e. the title only, the first paragraph, or the full document). Alternatively, retrieval failures could be due to the search strategy used or to problems arising during user-system interaction. The use of natural language (automatic) indexing systems eases some of the restrictions inherent in a controlled indexing language in that it creates many diverse avenues to obtain access to the stored information. On the other hand, new problems can be introduced by ambiguous or nonstandard uses of the vocabulary."*

It seems clear that both approaches stand in diametrical opposition to each other and research 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.

For example, Lin's [187] study of whether specific metadata searches (in the title, abstract or keyword fields) or full-text searches do generate more relevant results (in the context of the U.S. National Library of Medicine (NLM) premier bibliographic database MEDLINE, which contains more than 24 million references to journal articles in life sciences) shows mixed results.

In the findings, Lin states that full-text searches provide indeed more effective results in comparison to metadata-based retrievals. However, Lin clarifies that full-text retrieval only outperforms metadata retrieval in the case of the usage of so-called full-text "spans", which are paragraphs within the full-text. Lin [187, p. 8] summarizes that:

> *"[...] whereas simply treating entire articles as indexing units yields mixed results, span retrieval consistently outperforms abstract retrieval. Combining span- and article- level evidence yields the highest effectiveness across a range of experimental conditions."*

Hemminger, Saelim, Sullivan and Vision's [132, p. 2341] analysis of a similar comparison of both approaches for selected journals in the MEDLINE database showed that:

> *"[...] significantly more articles were discovered via full-text searching; however, the precision of full-text searching also is significantly lower than that of metadata searching."*

Hemminger et al. elaborate that the frequency of the search term within the full-text of a record does statistically indicate a higher usefulness or relevance. Furthermore, through the usage of a search-term, frequency-based relevance ranking of the records, the authors were able to show that full-searches can be of a similar or even better quality than metadata-based searches, suggesting that [132, p. 2341]: "full-text searching alone may be sufficient, and that metadata searching as a surrogate is not necessary.". Furthermore, a full transition to full-text searches as the new standard [132, p. 2350]:

> *"[...] could be accomplished by using certain features of the full-text article, such as number of hits of the search string or whether the search string is found in the metadata (i.e., our current metadata search) as filters that allow us to increase the precision of our results."*

In yet another study [343] comparing full-text and metadata searching in the case of the University of North Texas Scholarly Works repository, results seem to indicate that metadata-based search and retrieval tasks have advantages over full-text searches. According to Waugh, Tarver, Phillips and Alemneh [343, p. 3]:

> *"[...] many search queries had overlapping results in both the metadata and full-text, a number of item discoveries occurred only through metadata values or the combination of metadata and full-text. This suggests that creating local records does support item discovery and retrieval. Further research may offer additional information about where best to concentrate efforts, or the role of other value-added services that make use of metadata (e.g., faceted browsing) and that would not be possible with full-text searching alone."*

3.2.3 Repository Search Limitations

The brief review of studies in Section 3.2.2 illustrates a trade-off between full-text and metadata-based search and retrieval tasks, or 'precision' and 'recall' of the of the retrieved records. While a combination of both approaches is suggested [132, 187], shortcomings and idiosyncrasies in the search interfaces of the digital collections and repositories in this study render hybrid searches ineffective and therefore indicate limitations of the proposed methodology:

To begin with, the ACM and the IEEE *Xplore* Digital Libraries do essentially provide metadata and full-text searches. Hence, both repositories do not provide any span-level search and retrieval of records. In other words, it is currently not possible to search full-text within specific fields of a record in either of the databases.

Furthermore, search parameters and available Boolean operators amid the search interfaces in the ACM and IEEE *Xplore* Digital Libraries differ. For instance, the ACM DL permits unlimited search terms or phrases per retrieval query, while IEEE *Xplore* limits each search to a maximum of 15 search terms or phrases.

In addition, the IEEE *Xplore* DL advanced search interface does afford special operators, such as the ONEAR or NEAR parameters. IEEE does as well disclose the basic ranking algorithm [135] used to order the search results and indicates the usage of stemming. In contrast, the ACM Digital Library falls short in providing any of these interface affordances or background information with regards to searching, retrieving or ranking of records. Moreover, the ACM Digital Library does not permit searches within a search (so-called searches within a set), while such functionaries are provided in the IEEE *Xplore* interface.

Last but not least, arXiv [186], as the third potential candidate for a potential collection, provides the least affordances for powerful and efficient searches, in contrast to the ACM and IEEE Digital libraries. Examples of the limitations of the arXiv search interface are the restriction of the maximum field operators per retrieval query (three), a complete absence of any metadata export of the retrieved records as well as the lack of the ability to sort or save search results. As arXiv yields as well marginal results for SF (see beginning of this section), comparative searches in arXiv are not further pursued in the following section, which introduces comparative searches in the ACM and IEEE *Xplore* Digital Libraries, in the full-text and metadata scenario.

3.2.4 Prospective Coding Categories

This section introduces concisely 10 coding schemes, categories, and classifications located in the intersection of SF with real-world science, specifically computer science. In Section 3.2.5, 4 studies[9] [221, 222, 352, 151] are presented, which explicitly aim to classify the type of research paper as part of a review of HRI and HCI research.

In Section 3.2.6, half a dozen references are discussed, which correlate SF / SFMS and HCI / Computer Science research, ranging from a focus on the contextual usage of SF film in reference to the advancement of technology over time [183, 287, 177], to the SF–interface design [298] and SF–HCI relationship [199].

[9]Three of the four presented studies are in the context of SF and computer science research.

The presented variables, coding categories, classifications and taxonomies serve as guidelines to derive final coding categories in this dissertation, as well as a comparison of existing coding frameworks currently in use and available.

3.2.5 Type of Research Paper

(1) Mubin et al. (var 1): As a result of a scientometric analysis of the proceedings of three years of the Human-Agent Interaction (HAI) conference series, Mubin, Manalo, Ahmad and Obaid [221, p. 46] delineate 4 themes of HRI-focused research papers:

i) **Empirical/user studies:** Refers to papers with a focus on the involvement of human participants (quantitative or qualitative), where human response, perception or opinion plays a key role.

ii) **Theoretical models**: Refers to papers, where models or frameworks of Human-Agent Interaction are the main focus, such as mathematical models, which describe human-robot interaction.

iii) **Experimental methods:** Refers to papers which focus on Human-Agent Interaction, but do not involve a user (in contrast to empirical/user studies), while still presenting some some form of non-empirical data collection.

iv) **Technological advances:** Refers to papers which focus on Human-Agent Interaction in which a working system, functional prototype, or concept is presented as the main contribution of the paper with no user studies or evaluation mentioned.

(2) Mubin et al. (var 2): In another paper, part of the prior work of this dissertation [222], Mubin, Obaid, Wadibhasme and the author of this dissertation investigate the uses of 20 SF robots in the ACM Digital Library. Based on prior work by Mubin et al. [221], 4 (slightly different) types of research papers were defined in this more recent study:

i) **Empirical/user study based:** Refers to research papers, which focus on the gathering empirical data (qualitative or quantitative), typically in the relationship to a robotic context (technology, prototype, device, or envisionment).

ii) **Technological advancements:** Refers to research papers, which focus on a novel algorithm. interaction technique or artifact, typically in the context of HRI.

iii) **Theoretical framework or Model based:** Refers to research papers, which introduce new frameworks or models,

iv) **Philosophical or opinionated:** Refers to research papers, which present primarily a reflective or controversial stance on a contemporary HRI topic, with the aim of persuading the reader or provoking thought on an emerging topic, such ethical issues in human-robot relationships.

(3) Wobbrock and Kientz: With a stronger focus on HCI research, Wobbrock and Kientz [352, pp. 40-43] introduce seven types of HCI research papers, summarized below:

i) **Empirical research contributions:** Refers to scientific papers with a main focus on the gathering of new observational data of qualitative or quantitative nature, ranging from experiments, interviews, field research or ethnographic studies.

ii) **Artifact contributions:** Refers to scientific papers with a main focus on the creation of new artifacts due to an innovation or invention, along with the associated interfaces, interactions and usage contexts. Examples of artifact contributions include, but are not limited, design propositions, physical prototypes, hardware tool kits and design envisionments.

iii) **Methodological contributions:** Refers to scientific papers with a main focus on the contribution of a new instrument to measure a phenomenon. Similarly, these type of contributions can also validate or extended an already existing method and usually explain in a pre- or descriptive fashion *how to measure a phenomenon*. Examples of this category range from the introduction of novel research methods, such as questionnaires or scales, with a focus on the reliability, utility and reproducibility of the method, instead of a focus on the actual results (in contrast to empirical research contributions).

iv) **Theoretical contributions:** Refers to scientific papers with a main focus on the contribution of a new conceptual framework or novel description or explanation of a phenomena. Theoretical contributions provide a non-empirical, analytical explanation of *why things work the way they do*. Examples of this category range from quantitative or conceptual models to the definition of new design spaces.

v) **Dataset contributions:** Refers to scientific papers with a main focus on the contribution of a raw or curated dataset, for instance comparative benchmarks of algorithms or research and test corpi of AI training sets.

vi) **Survey contributions:** Refers to scientific papers with a main focus on the presentation of a consolidated corpus of research, for instance a metadata review of an emerging research topic. Survey contributions are not to be confused with for example empirical surveys,such as questionnaire research with human participants. Instead, survey contributions aim to extrapolate the current-state-of-the-art of a knowledge domain in a concise fashion.

vii) **Opinion contributions:** Refers to scientific papers with a main focus on the contribution a philosophical argument, a critical view or a reflective assessment of a specific topic or emerging domain, commonly in essay form.

(4) Jordan et al.: In the first pilot study [151] on the occurrence and utilization of general SF in the CHI proceedings, a qualitative review of 83 research papers lead to five research themes, wherein SF and HCI interconnect:

i) **Theoretical:** Publications on design research, ideation, and design fiction.

ii) **New interactions:** Novel interfaces and interaction modes, body tracking, data visualization and navigation data (gestural, haptic, shape-changing).

iii) **Human-body modification/extension:** End-of-life technologies, on-body fabrication of artifacts, implants and in-body insertables.

iv) **Human-Robot Interaction and AI:** Human-robot or human-agent interaction and agency, artificial intelligence, natural language interfaces, and ethics.

v) **HCI and Computer vision:** Technology in conjunction with agency and power, for example autonomous cars and systems and ubiquitous computing.

3.2.6 Usage and Relationship of SF in the Paper Context

This section presents selected coding categories, relating to SF / SFMS and HCI / Computer Science research.

(5-7) Levin and De Filippo: Levin and De Filippo's study [183] investigates the contextual uses of 20 SF films in 93 publications retrieved in the Clarivate Analytics Web of Science[10].

The study provides a multiplicity of variables and attributes useful for this dissertation, among those the (1) purpose or contextual usage of the SF film reference, (2) quantitative characteristics associated to the referral within the publication (e.g. location of the SF film reference in the text) and (3) four motives or reasons why a SF film reference is used in a research paper. All three variables and their respective attributes are briefly outlined below:

(5) Purpose/contextual usage of the film reference:

i) **Educational instrument:** Refers to the use of a SF film in a formal educational context, both as part of an educational strategy and as a resource in itself.

ii) **Dissemination, opinion formation:** Refers to the papers in which a SF film reference is used to disseminate an idea, to form an opinion or to convince the reader in a wider communication context, not belonging to formal education.

iii) **Predictive elements:** Refers to a reference to a SF film to show either, (i) elements predicting scientific developments that actually occurred after the release of the SF film, or (ii) that still have to occur.

iv) **As an example of a process or a concept:** Refers to a SF film reference to exemplify or to stress something that is being explained in the paper.

[10] At the time of the publication of the study in 2014, the Clarivate Analytics Web of Science was called the Institute for Scientific Information (ISI) Web of Science.

v) **Study subject:** Refers to a SF film reference are part of the data that the paper presents as a study subject.

vi) **In support of science:** Refers to a SF film reference to highlight a positive aspect of scientific development, concerning the film itself or the paper argument.

vii) **Negative element:** Refers to a SF film reference to highlight a negative aspect of scientific development, concerning the film itself or the paper argument.

(6) Quantitative characteristics:

i) **Location:** Codes the location of the SF referral in the text of the document (e.g. Title, Abstract, Keywords, Introduction, Body, Conclusions, Bibliography, Other).

ii) **Frequency:** Codes the frequency of the SF film reference in the document (e.g. 1, 2-5, 6-10, over 10).

iii) **References:** Codes the referral to other SF films in the document under review (yes, no).

iv) **Origin of mention:** Codes the source of the SF film referral the film (directly from the author or a referred/other source).

v) **Formal citation:** Codes if the SF film reference is informally mentioned in the text or formally cited (e.g. yes, no).

(7) Motives of referral:

i) **SF films as study object:** Refers to the usage of SF films in scientific publications with the motive to study the film, or aspects of the film, itself.

ii) **Analysis of the film medium:** Refers to the usage of SF films with the motive to reflect on the film's presentation, such as the analysis of the film medium itself, or the format the film is presented to the public.

iii) **Relationship between the SF film and the public:** Refers to the usage of SF films with the motive to study the way cinema depicts or foresees reality or presents arguments in favor or against scientific and technological development.

iv) **Depict a specific technological advancement:** Refers to the usage of SF films with the motive to present the reader a specific scientific development, such as an emerging or soon-to-be device, interface, technology or future.

(8) Schmitz: Schmitz' [287] study uses a temporal classification to review the as depicted HCI in a selected, very small set of SF movies ($\leq$5 films), at the time of their release. The 4-stage, temporal classification is very simple and solely based selected interface examples from SF films (e.g. the video-telephone in METROPOLIS [174] from 1927), and the relationship to the state-of-the-art of computer science research (or lack thereof) in the last 100 years.

The categories are as following: i) SF Films pre-computer Interaction; ii) SF Films depicting a simple technology adaption; iii)SF Films depicting an advanced technology with well-known interaction and iv), SF Films depicting unrealized HCI visions.

(9) Larson: In yet another study, Larson [177] presents ten categories or eras which capture key features of computing technology and HCI from the 1960s onwards. Among those are for example the *internet era* or the*mobile computing era*. Larson cross-tabulates these eras with the portrayal of technology in SFMS originating in the same time period.

For example, Larson [177, p. 295] defines the categories of SFMS which portray non-existent technology as film featuring:

> *"[..] computing technology that does not yet exist because it is currently not possible or has not been pursued. Holographic computer displays, for example, fit into this category, as do depictions of high-functioning artificial intelligence. Humanoid robots are also in this category. Era: unavailable today; possibly available in the future."*

While many of the other categories seem outdated, for instance *computer mainframes* or *CRT screen technology*, Larson's [177] study is of importance as it analyzes the depiction of technology (specifically computer technology) in SF films from an chronological, longitudinal perspective.

(10) Shedroff and Noessel: As one more example of a study to derive a categorization and coding scheme, Shedroff and Noessel [298, p. 7] suggest four categories where SF influences design in their review of more than 100 SFMS:

i) **Inspiration:** Refers to a direct influence in the form of science fiction media influencing the development of real product interfaces.

ii) **Expectations:** Refers to interfaces to technology in science fiction became expected solutions to real products.

iii) **Social context:** Refers to technological interfaces depicting social interactions, particularly with a variety of anthropomorphized imagery, form, sound, and behavior.

iv) **New paradigms:** Refer to science fiction as an opportunity to invent and establish new paradigms in the interface, for both new behaviors and new forms.

In addition, Shedroff and Noessel [299] present 10 thematic categories in their study of SF interfaces in SFMS, among those visual, sonic and brain interfaces – providing a categorization scheme for the distinct area of interface design.

(10) Marcus As one last source, Marcus [199] presents a taxonomy of HCI components and SF literature, see Table 3.1 and Marcus [199, p. 6]. Marcus suggests herein a cross-combination of the HCI and SF components for a future analysis of the relationship of both domains, thus explicating distinct topical areas in either field – the taxonomy can serve as a guideline in the coding process of this dissertation.

Table 3.1: Taxonomies of HCI and SF

HCI components	SF literature components
Hardware	Genre
Software	Story narrative
User community	Technology
Subject-matter content	Society
Metaphors	Temporal view
Mental Models	Culture
Navigation	Hardware
Interaction	Software
Appearance	Medium

3.2.7 SF–Computer Science / HCI Coding Schemes, Classifications and Taxonomies

In summary, 10 classification and coding approaches to investigate SF / SFMS and computer science / HCI research are available, as summarized in this section.

Regardless if one aims to classify the publication type 4.4.3 or the contextual uses of a SF referral 3.2.6, a review of the presented coding schemes indicates that boundaries are fluid and classifications are highly subjective in nature and prone to qualitative interpretation.
Wobbrock and Kientz [352] specifically state that the contribution types might overlap within the individual research paper. For instance, an empirical contribution might come hand in hand with an artifact contribution. Similarly, a dataset contribution can be associated with a methodological contribution, i.p. a survey instrument which was used to gather said dataset.

Furthermore, a second commonality identified across all presented classification schemes, from categorizing specific types of research contributions in HRI [221, 222, p. 46], HCI research paper types [352], HCI / SF concepts [199], to uses of SF films [183], is that the SF–computer science / HCI relationship is multi-layered and varies in granularity of analysis. For example, Shedroff and Noessel [298] focus solely on SF interfaces, whereas Marcus [199] provides a holistic approach of the SF-HCI relationship by presenting a general taxoninmy. Similarly, Levin and De Filippo [182] focus on SF film not limited to computer science research, whereas for instance Larson [177] relates SF film technologies to real-world developments over the range of decades (1960-2000s).

It is obvious that no single method or coding scheme is appropriate or valid for the context at hand. Therefore, based on this review and the prior pilot studies [148, 151, 222], a coding scheme for the study in this dissertation is based on this review and emerges from a qualitative review of the retrieved papers in $C_{4\ 125}$ accordingly.

3.2.8 Inter-rater Reliability

The establishment of reliability of any coding scheme, especially when subjective, interpretative variables and attributes are utilized, is of critical importance in any qualitative study or content analysis. In order to measure a basic agreement of the categorical variables, a variety of approaches exist in the field of qualitative research.

Two of these, Cohen's κ and Krippendorff's α statistics seem suitable for this dissertation in addition to being two of the most popular, established and widely used methods at hand.

Cohen's κ Cohen's κ statistic [98], introduced more than 50 years ago [65] as a co-efficient to measure agreement on nominal scales for multivariate, categorical data. Cohen later on published a weighted κ [66] statistic for ratio-based scales and the measure has since become a staple method in social science research and qualitative data-analysis. Despite its age, the κ statistic is widely used, reviewed, adapted and criticized up to the present time (see e.g. [334, 26]).

Generally speaking, Cohen's κ measures agreement over agreement by chance, between not more than two[11] raters raters. κ ranges from 0 to 1 with $\kappa = 0.0$ indicating a poor agreement and $\kappa = 1.0$ indicating perfect agreement. Antoine, Villaneau, and Lefeuvre [552][17] state that prior research is inconclusive with regards to the interpretation and magnitude of cohen's κ:

> *"Carletta [59] advocates 0.8 to be a threshold of good reliability, while a value between 0.67 and 0.8 is considered sufficient to allow tentative conclusion to be drawn. On the opposite, Krippendorff [164] claims that this 0.67 cutoff is a pretty low standard while Neuendorf [231] supports an even more restrictive interpretation. Thus, the definition of relevant levels of reliability remains an open problem."*

Rusself Bernard [36, p. 260] specifies further that:

> *"Most researchers today would accept $\kappa = 0.80$ or better as strong agreement or high reliability and $\kappa = 0.70$ - 0.79 as adequate, but these standards are ad hoc and are still evolving."*

Krippendorff's α Krippendorff's α [163, 164, 98, 165] is a measure used in content analysis to calculate the ratio of disagreement (in contrast to the calculation of agreement in cohen's κ) on a set of units, applicable by any number of raters, for any known scale (nominal, ordinal, interval, ratio, etc.). Krippendorff's α integrates several specialized agreement measures, among those Fleiss's κ

[11] See e.g. Fleiss [110] κ statistic as a means to calculate IRR between more than two raters.

[110] or Scott's π [292]. With regards to Krippendorff's α coefficient, Krippendorff [164, p. 241] initially stated that:

> *"[...] it is customary to require $\alpha \geq .800$. Where tentative conclusions are still acceptable, $\alpha \geq .667$ is the lowest conceivable limit."*

According to Artstein and Poesio's [18, p. 576] survey article, however, Krippendorff rephrased his initial magnitude interpretation of α later on:

> *"However, the description of the 0.67 boundary in Krippendorff was actually 'highly tentative and cautious,' and in later work Krippendorff clearly considers 0.8 the absolute minimum value of α to accept for any serious purpose: "Even a cutoff point of $\alpha = .800$ [...] is a pretty low standard".*

3.2.9 Magnitudes and Interpretation of Cohen's κ and Krippendorff's α

As indicated in the prior sections, the pros, cons and interpretation ranges of Cohen's κ and Krippendorff's α are an object of continuous debate in social science research [18, 164] and extend the scope of this dissertation. In summary, Table 3.2 shows the initial interpretation and magnitude ranges for cohen's κ (e.g. according to Viera [334, p. 362] and Landis and Koch [173, p. 165]).

Table 3.2: κ and α ranges and interpretation

Interpretation of κ	
κ	Interpretation
< 0	Less than chance agreement
0.01-0.20	Slight agreement
0.21-0.40	Fair agreement
0.61-0.80	Substantial agreement
0.81-0.99	Almost perfect agreement

Interpretation of α	
α	Interpretation
≥ 0.667	Tentative conclusions acceptable
≥ 0.8	Good reliability
1.00	Perfect agreement

These suggested ranges and interpretations for κ are found in many other studies (e.g. [51]. Table 3.2 also shows the suggested magnitude ranges for Krippendorff's alpha [164, p. 241] (also cited by Zwischenberger [364, p. 113]. In this dissertation, both agreement coefficients will be calculated and presented side by side in Section 5.4.

3.2.10 Summary of the Methodological Background

This section presented the methodological background of this dissertation. First, the research tools were introduced alongside a discussion of the differences of metadata and full-text search retrievals. In addition, particular focus was given on the introduction of the possible coding categories for the analysis of $C_{4\ (500)}$. The methodological background concluded with a short introduction of two commonplace inter-rater reliability measures in the field of content analysis.

CHAPTER 4
METHODOLOGY

In this chapter, the methodology for a comprehensive investigation of the occurrence and contextual usage of SF / SFMS in computer science publications in this dissertation is outlined. The methodology is inspired by Levin and De Filippo's [183] study and has since been suggested in a conference paper in 2016 [149] and was in addition successfully applied in three pilot studies [148, 151, 222].

Section 4.1 provides a concise overview of the research process and method. Next, Section 4.2 introduces the sampling method, while Section 4.3 describes the Inter-rater Reliability (IRR) approach between two raters. Lastly, Section 4.4 defines the final coding categories for this dissertation.

4.1 Method Overview

Nomenclature: In the remainder of this document, the following conventions will be used:

i) $\mathbf{C_{4\ (2784)}}$: Refers to candidate set 4 before the search facets were applied. This set contains of 2784 records.

ii) $\mathbf{C_{4\ (1647)}}$: Refers to candidate set 4 after the search facets were applied. This set contains of 1647 records.

iii) $\mathbf{C_{4\ (500)}}$: Refers to a random subset of 500 records, drawn from $C_{(4\ 1647)}$, for further qualitative analysis. This set includes $C_{4\ (125)}$.

iv) $\mathbf{C_{4\ (125)}}$: Refers to the inter-rater sample of 125 records, randomly drawn from $C_{4\ (500)}$, for the validation of the qualitative analysis and coding scheme[12].

Research Process: Figure 4.1 shows a simplified overview of the research process and method in this dissertation. The individual steps in Figure 4.1 will be sketched out in this section accordingly and serve as a guideline for the presentation and structure of the results Chapter 5.

Step 1 – Research Questions: The main three research question investigated are listed below[13]:

i) **RQ1:** What are the metadata characteristics of computer science publications, which reference science fiction?

ii) **RQ2:** What science fiction particulars co-occur in the context of computer science publications which reference science fiction?

[12] The IRR analysis was conducted before the main author proceeded to code the remaining 375 publications individually.

[13] The research questions are as well introduced in more detail in Section 2.5 on page 19.

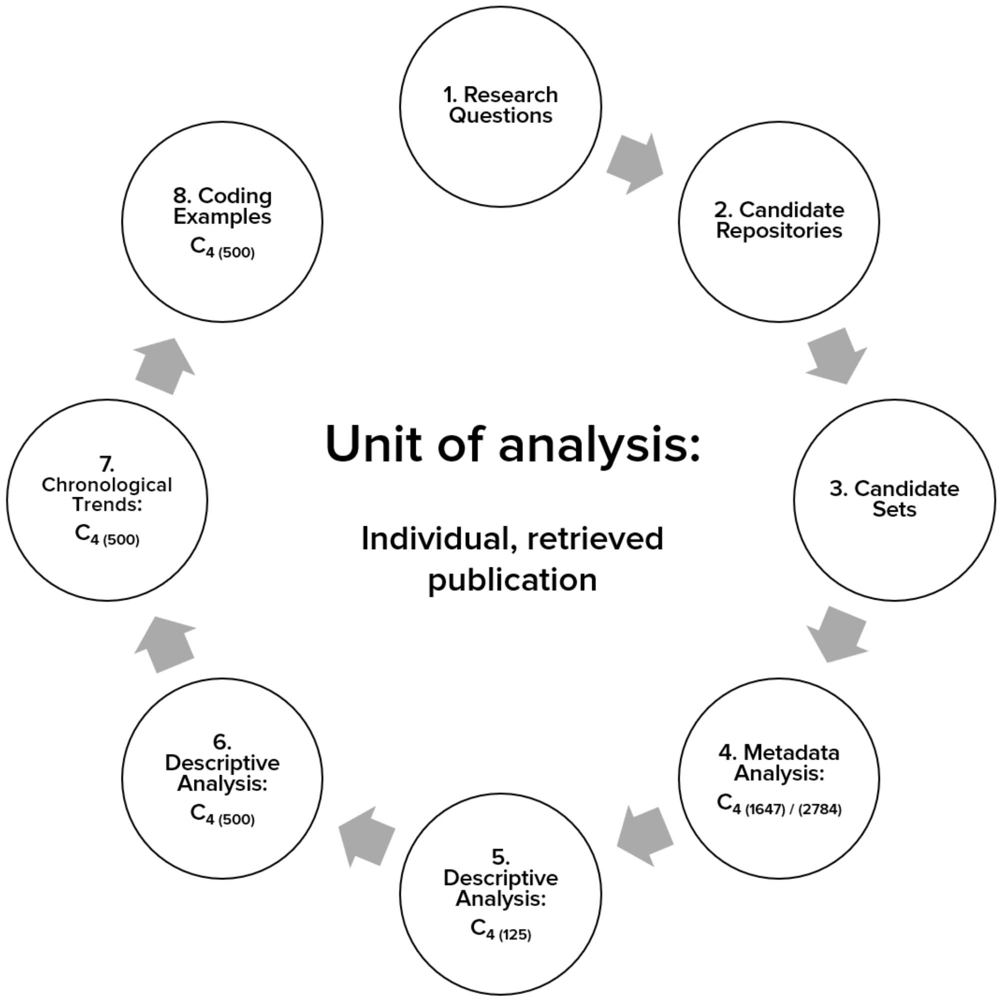


Figure 4.1: Research process

iii) **RQ3:** What is the purpose of references to science fiction, and science fiction particulars, which co-occur in the context of science fiction references, in computer science publications?

Step 2 – Candidate Repositories: In order to estimate the occurrence of SF / SFMS and its related concepts, initial exploratory searches for science fiction and term derivatives in selected computer science collections, such as the ACM Digital Library, the IEEE *Xplore* Digital Library, or arXiv are conducted.

These preliminary searches use generic SF terms, synonyms and utilize advanced search parameters (i.p. Boolean operators) the search interfaces of the respective repositories offer. The purpose of these searches is to assess the viability of a repository of choice, in addition to the assessment of the repository-specific search parameters and export functionalities, available.

After an initial comparative assessment of 16 retrieved queries from two databases – the ACM and IEEE *Xplore* Digital Libraries – four candidate sets are selected for further investigation.

Step 3 – Candidate Sets: In the third step, the four retrieved candidate sets are contrasted and further scrutinized in order to deduce a final candidate for analysis. Furthermore, a justification to proceed with a full-text search for "science ficiton" in the IEEE *Xplore* Digital Library – in the following abbreviated as C_4 – is presented.

Step 4 – Metadata Analysis: $C_{4\ (2784)}$ and $C_{4\ (1647)}$ In a fourth step, a descriptive analysis of $C_{4\ (2784)}$ and $C_{4\ (1647)}$ is conducted. This includes a metadata analysis (publication types, publication years) of $C_{4\ (2784)}$) and, after the application of repository-specific facets, of $C_{4\ (1647)}$. In addition, the publication keywords and indexing terms of $C_{4\ (2784)}$ and $C_{4\ (1647)}$ are calculated.

Step 5 – Descriptive Analysis: $C_{4\ (125)}$ Next, a random sample of n=500 publications – $C_{4\ (500)}$ – from $C_{4\ (1647)}$ is drawn. From these 500 records, $C_{4\ (125)}$ is drawn consisting of 125 records (25%), which are subjected to an inter-rater reliability (IRR) analysis of two interpretative variables (type or research paper, contextual referral of SF in the research paper). The IRR for both variables is calculated by cohen's κ and Krippendorff's α coefficients (see Section 3.2.8 for a background on calculating IRR).

Step 6 – Descriptive Analysis: $C_{4\ (500)}$ After the establishment of IRR, the remaining 375 records from $C_{4\ (500)}$ are coded. Results on the general makeup of the sample, e.g. the distribution of publication years, the makeup of different types of research papers as well as summaries of the frequencies of the SF particulars in $C_{4\ (500)}$ are presented.

Step 7 – Chronological Trends: $C_{4\ (500)}$ Building on the analysis in the prior step, this section of the analysis presents trends over time of specific variables found in $C_{4\ (500)}$.

Step 8 – Coding Examples: $C_{4\ (500)}$ The final step of the outlined method and subsequent presentation of results in Chapter 5 is a detailed, in-depth presentation of selected quotations and examples for each paper category and also investigates chronological patterns of SF references in $C_{4\ (500)}$.

4.2 Method Sampling

Figure 4.2 visualizes the principal sampling of the candidate set in the IEEE *Xplore* Digital Library.

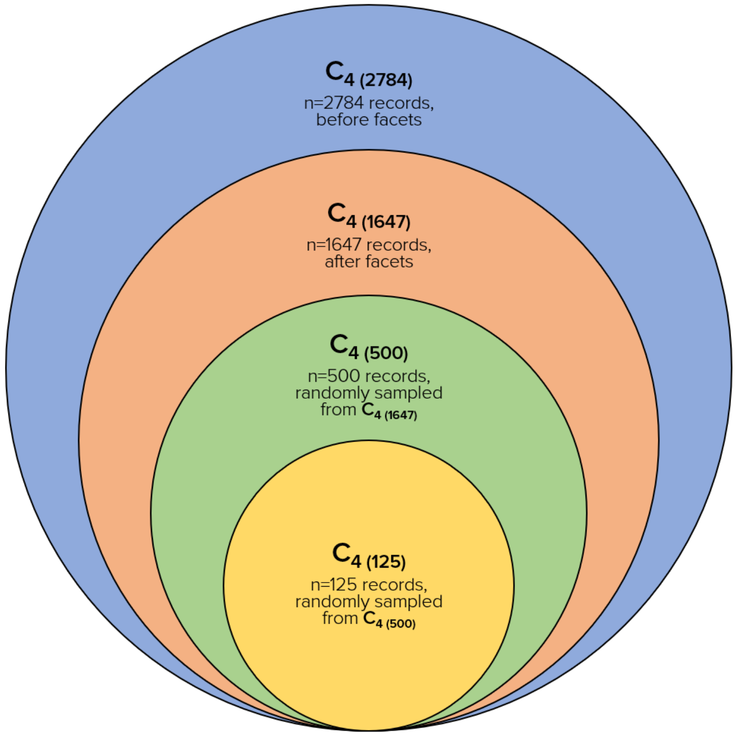


Figure 4.2: Principal sampling of the dataset

A full-text search for "science fiction" returns 2784 records – $C_{4\ (2784)}$ – in the IEEE *Xplore* Digital Library. After the application of facets, this set is reduced to 1647 records – $C_{4\ (1647)}$. This set is retrieved and descriptively analyzed in Section 5.3.

Next a random sample of n=500 records – $C_{4\ (500)}$ – is drawn from $C_{4\ (1647)}$. Finally, 125 randomly selected records – $C_{4\ (125)}$ – of $C_{4\ (500)}$ are subjected to an Inter-rater Reliability (IRR) evaluation of two interpretative variables (type of research contributions, contextual usage of the SF referral).

4.3 Inter-rater Reliability: $C_{4\ (125)}$

In the first step, the author (R1) randomly sampled $C_{4\ (125)}$, as part of the random sample from $C_{4\ (500)}$, through a random number generator [265] and proceeded to qualitatively review the publications for the variables listed in Section 4.4. After an independent coding by R1 of $C_{4\ (125)}$ for the two interpretative variables in this study – i) type of research contribution (according to Wobbrock and Kientz [352] and ii) the contextual usage of the SF referral (see Section 4.4) – an initial coding scheme was established and $C_{4\ (125)}$ made available to a second rater (R2).

Rater 2 is a design innovation researcher and practitioner with 15+ years of HCI experience. Rater 2 volunteered her time and expertise to rate $C_{4\ (125)}$ for no compensation or reimbursement.

In addition, Rater 2 is a colleague of the author and has been recruited in the past as collaborator for prior pilot studies [151, 222] and coding tasks .

Following a general introduction to the coding scheme by R1, R2 did code independent $C_{4\ (125)}$ using the coding rubric for the two interpretative variables and attributes provided by R1. Regular check-ins by R1 with R2 ensured that any questions or issues were addressed during the independent coding of $C_{4\ (125)}$ by R2.

After R2 did provide 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 $C_{(4\ 125)}$, one after R2 finished coding $C_{4\ (125)}$ by R1 served to resolve disagreements and finalize the final coding scheme, hence allowing R1 to proceed to code the remaining 375 records in $C_{4\ (500)}$.

4.4 Final Coding Categories: $C_{4\ (500)}$

The final coding categories for the qualitative review of $C_{4\ (500)}$ represent a deduction of applicable codes, variables and attributes, in context of the research questions this dissertation explores as well as the methodological background in Section 3.2.4. Each of the 10 variables is described in more detail in the following sections below.

4.4.1 Location of the SF Referral

Following Levin and de Filippo [183, 182], the variable location(s) of the SF referral(s) is coded into four attributes, which refer to the location of the SF referral in the text has the following attributes: i) **Title (T)**, ii) **Abstract (A)**, iii) **Body (B)**, iv) **Footnotes (F)** and v) **References (R)**. As multiple SF referrals might co-occur in the same publication, but in different parts of the document, this variable is of nominal nature and non-mutually exclusive.

While a more nuanced coding scheme for this variable would have been preferred (e.g. SF in the introduction, background, method, results or discussion), the sheer diversity of records retrieved in $C_{4\ (500)}$, extending from 'classical research contributions' to readers' and editors' letters, obituaries, presentation slides, interviews, columns, panel introductions and so on and forth, the structuring of the SF referral location into the introduced five categories represents a reasonable compromise applicable throughout $C_{4\ (500)}$.

4.4.2 Frequency of the SF Referral

The variable frequency of the SF referral counts the occurrences of the search term 'science fiction' in the publication under review. This variable is of ratio scale with a true zero. Furthermore, the variable is of integral nature (e.g. 1, 2, .., 10 SF referrals per publication).

4.4.3 Type of Research Paper

In order to judge which type of research contribution is under scrutiny, the primary – or main – contribution of the paper will be coded along 7 mutually exclusive categories following Wobbrock and Kientz [352, pp. 40-43]. This variable is of categorical nature, mutually exclusive and has below 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** (method application, method innovation, method adaption, 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**[14]**:** (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)

4.4.4 Contextual SF Referral

In order to classify the primary – or main – contextual usage[15] of the SF referral(s) in the publication(s) under review, a non-mutually exclusive variable called 'Contextual usage of the SF referral' with 8 attributes is coded.

These 8 attributes emerge from an inter-rater coding by 2 Raters of $C_{4\ (125)}$, randomly selected, publications and can be conceptually classified into three broader domains:

[14]This category has been added and is not listed as part of the original 7 categories from Wobbrock and Kientz [352, pp. 40-43]. 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, which are commonly found in opinion contributions.

[15]In cases where multiple SF referrals occur in a publication (Unit of Analysis), 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.

4.4.5 Contextual SF Particulars

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[16]:** (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)
5. **SF Devices, Technologies, Concepts, Ideas:** (e.g. TRICORDER, SMART DUST, CYBORGS)

Table 4.1 on page 63 presents the 10 final variables, along with a short description, the scale type they are measured on, the attribute per variable, data type, coding approach and mutual exclusivity.

4.5 Summary

This chapter introduced the underlying research methodology of this dissertation. It established first, the general steps in the research process, from the recap of the research questions and initial reduction of $C_{4\ (2784}$ to two subsets, $C_{4\ (500)}$ and $C_{4\ (125)}$, as well as the following steps in the subsequent content analysis.

In addition, the chapter also provided a rationale and overview of 10 variables — the final coding categories — for the analysis of $C_{4\ (500)}$.

[16]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 Books or Movie categories is chosen.

Table 4.1: Overview of variables, attributes, scales and data types

Variable	**Description**	**Scale Type**
SF_Freq	Frequency of the SF Referral(s)	Ratio
SF_Loc	Location of the SF Referral(s)	Nominal
Pub_Year	Publication Year	Interval
SF_Cont	Contextual Usage of the SF Referral	Nominal
Paper_Type	Type of Research Paper	Nominal
SF_Auth	SF Authors	Nominal
SF_Books	SF Books, Novels, Short Stories, Magazines	Nominal
SF_Vid	SF Movies or Shows	Nominal
SF_Tech	SF Devices, Technologies, Concepts	Nominal
SF_Char	SF Characters	Nominal

Variable	**Attributes**	**Data Type**
SF_Freq	1,2,3,...	Quantitative
SF_Loc	T,A,B,F,R	Qualitative
Pub_Year	...,1988, 1989,...	Quantitative
SF_Cont	...to describe SF concept...	Qualitative
Paper_Type	Artifact contribution, ...	Qualitative
SF_Auth	H.G. Wells	Qualitative
SF_Books	Neuromancer	Qualitative
SF_Vid	Alien, Fantastic Voyage	Qualitative
SF_Tech	Tricorder, Cyborgs, AI,...	Qualitative
SF_Char	Mr. Data, HAL 9000, etc	Qualitative

Variable	**Coding**	**Mutually Exclusive**
SF_Freq	In vivo counting by R1	Yes
SF_Loc	In vivo counting by R1	No
Pub_Year	In vivo counting by R1	Yes
SF_Cont	Inter-rater validation between R1 and R2	Yes
Paper_Type	Inter-rater validation between R1 and R2	Yes
SF_Auth	In vivo counting by R1	No
SF_Books	In vivo counting by R1	No
SF_Vid	In vivo counting by R1	No
SF_Tech	In vivo counting by R1	No
SF_Char	In vivo counting by R1	No

CHAPTER 5
RESULTS

This chapter reports on the main results of this study:

i) Section 5.1 on page 64 reports concisely on three potential computer science repositories (ACM DL, IEEE *Xplore* Digital Library, arXiv) and outlines selection criteria.

ii) Section 5.2 on page 65 presents the retrieval of four candidate sets – (C_1, C_2, C_3, C_4) – from the ACM Digital Library and the IEEE *Xplore* Digital Library, in a comparative view. The section concludes to to proceed with C_4, a full-text search for 'science fiction' in the IEEE *Xplore* Digital Library, for further analysis.

iii) Section 5.3 on page 74 provides essential, descriptive results of C_4 with a focus on a metadata analysis (publication types, years, venues, keywords and index terms), prior to the application of facets or any sort of sampling.

iv) Section 5.4 on page 82 describes the meta data characteristics (publication years, location of the SF referral), in addition to the results of the inter-rater reliability (IRR) coding between two raters, of n=125 ($C_{4\ (125)}$) randomly sampled records of C_4.

v) Section 5.5 on page 87 provides a contextual analysis of n=500 ($C_{4\ (500)}$) publications, randomly selected of C_4. This part of the analysis describes the publication years and types as well as the characteristics of SF referrals (location, contextual usages, types). Furthermore, the section provides an overview of the most frequent SF authors, SF writings, SF movies, SF characters and ideas, concepts, technologies, devices and interfaces, associated with the SF referrals in addition to chronological trends of specific SF referrals over time.

vi) Section 5.7 on page 106 provides a selection of more than 50 coding examples, via quotes, with a focus on the presentation of examples, which are representative of SF referrals in the respective paper types in $C_{4\ (500)}$.

5.1 Candidate Repositories

The main goal in this dissertation is the identification and contextual analysis of SF referrals in scientific publications with a focus computer science / HCI research. In order achieve said goal, an accessible repository with topic-relevant research must be identified first.

At the present time, a plethora of academic repositories and scientific collections of peer-reviewed research is available, among those Clarivate Analytic's Web of Science [12], Elsevier's ScienceDirect [94], Springer Link [229] and Google Scholar, [290]. In addition to the prior named comprehensive and more general databases and repositories, the ACM and the IEEE *Xplore* Digital Libraries, as well as Cornell University's pre-print repository (arXiv), represent a narrower, but more specialized collections with an exclusive focus on computer science and/or STEM research.

For example, Clarivate Analytics Web of Science for instance, indexes around 90 million records, ranging from general STEM fields [13] (e.g. Physics, Mathematics), to Performative Arts (e.g. Poetry, Theater), as well as socio-economic disciplines (e.g. Business, Political Science). In contrast, the IEEE *Xplore* Digital Library indexes around 4.5 million records, with a narrower focus on electrical engineering and computer science.

Criteria for database selection: This selection of the three databases is based on the following three criteria: i) Potential relevance, impact, and significance of the database in computer science research; ii) Access and availability of the database through the University of Hawai'i at Mānoa library subscription; iii) Advice from the dissertation committee members in the selection of the database.

According to Google Scholar Metrics [290], the ACM Digital Library or IEEE *Xplore* index some of the highest impact conferences, journals and symposiums in the field of HCI. Among those are the CHI conference (h5-index, 86), the IEEE Transactions on Affective Computing (h5-index of 39), the ACM/IEEE International Conference on Human-robot Interaction (h5-index of 35) and the ACM Transactions on Computer-Human Interaction (TOCHI) (h5-index of 36).

Both, the IEEE *Xplore* and the ACM Digital Libraries are accessible through the University of Hawai'i Library system. The arXiv preprint archive is widely known as an important pre-print collection for journal articles in the fields of computer science and other STEM disciplines.

It is important to note that the ACM and IEEE *Xplore* Digital Libraries do both provide basic bibliometrics, e.g. citation counts, publication downloads and cross-references within their search interfaces, whereas arXiv does not.

5.2 Candidate Sets

Initially, multiple variations of dozens of metadata and/or full-text searches[17] in the ACM and IEEE *Xplore* Digital Libraries were conducted in order to assess the viability, quality and quantity of specific retrieval queries for a subsequent analysis.

arXiv as potential repository was ruled out early on as a potential repository due to the fact that query results for SF were of marginal quantity, especially in comparison to the retrievals founds in the ACM and IEEE *Xplore* Digital Libraries. For example, a simple full-text search over all fields of the records in arXiv returns 57 records as of April 2019[18]. Therefore, searches for SF focused on the ACM and IEEE *Xplore* Digital Libraries.

[17] Searches were conducted in Winter 2017.
[18] See also here: arXiv search for "science fiction" over all fields.

5.2.1 Initial Queries

This section presents 16 of these comparative search queries (8 queries in each, the ACM and the IEEE *Xplore* Digital Libraries for similar queries) accordingly. These initial searches – through the usage of synonyms and the instantiating of different search fields, Boolean operators, synonyms of SF and related concepts – increased in complexity and are listed below in conjunction with the query code and retrieved records:

i) **Title only:**

   (a) **ACM DL:** *(acmdlTitle:(science AND fiction))*: **73 records**

   (b) **IEEE *Xplore* DL:** *"Document Title":"science" AND "fiction"*: **57 records**

ii) **Title OR Abstract (var 1):**

   (a) **ACM DL:** *(acmdlTitle:(science AND fiction)) OR (recordAbstract:(science AND fiction))*: **461 records**

   (b) **IEEE *Xplore* DL:** *"Document Title":"science" AND "fiction" OR "Abstract":"science" AND "fiction"*: **289 records**

iii) **Title OR Abstract (var 2):**

   (a) **ACM DL:** *(acmdlTitle:(science AND fiction)) OR (recordAbstract:(science AND fiction) 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"))*: **554 records**

   (b) **IEEE *Xplore* DL:** *Document Title:"science" AND "fiction" OR "Abstract":"science" AND "fiction" OR "Abstract":"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"*: **319 records**

iv) **Title OR Abstract OR Keywords (var 1):**

   (a) **ACM DL:** *(acmdlTitle:(science AND fiction)) OR (recordAbstract:(science AND fiction)) OR (keywords.author.keyword:(science AND fiction))*: **471 records**

   (b) **IEEE *Xplore* DL – Title OR Abstract OR Keywords:** *Document Title:"science" AND "fiction" OR "Abstract":"science" AND "fiction" OR "Author Keywords":"science" AND "fiction"*: **301 records**

v) **Title OR Abstract OR Keywords (var 2):**

   (a) **ACM DL:** *acmdlTitle:(science fiction) OR recordAbstract:(science fiction) OR keywords.author.keyword:(science fiction)*: **392 records**

(b) **IEEE *Xplore* DL:** *"Document Title":"science fiction" OR "Abstract":"science fiction" OR "Author Keywords":"science fiction" "Author Keywords":"science fiction"*: **286 records**

vi) **Title OR Abstract OR Keywords (var 3):**

(a) **ACM DL:** *acmdlTitle:(science AND fiction)) OR (recordAbstract:(science AND fiction)) OR (keywords.author.keyword:(science AND fiction)) OR "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"*: **636 records**

(b) **IEEE *Xplore* DL:** *(Document Title:"science" AND "fiction" OR "Abstract":"science" AND "fiction" OR "Author Keywords":"science" AND "fiction" OR "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"")*: **353 records**

vii) **Full metadata / No Full-text:**

(a) **ACM DL:** *(("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") AND content.ftsec:(-"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"))*: **378 records**

(b) **IEEE *Xplore* DL:** *"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"*: **337 records**

viii) **Full-text only:**

(a) **ACM DL:** *content.ftsec:"science fiction"* : **2712 records**

(b) **IEEE *Xplore* DL:** *"science fiction"*: **2784 records**

Figure 5.1 shows the initial retrieval results of these 16 searches.

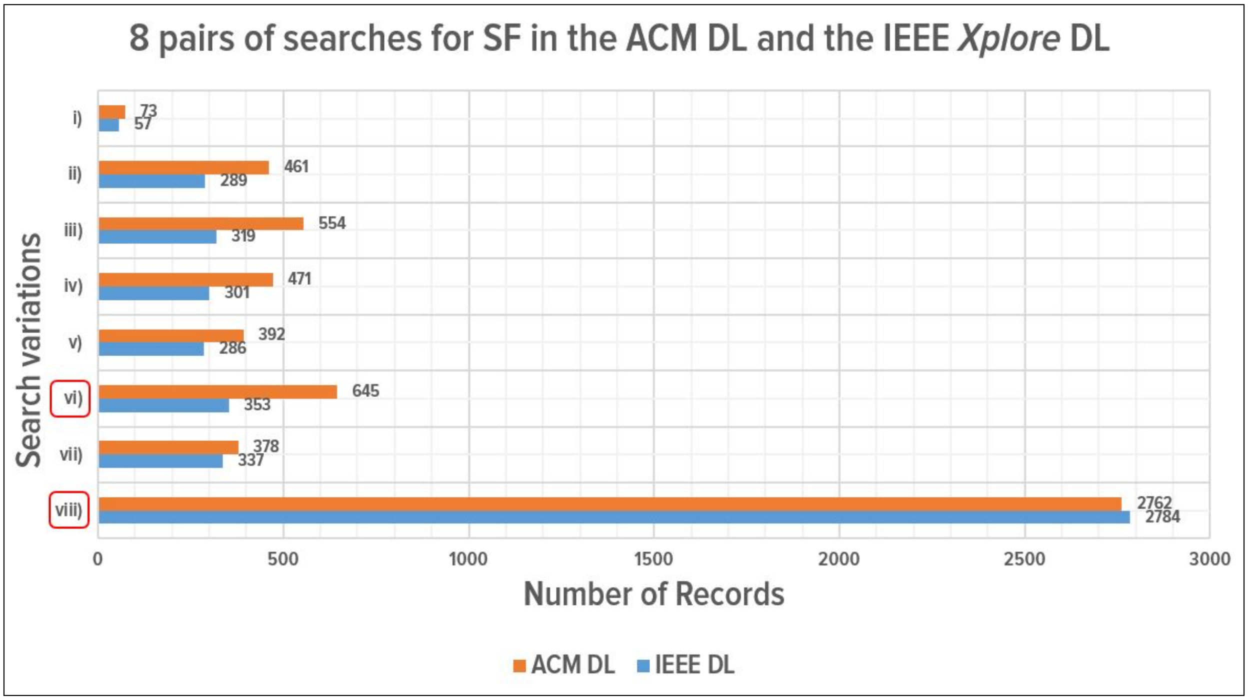


Figure 5.1: Searches and retrievals for SF in the ACM and IEEE *Xplore* Digital Libraries

The reference set size of the ACM DL, at the time of the queries in December 2017, consisted of 2,716,335 records (ACM Guide to Computing Literature), respectively 480,230 for the ACM Full-text collection. Retrievals vi) and viii) (indicated with a red rectangle) are considered as candidate sets for further assessment in the next section.

5.2.2 Final Candidate Sets

Based on an analysis of the amount of retrieved records of the prior 16 searches in the ACM Digital and IEEE *Xplore* Digital Libraries, queries vi) and viii) in Figure 5.1 are selected for a further investigation:

Query vi) returns the most records for a metadata-based search (645 records in the ACM Digital Library, 353 records in the IEEE *Xplore* Digital Library).

Query viii) returns the largest amount of records overall (2762 records in the ACM Digital Library, 2784 records in the IEEE *Xplore* Digital Library). Figure 5.2 shows these final four search queries in more detail. In the following, query vi) and query viii) will be briefly analyzed.

Query iv): Metadata-based search: The metadata-based search and retrieval query vi) (Figure 5.2) utilizes a logical 'Science' *AND* 'Fiction' search pair over the title, abstract and keyword fields of the records. In addition, the query retrieves a variation of SF synonyms, among those "sci-fi" as well SF specifics, such as "sf film" or "sf movie" over all metadata fields of the records. The query is

	vi) Metadata	viii) Full-text
ACM DL DIGITAL LIBRARY	(acmdlTitle:(science AND fiction)) OR (recordAbstract:(science AND fiction)) OR (keywords.author.keyword:(science AND fiction)) OR "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"	content.ftsec:("science fiction")
IEEE Xplore® Digital Library	(Document Title:"science" AND "fiction" OR "Abstract":"science" AND "fiction" OR "Author Keywords":"science" AND "fiction" OR "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")	("science fiction")

Figure 5.2: 2*2 search and retrieval approach

furthermore applying logical *OR* operators for the title, abstract and keyword component, as well as for all synonyms and term variations of SF over all record fields.

Query viii:) Full-text based search: The full-text search and retrieval query viii) (Figure 5.2) utilizes an exact phrase query ("science ficiton") over the full-text, including all metadata fields, of all records listed in the database.

Table 5.1 on page 70 presents all four candidate sets in a concise overview. All searches were conducted in December 2017.

Table 5.1: Overview of candidate sets

	Collection/Parameters	**Records retrieved**
Set 1: MD	ACM Guide	645
	ACM Full-Text	171
	ACM Guide – Periodicals, Proceedings	371
	ACM Full-Text – Periodicals, Proceedings	170
	ACM Guide – Periodicals, Proceedings, PDF only	**157**
	ACM Full-Text – Periodicals, Proceedings, PDF only	**154**
Set 2: MD	IEEE *Xplore*	353
	IEEE *Xplore* – Journals, Magazines, Conference Publications	326
	IEEE *Xplore* – Journals, Magazines, Conference Publications, Subscribed content	**265**
Set 3: FT	ACM Guide	2762
	ACM Full-Text	1548
	ACM Guide – Periodicals, Proceedings	2615
	ACM Full-Text – Periodicals, Proceedings	1540
	ACM Guide – Periodicals, Proceedings, PDF only	**1452**
	ACM Full-Text – Periodicals, Proceedings, PDF only	**1403**
Set 4: FT	IEEE *Xplore*	2784
	IEEE *Xplore* – Journals, Magazines and Conference Publications	2401
	IEEE *Xplore* – Journals, Magazines, Conference Publications, Subscribed content	**1647**

5.2.3 C_1: Candidate Set 1 – ACM Digital Library – Metadata

Candidate set 1 consists of an advanced Boolean search over metadata fields in the ACM Digital Library. This search uses three Boolean AND operators for "science AND fiction" in the title, abstract and keyword fields in conjunction with the OR operator of 11 name derivations and synonyms of the term science fiction, over all metadata fields in the ACM Guide.

This metadata-based search returned on 12/30/2017 645 records in the ACM Guide, respectively 171 results in the ACM Full-text collection. After the application of facets, in particular "Periodicals and Proceedings", the search returns 371 records in the ACM Guide, respectively 170 records in the ACM Full-Text collection. After further refinement through the facet "PDF content format", this search returns 157 records in the ACM Guide, respectively 154 in the ACM Full-Text collection.

The initial search query and amount of retrieved records are shown below:

Search syntax

```
Search Run Date: 2017-12-30 at 5:48:05 AM EST
Search Result Count: 645
Query Syntax:
```

```
"query": { (acmdlTitle:(science AND fiction)) OR (recordAbstract:(science AND
fiction)) OR (keywords.author.keyword:(science AND fiction)) OR "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" ) }
"filter": {owners.owner=GUIDE}
```

5.2.4 C_2: Candidate Set 2 – IEEE *Xplore* – Metadata

Candidate set 2 consists of an advanced Boolean search over metadata fields in the IEEE *Xplore* Digital Library. This search uses three Boolean AND operators for "science AND fiction" in the title, abstract and keyword fields, the OR operator of 11 name derivations and synonyms of the term science fiction, over all metadata fields.

This metadata-based search returns on 11/14/2017 353 records in the IEEE *Xplore* Digital Library. After refining the results through the application of the "Content Type: Journals & Magazines" and "Content Type: Conference Publications" facets, this search returns 326 records in the IEEE *Xplore* Digital Library. After refining the results further through the facet "Show: My Subscribed Content", this search returns 265 records in the in the IEEE *Xplore* Digital Library.

The initial search query and amount of retrieved records are shown below:

Search syntax

```
Displaying results 1-25 of 353 for
(Document Title:"science" AND "fiction" OR "Abstract":"science" AND "fiction" OR
"Author Keywords":"science" AND "fiction" OR "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")
```

5.2.5 C_3: Candidate Set 3 – ACM Digital Library – Full-text

Candidate set 3 consists of a simple search over all record fields, including full-text where applicable, for the precise phrase "science ficiton", in the ACM Digital Library.

This full-text search returns on 12/30/2017 2762 records in the ACM Guide, respectively 1548 results in the ACM Full-text collection. After refining for "Periodicals and Proceedings", the search returns 2615 records in the ACM Guide, respectively 1540 records in the ACM Full-Text collection. After further refinement by application of the facet "PDF content format", this search returns 1452 records in the ACM Guide, respectively 1403 in the ACM Full-Text collection.

The initial search query and amount of retrieved records are shown below:

```
Search Run Date: 2017-12-30 at 5:37:20 AM EST
```

```
Search Result Count: 2,762
Query Syntax:
"query": { content.ftsec:("science fiction") }
"filter":
{owners.owner=GUIDE}
```

5.2.6 C_4: Candidate Set 4 – IEEE *Xplore* – Full-text

Candidate set 4 consists of a simple full-text search for the precise phrase "science ficiton", over all fields of the record in the IEEE *Xplore* Digital Library and returns 2718 records After the application of the facets "Content Type: Journals & Magazines" and "Conference Publication", this search returns 2401 records in the IEEE *Xplore* Digital Library. After further refinement with the facet "My Subscribed Content", this search returns 1647 records in the IEEE *Xplore* Digital Library.

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

5.2.7 Dataset Facets

Irregular and fragmented database subscriptions of the University of Hawai'i Library mandate the usage of facets to filter content for articles, which are actually available for the subsequent content analysis. In the case of the ACM Digital Library, the facet "PDF only" therefore shows articles, which are directly available for download in the ACM Digital Library. Similarly, in IEEE *Xplore*, the facet "My subscribed content" filters records readily available for access and download as well. Therefore, these facets must be applied after formulating the initial search queries.

Furthermore, the decision to filter for conference articles (Proceedings/ Conference Publications) and journal articles (Periodicals/Journals & Magazines) in both databases ensures that other non-textual materials (such as videos in the ACM Digital Library), which extend the scope of analysis in this dissertation, are excluded in the retrieval process.

5.2.8 C_4 as Final Dataset

All of the final four outlined candidate datasets in the prior Section 5.2.2 are promising candidates for further analysis: The full-text retrieval query viii) yields the lion share of records in both repositories, while the metadata-based query vi) retrieves the most records in the metadata scenario accordingly, see Figure 5.1.

ACM DL versus IEEE *Xplore* DL: While both, the ACM or IEEE *Xplore* Digital Libraries are potential repositories, it is important to note that all three prior pilot studies [148, 151, 222] did analyze records retrieved in the ACM Digital Library. In particular, pilot study 1 [148] did analyze 232 records retrieved for a full-text query for the search phrase "Star Trek". Pilot study 2 [151] did investigate the usage of six variations of SF[19] in the full-text of the 137 records retrieved in the CHI proceedings, which are listed in the ACM Digital Library. Pilot study 3 [222] analyzed the referrals of 22 science fiction robots[20] in 102 records, retrieved in a full-text search in the ACM Digital Library.

While the prior pilot studies studies did yield useful retrieval queries and, as a consequence, important insight, the records in the ACM Digital Library have been queried three times for significant amount of SF referrals and variations thereof. This raises the potential concern that a fourth cache of SF-relevant records, retrieved in the ACM Digital Library might overlap with publications analyzed in prior studies, specifically pilot study 2 [151].

In addition to the aforementioned point, the IEEE *Xplore* Digital Library has unique advantages over the ACM Digital Library, among those:

i) The IEEE *Xplore* Digital Library allows the export of records along with their full abstracts.

ii) The IEEE *Xplore* Digital Library interface permits 'bulk-downloads' of up to 10 articles per request, whereas in contrast each record in the ACM Digital Library must be retrieved individually.

iii) The IEEE *Xplore* Digital Library indexes only articles which have been pre-processed through optical character recognition (OCR), which is not at all times the case in the ACM Digital Library.

For reasons of novelty with regards to the prior work, as well as the above outlined advantages of the IEEE *Xplore* search and retrieval interface (in contrast to equivalent interface in the ACM Digital Library), the study in this dissertation is conducted in the IEEE *Xplore* Digital Library.

Metadata versus full-text: This effectively limits the decision for a final candidate set (see section 5.2 on page 65) between two potential candidate sets in the IEEE *Xplore* Digital Library – a full-text search for "science fiction" yielding 2784 records and a metadata-based search for a complex, boolean query yielding 353 records.

As prior studies showed that full-text queries yield both, more type 1 errors but as well more relevant records due to the overall more inclusive nature, a tendency toward favoring the full-text query in the IEEE *Xplore* Digital Library seems reasonable at this point. In addition, research questions 2 and 3 (see section 2.5, page 19) state a focus on the investigation of the *contextual usage* of SF / SFMS in computer science research publications. In order to assess the context of usage

[19]The following SF term variations were queried in pilot study 2: "sci-fi", "sciencefiction", "science fiction", "scifi", "sci fi", "science-fiction".

[20]The following 22 SF robots were queried in pilot study 3: Astro Boy, Ava, Baymax, C-3PO, Data, David, Gerty, Gort, HAL9000, Huey Dewey Louie, Maria, R2-D2, Robbie, the robot, T-800, Wall-E, Smith, Oracle, Tars, Jarvis, Terminator, Sentinel, Skynet.

of SF within a scientific publication, it can be reasoned that a full-text retrieval (which includes obviously 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 publiciton under scrutinty.

For these reasons, candidate set 4, a full-text search of "science fiction", is chosen over candidate set 2 as, with a very high probability, is inclusive of the majority of records of the metadata search of the science fiction terms. Furthermore, candidate set 4 also yielded the most records overall, thus candidate set 4, which uses a full-text search in the IEEE *Xplore* Digital Library is used for the following, final analysis.

5.3 Metadata Analysis: $C_{4\ (1647)}$ and $C_{4\ (2487)}$

5.3.1 Publication Types: $C_{4\ (2784)}$ and $C_{4\ (1647)}$

On December 26, 2017, the IEEE *Xplore* Digital Library was searched, full-text, over all fields of the records. This search returned at that date 2784 records for "science fiction".

Before the application of facets, $C_{4\ (2784)}$ consists of 1262 records classified as "Journals and Magazines", 1086 records classified as "Conferences", 429 records classified as "Books" and 7 so-called "Early Access Articles".

After the application of the facets "My subscribed content", "Content Type: Journals & Magazines", "Conference Publications", and "Early Access Articles", $C_{4\ (1647)}$ consists of 1647 records in the *IEEE* Xplore Digital Library.

Table 5.2 shows the distribution of publication types in $C_{4\ (2784)}$ and $C_{4\ (1647)}$.

Table 5.2: Publication Types: $C_{4\ (2784)}$ and $C_{4\ (1647)}$

	Number of records retrieved ...	
Type of Record	$\mathbf{C_{4\ (2784)}}$	$\mathbf{C_{4\ (1647)}}$
Journals & Magazines	1262	1047
Conferences	1086	593
Books	429	0
Early Access Articles	7	7
Total	**2784**	**1647**

5.3.2 Publication Years: $C_{4\ (2784)}$ and $C_{4\ (1647)}$

In $C_{4\ (2784)}$, the earliest retrieved record dates back to 1948, with the most recent records published in 2017[21]. Exhibiting similar trends, the earliest publication retrieved in $C_{4\ (1647)}$ dates back to 1948, while the most recent records are from 2017.

[21]The retrieval did not include publications from 2018 onwards.

The vast majority of records in both sets were published in the most recent decades. From 2784 records in $C_{4\ (2784)}$, 1895 were published between 2002 - 2017. This equals to approximately 68% of the full set size of $C_{4\ (2784)}$. Likewise, from 1647 records in $C_{4\ (1647)}$, 1275 were published between 2003 to 2017. This equals roughly 77% of the full set size of $C_{4\ (1647)}$. Figure 5.3 on page 76 shows the distributions of records per year of $C_{4\ (2784)}$ and $C_{4\ (1647)}$ as scatter plots.

As indicated in Figure 5.3, the frequency of publications which reference science fiction roughly doubled in the year 2012 onwards in comparison to the previous years with the year 2016 producing the most records in $C_{4\ (2784)}$ (n=206).

Figure 5.3 further indicates comparable frequency patterns of records in $C_{4\ (1647)}$, which reference science fiction, from 1948 - 2017. Similarly, the faceted search returns for the year 2016 the most records in $C_{4\ (1647)}$ (n=135). In the year 2010, however, a drop in records in $C_{4\ (2784)}$ can be observed, which is not detectable in $C_{4\ (1647)}$.

In both sets, $C_{4\ (2784)}$ and $C_{4\ (1647)}$, a comparable, stark increase of records in the early 2010s is indicated. Figure 5.3 shows in addition exponential trend lines for each data series. Regardless of the outlier in the year 2010 in $C_{4\ (2784)}$, the overall resemblance between of all four sets is evident.

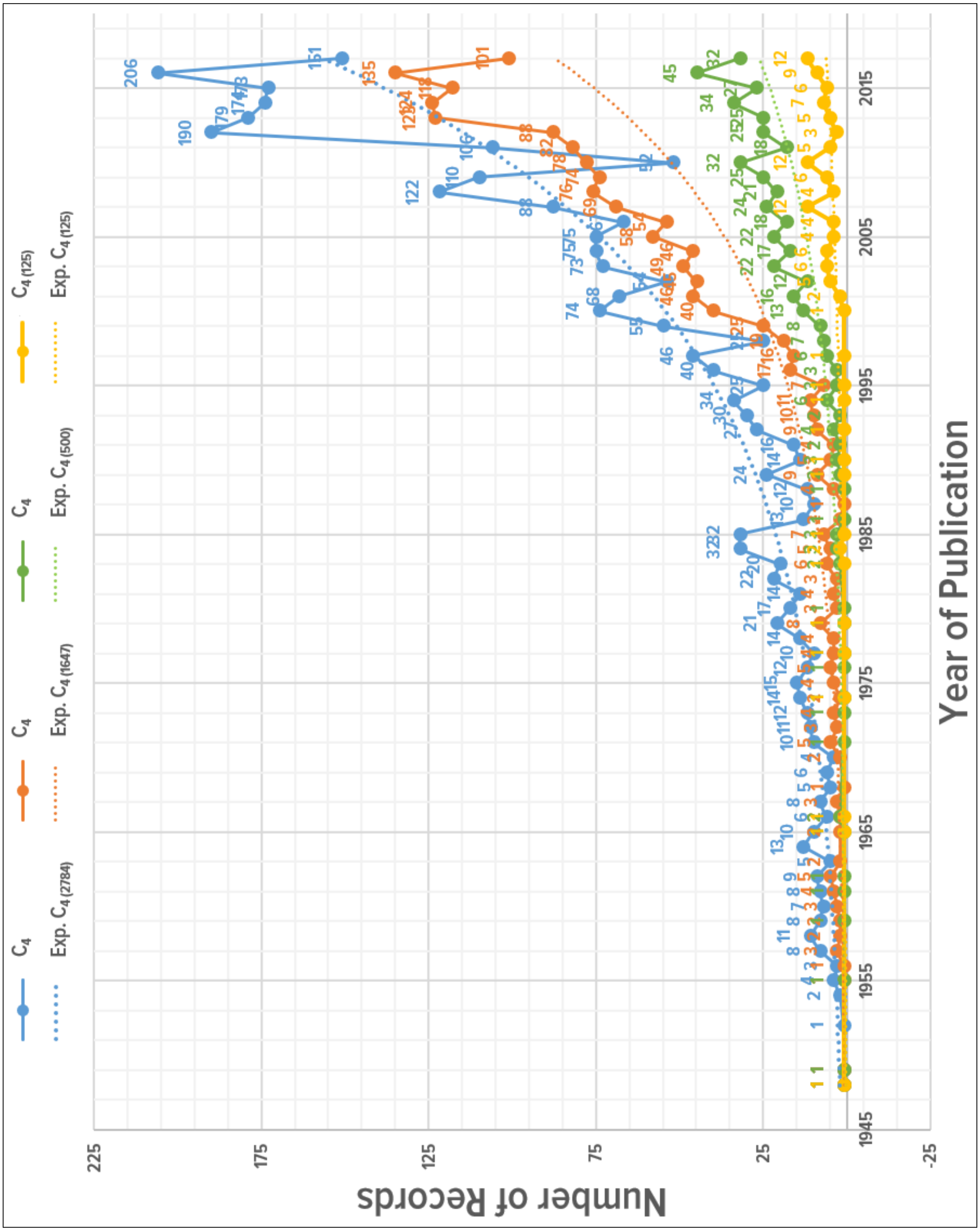


Figure 5.3: $C_{4\ (2784)}$, $C_{4\ (1647)}$, $C_{4\ (500)}$, $C_{4\ (125)}$

5.3.3 Publication Venues: $C_{4\ (2784)}$ and $C_{4\ (1647)}$

Figure 5.4 shows all 30 venues of the 2784 publications retrieved in $C_{4\ (2784)}$, with a minimum of ≥10 publications per venue.

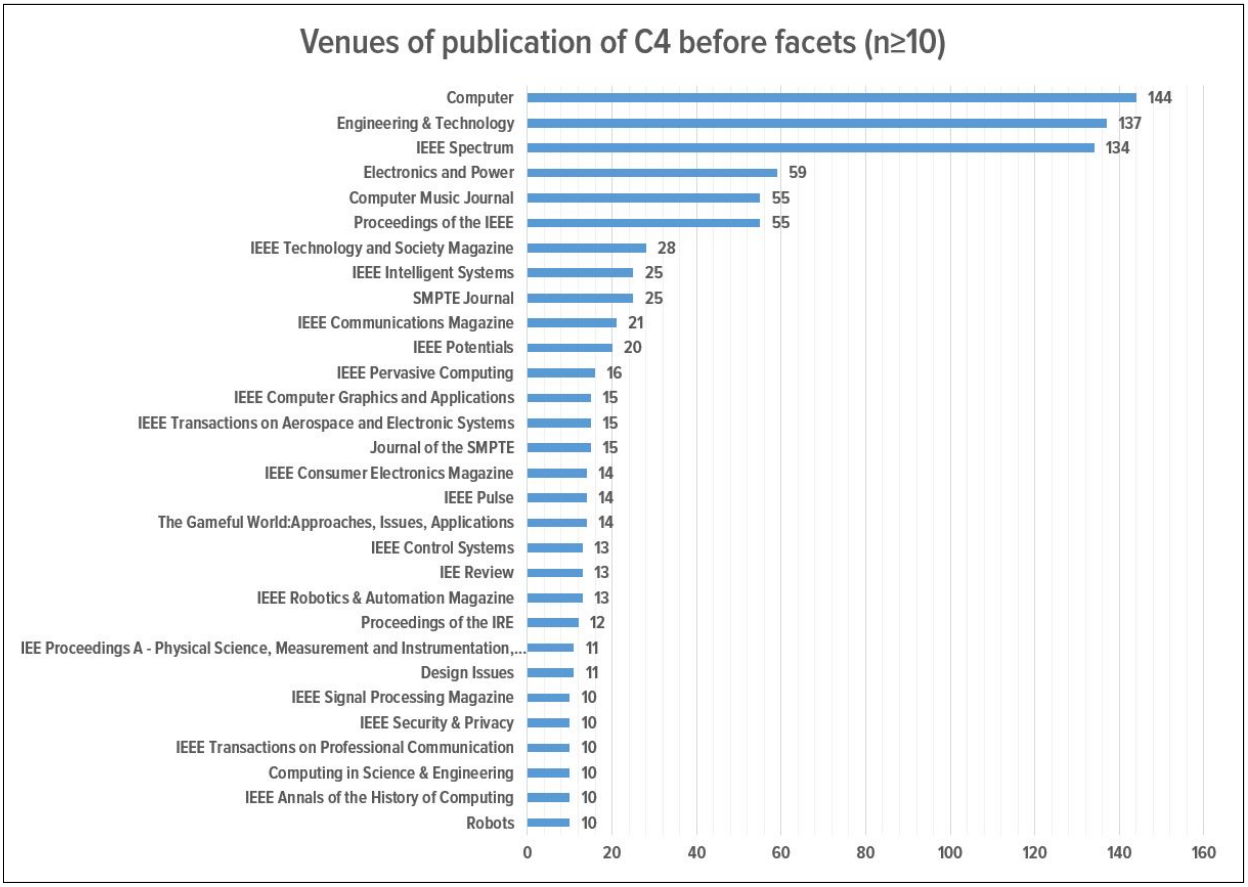


Figure 5.4: C4 before facets, showing venues ≥10 publications

In total, the metadata analysis of figure 5.4 lists 1259 individual venues[22] for the 2784 records in $C_{4\ (2784)}$. The top three publication venues of the 2784 retrieved records of $C_{4\ (2784)}$ are the IEEE Computer Journal (144 records), the IET Engineering & Technology, respectively, (137 records) the IEEE Spectrum (134 records) magazines.

Figure 5.5 shows all venues of the 1647 publications retrieved in $C_{4\ (1647)}$, with a minimum of ≥10 publications.

[22]IEEE *Xplore*, however, lists similar venues in different iterations separately. For instance, the 1999 and 2000 IEEE Aerospace Conferences are retrieved as a separate venues.

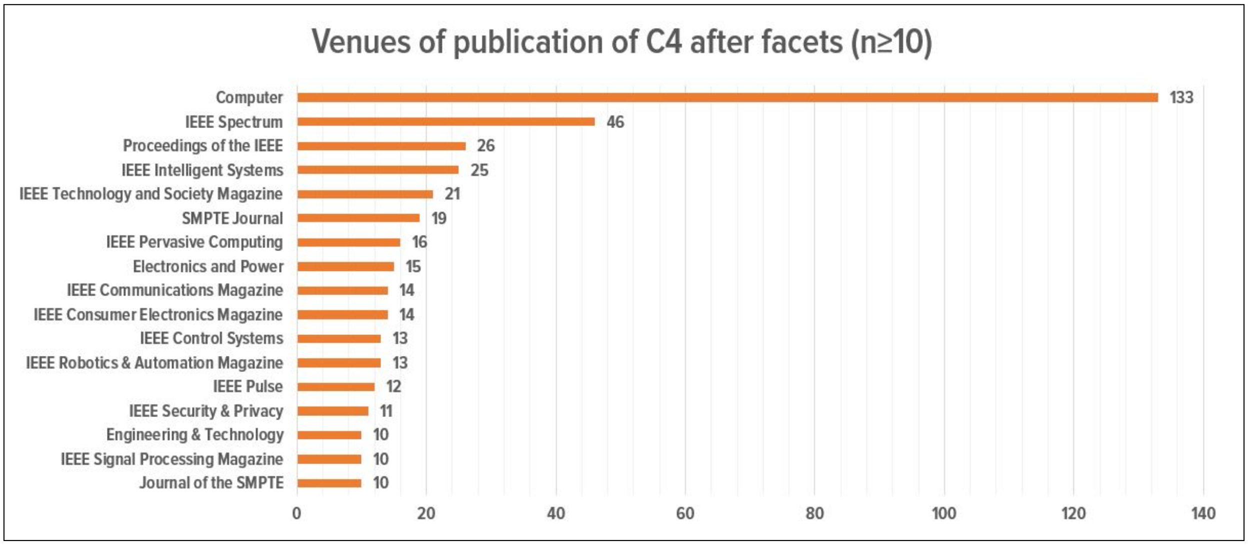


Figure 5.5: C4 after facets, showing venues ≥10 publications

In total, the metadata analysis yielded 989 individual venues. The top three publication venues of the 1647 retrieved records of $C_{4\ (1647)}$ are the IEEE Computer journal (133 records), IEEE Spectrum magazine (46 records) and the Proceedings of the IEEE journal (26 records).

Furthermore, Figure 5.6 shows both sets – $C_{4\ (2784)}$ and $C_{4\ (1647)}$ – for publication venues with a minimum of 10 retrieved records in direct comparison.

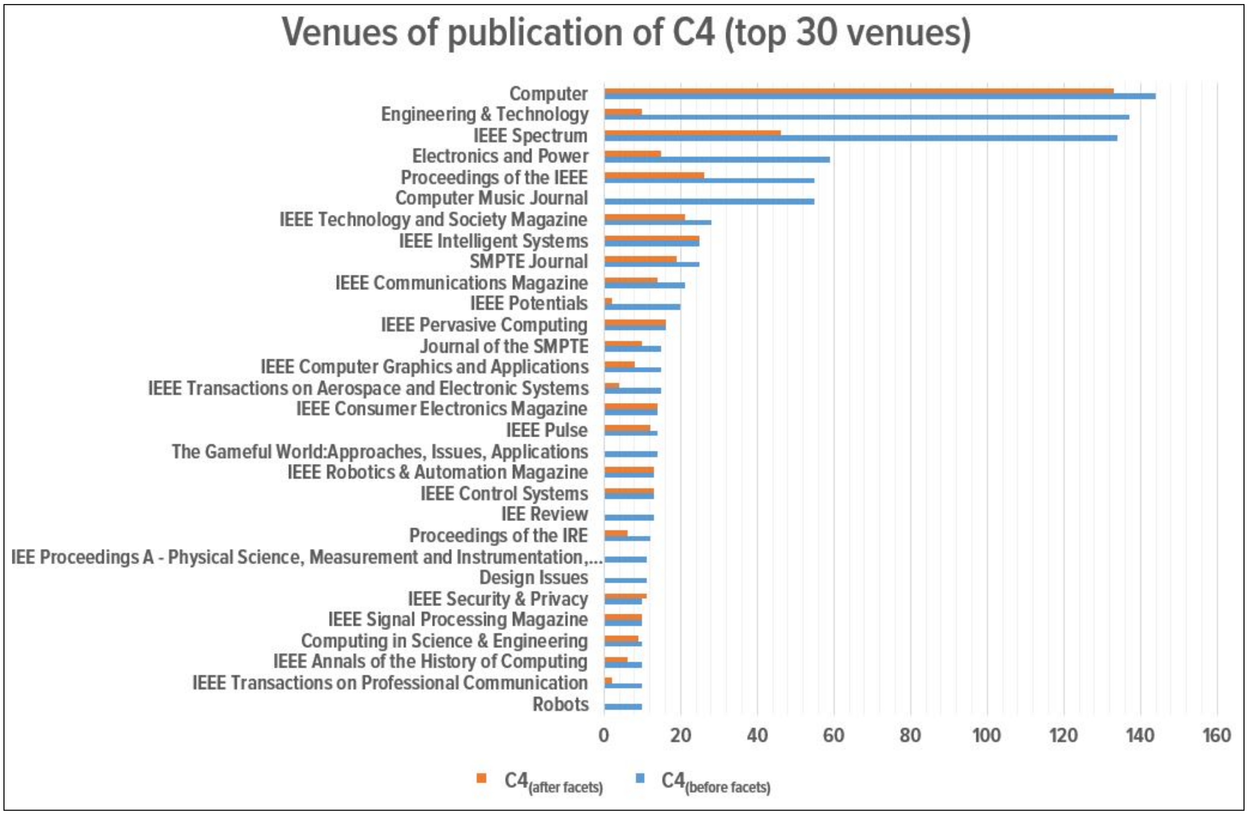


Figure 5.6: $C_{4\ (2784)}$ in comparison to $C_{4\ (1647)}$ for venues ≥10 publications

Figure 5.6 shows that $C_{4\ (1647)}$ does include publications in 26 venues retrieved in $C_{4\ (2784)}$. The six venues, which return no records for $C_{4\ (1647)}$ are: i) the Computer Music Journal; ii) the Gameful World:Approaches, Issues, Applications; iii) the IEE Review; iv) the IEE Proceedings A - Physical Science, Measurement; and Instrumentation, Management and Education - Reviews; v) Design Issues; and vi) Robots.

5.3.4 Publication Keywords and Index Terms: $C_{4\ (2784)}$ and $C_{4\ (1647)}$

With regards to publication keywords, a total of four categories of metadata are available for analysis. Using Atlas.ti, keyword frequencies for both, $C_{4\ (2784)}$ and $C_{4\ (1647)}$, are analyzed with a threshold of the top 20 most frequent words in each of the four categories (author keywords, IEEE terms, INSPEC controlled terms and INSPEC non-controlled terms). Filler words (e.g. and; as; the; of) and symbols (e.g semi-colons, hyphens, pound signs, etc.) are removed via a character filter in below analysis.

Author Keywords: In total, the metadata of $C_{4\ (2784)}$ (2784 records) consists of 6820 individual author keywords. $C_{4\ (1647)}$ (1647 records) had in total 6206 keywords for the analysis.

IEEE Terms: In total, the metadata of $C_{4\ (2784)}$ (2784 records) consists of 21968 IEEE terms. $C_{4\ (1647)}$ (1647 records) had in total 6206 keywords for the analysis.

INSPEC Controlled Terms: $C_{4\ (2784)}$ (2784 records) consists of 10601 INSPEC controlled terms. $C_{4\ (1647)}$ (1647 records) had in total 9169 INSPEC Controlled Terms for the analysis.

INSPEC NON-CONTROLLED Terms: $C_{4\ (2784)}$ (2784 records) consists of 28460 INSPEC non-controlled terms. $C_{4\ (1647)}$ (1647 records) had in total 24905 INSPEC non-controlled terms for the analysis.

Top 20 keywords in comparison: Table 5.3 on page 81 shows the top keywords (absolute counts, multiple counts per publication) across all 4 categories. Table 5.3 also shows that (science) fiction as a keyword is solely used in the author keywords category (fourth most frequent term in $C_{4\ (2784)}$; third most frequent term in $C_{4\ (1647)}$).

Table 5.3: Top 20 keywords and indexing terms: $C_{4\ (2784)}$ and $C_{4\ (1647)}$

	Author Keywords			
	$C_{4\ (2784)}$	Count	$C_{4\ (1647)}$	Count
1	computing	93	computing	84
2	**science**	81	**science**	74
3	systems	58	**fiction**	57
4	**fiction**	61	systems	57
5	technology	51	interaction	54
6	interaction	63	data	47
7	learning	48	design	45
8	design	50	learning	45
9	artificial	43	technology	45
10	intelligence	46	artificial	42
11	data	48	intelligence	42
12	robotics	48	virtual	42
13	future	39	virtual	42
14	system	41	system	41
15	reality	43	reality	40
16	robot	40	robot	40
17	social	44	robotics	38
18	virtual	46	social	38
19	engineering	34	prototyping	37
20	prototyping	37	future	35

	IEEE Terms			
	$C_{4\ (2784)}$	Count	$C_{4\ (1647)}$	Count
1	systems	439	computer	322
2	computer	385	engineering	200
3	technology	296	control	190
4	engineering	290	humans	182
5	robots	287	computing	171
6	control	218	communication	167
7	humans	217	robot	160
8	computing	205	educational	154
9	communication	203	intelligent	151
10	software	187	networks	136
11	educational	182	information	127
12	robot	169	management	123
13	space	166	internet	120
14	intelligent	157	institutions	118
15	networks	157	modeling	117
16	management	156	intelligence	115
17	information	153	motion	114
18	institutions	140	data	111
19	intelligence	136	mobile	107
20	internet	129	artificial	102

	INSPEC CONTROLLED Terms			
	$C_{4\ (2784)}$	Count	$C_{4\ (1647)}$	Count
1	computer	243	computer	219
2	systems	237	systems	215
3	computing	211	computing	202
4	robots	189	robots	174
5	engineering	146	data	144
6	data	142	processing	129
7	processing	138	control	124
8	control	129	engineering	121
9	internet	119	internet	108
10	mobile	112	aspects	98
11	aspects	109	mobile	95
12	interfaces	101	interfaces	90
13	management	88	interaction	88
14	interaction	87	artificial	84
15	reality	84	intelligence	80
16	education	82	education	77
17	social	81	reality	77
18	analysis	75	management	75
19	human	74	social	72
20	user	73	analysis	68

	INSPEC NON-CONTROLLED Terms			
	$C_{4\ (2784)}$	Count	$C_{4\ (1647)}$	Count
1	information	199	system	289
2	data	173	systems	204
3	design	170	robot	203
4	computer	154	technology	202
5	human	152	information	163
6	control	145	data	162
7	engineering	131	design	160
8	model	123	human	138
9	computing	121	control	130
10	network	113	social	125
11	analysis	112	science	123
12	learning	112	computer	122
13	communication	101	model	117
14	internet	101	computing	113
15	digital	99	virtual	110
16	mobile	99	learning	108
17	interaction	96	analysis	103
18	intelligence	94	user	102
19	3d	92	engineering	101
20	intelligent	90	interaction	99

5.4 Descriptive Analysis: $C_{4\ (125)}$

5.4.1 Publication Years: $C_{4\ (125)}$

Figure 5.7 shows the distribution of records per year of $C_{4\ (125)}$ as scatter plot.

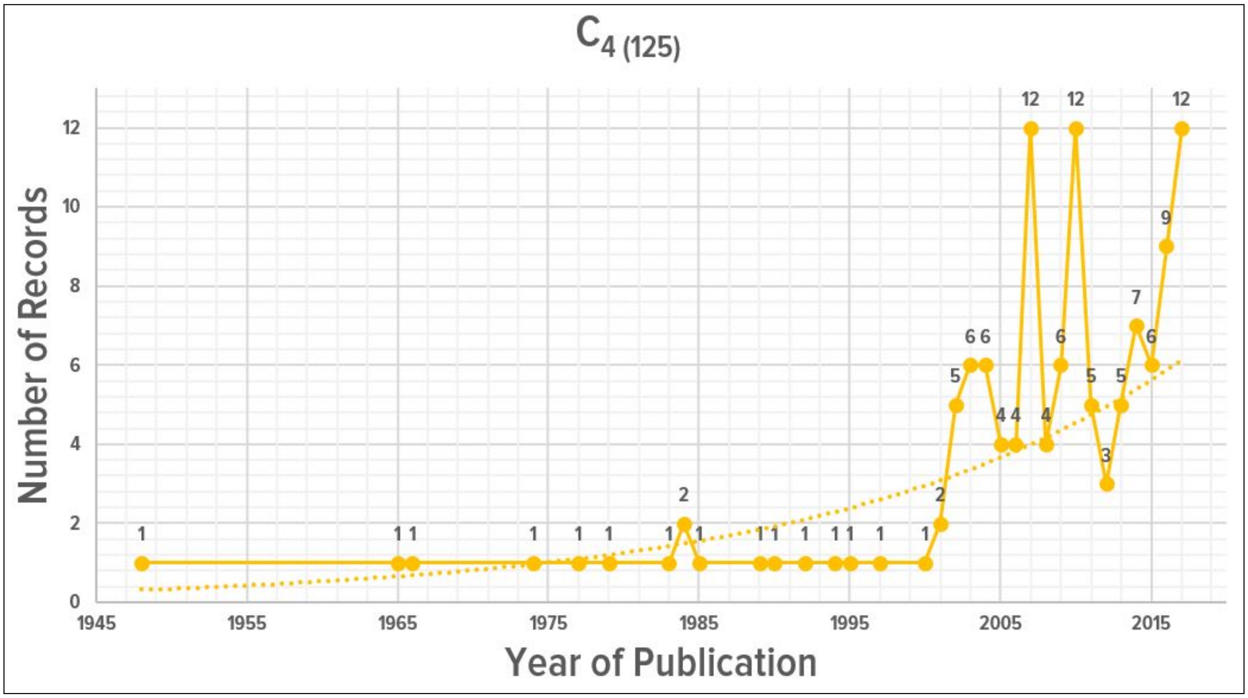


Figure 5.7: Distribution of publication years: $C_{4\ (125)}$

The earliest record in $C_{4\ (125)}$ dates from 1949 while the most recent papers were published in 2017. Figure 5.7 also shows that 16 out of the 125 records (13%) in $C_{4\ (125)}$ were published before 2000, while the bulk of retrieved papers (n=109, 87%) was published in the year 2000 or later. $C_{4\ (125)}$ is overall representative of the distribution pattern of records across publication years in comparison to $C_{4\ (500)}$, $C_{4\ (1647)}$ and $C_{4\ (2784)}$, see Figure 5.3 on page 76.

5.4.2 SF Referral Frequency and Location: $C_{4\ (125)}$

In total, 187 referrals to 'science fiction' are identified in $C_{4\ (125)}$. Table 5.4 shows that the vast majority of referrals (n=152, 81%) are located in the body of the reviewed publications, n=19 (10%) in the references, n=12 (6%) in the abstracts, n=2 (1%) in the titles and n=2 (1%) in the footnotes.

Table 5.4 shows as well the distribution of the SF referral frequency in $C_{4\ (125)}$. On average, every publication in $C_{4\ (125)}$ did refer 'science fiction' 1.5 times/record, with a maximum of 11 referrals in one single record. In addition, Table 5.4 shows that the lion's share of the records (98 out of 125 records, 78%) in $C_{4\ (125)}$ refer 'science fiction' one time.

Table 5.4: SF Referral frequency and location: $C_{4\ (125)}$

Referral frequency	**Records**	**% of $C_{4\ (125)}$**
1	98	78%
2	15	12%
4	4	3%
3	3	2%
6	1	1%
5	2	2%
7	1	1%
11	1	1%
Total	**125**	**100%**

Referral location	**Frequency**	**% of $C_{4\ (125)}$**
Title	2	1%
Abstract	12	6%
Body	152	81%
Footnotes	2	1%
References	19	10%
Total	**187**	**100%**

5.4.3 Inter-rater Reliability: $C_{4\ (125)}$

As all other variables are non-interpretative or coded in vivo, only the variables "Type of Research Paper" and "Contextual Usage of the SF Referral" and were subjected to an IRR assessment.

R2 did indicate in 33 of the 125 records in $C_{4\ 125}$ (36 of 250 possible codes) alternative codes for either, the research paper type, or the contextual usage of the SF referral. These 36 alternative codes were reviewed and consolidated between the raters. Next, the IRR coefficients of cohen's κ, respectively Krippendorff's α as an alternative measure, were calculated through IBM SPSS [72].

IRR for paper type:

cohens's κ The IRR analysis of the agreement of R1 and R2 with regards to the type of research paper of $C_{4\ (125)}$ showed a substantial agreement (κ between 0.61-0.80, see Table 3.2) between R1 and R2, with a κ of 0.71, see Figure 5.8a on page 85.

Krippendorff's α The IRR analysis of the agreement of R1 and R2 with regards to the type of research paper of $C_{4\ (125)}$ resulted in an α coefficient of 0.71 ($\alpha \geq 0.667$, see Table 3.2) allowing for tentative conclusions to be drawn, see Figure 5.8b on page 85.

IRR for contextual SF referral:

cohens's κ The IRR analysis of the agreement of R1 and R2 with regards to the type of the contextual SF referral in $C_{4\ (125)}$ showed a substantial agreement (κ between 0.61-0.80, see Table 3.2), with a κ of 0.65, see Figure 5.9a on page 86.

Krippendorff's α The IRR analysis of the agreement of R1 and R2 with regards to the type of the contextual SF referral in $C_{4\ (125)}$ resulted in an α coefficient of 0.68 ($\alpha \geq 0.667$, see Table 3.2) allowing for tentative conclusions to be drawn, see Figure 5.9b on page 86.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Rater_1 * Rater_2	125	100.0%	0	0.0%	125	100.0%

Rater_1 * Rater_2 Crosstabulation

Count

		Rater_2							Total
		Artifact	Empirical	Methodological	Opinion	Other	Survey	Theoretical	
Rater_1	Artifact	16	0	0	0	0	1	2	19
	Empirical	4	9	2	0	0	0	0	15
	Methodological	0	0	8	0	0	0	0	8
	Opinion	1	1	1	15	5	0	4	27
	Other	0	0	0	2	21	0	0	23
	Survey	0	0	2	2	0	12	2	18
	Theoretical	0	0	2	0	0	0	13	15
Total		21	10	15	19	26	13	21	125

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	.709	.045	19.208	.000
N of Valid Cases		125			

(a) Cohens's κ of $C_{4\ (125)}$ for paper type

```
Krippendorff's Alpha Reliability Estimate


             Alpha    LL95%CI    UL95%CI      Units    Observrs      Pairs
Nominal      .7086      .6146      .7932   125.0000      2.0000   125.0000

Probability (q) of failure to achieve an alpha of at least alphamin:
   alphamin          q
      .9000     1.0000
      .8000      .9773
      .7000      .4538
      .6700      .1731
      .6000      .0106
      .5000      .0000

Number of bootstrap samples:
  10000

Judges used in these computations:
 Rater_1_ Rater_2_
```

(b) Krippendorff's α of $C_{4\ (125)}$ for paper type

Figure 5.8: IRR coefficients for the type of research paper: $C_{4\ (125)}$

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Rater_1 * Rater_2	125	100.0%	0	0.0%	125	100.0%

Rater_1 * Rater_2 Crosstabulation

Count

		Rater_2: Coming from SF	Making SF a Science Reality	Seen in SF but non-existent in the real world	SF and the Author or Researchers	SF and the Community or Public	SF and the Paper Research Method	SF in the References	Total
Rater_1	Coming from SF	15	3	2	4	2	0	1	27
	Making SF a Science Reality	3	22	5	0	2	0	0	32
	Seen in SF but non-existent in the real world	0	3	9	1	0	0	0	13
	SF and the Author or Researchers	1	0	0	9	0	0	0	10
	SF and the Community or Public	0	1	0	0	8	0	0	9
	SF and the Paper Research Method	2	1	0	2	4	14	0	23
	SF in the References	0	0	0	0	0	0	11	11
Total		21	30	16	16	16	14	12	125

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	.648	.049	17.156	.000
N of Valid Cases		125			

(a) Cohens's κ of $C_{4\ (125)}$ for the contextual SF referral

```
Krippendorff's Alpha Reliability Estimate



             Alpha    LL95%CI    UL95%CI      Units    Observrs      Pairs
Nominal      .6832      .5881      .7782   125.0000      2.0000   125.0000

Probability (q) of failure to achieve an alpha of at least alphamin:
   alphamin          q
      .9000     1.0000
      .8000      .9958
      .7000      .6173
      .6700      .3716
      .6000      .0623
      .5000      .0003

Number of bootstrap samples:
  10000

Judges used in these computations:
 Rater_1_ Rater_2_
```

(b) Cohens's κ of $C_{4\ (125)}$ for the contextual SF referral

Figure 5.9: IRR coefficients for the contextual SF referral: $C_{4\ (125)}$

5.5 Descriptive Analysis: $C_{4\ (500)}$

5.5.1 Publication Years: $C_{4\ (500)}$

Figure 5.10 on page 87 shows the distribution of records per year of $C_{4\ (500)}$ as scatter plot.

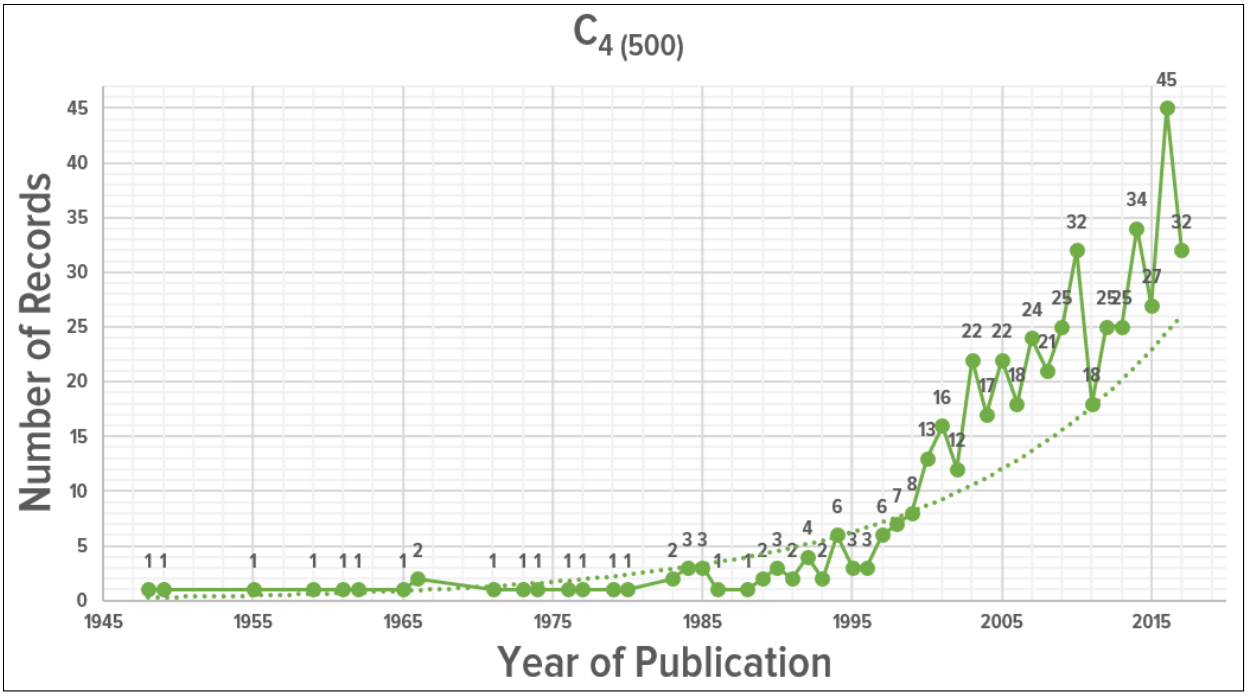


Figure 5.10: Distribution of publication years: $C_{4\ (500)}$

The earliest record in $C_{4\ (500)}$ dates from 1948 while the most recent papers in $C_{4\ (500)}$ were published in 2017. Figure 5.10 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 in $C_{4\ (125)}$, $C_{4\ (1647)}$ and $C_{4\ (2784)}$, see Figure 5.3 on page 76.

5.5.2 SF Referral Frequency and Location: $C_{4\ (500)}$

Table 5.5 shows the distribution of SF referrals in $C_{4\ (500)}$.

In total, 899 referrals to 'science fiction' are identified with the vast majority of referrals (n=761, 85.6%) 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.

In addition, Table 5.5 shows that the lion's share 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 $C_{4\ (125)}$, see Table 5.4 on page 83.

Table 5.5: SF Referral frequency and location in $C_{4\ (500)}$

Referral frequency	**Records**	**% of $C_{4\ (500)}$**
1	380	76.0%
2	60	12.0%
3	21	4.2%
4	12	2.4%
5	9	1.8%
6	3	0.6%
7	2	0.4%
8	1	0.2%
10	2	0.4%
11	2	0.4%
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%**

Referral location	**Records**	**% of $C_{4\ (500)}$**
Title	21	2.3%
Abstract	49	5.5%
Body	761	84.6%
Footnote	4	0.4%
References	64	7.1%
Total	**899**	**100%**

5.5.3 Type of Research Paper: $C_{4\ (500)}$

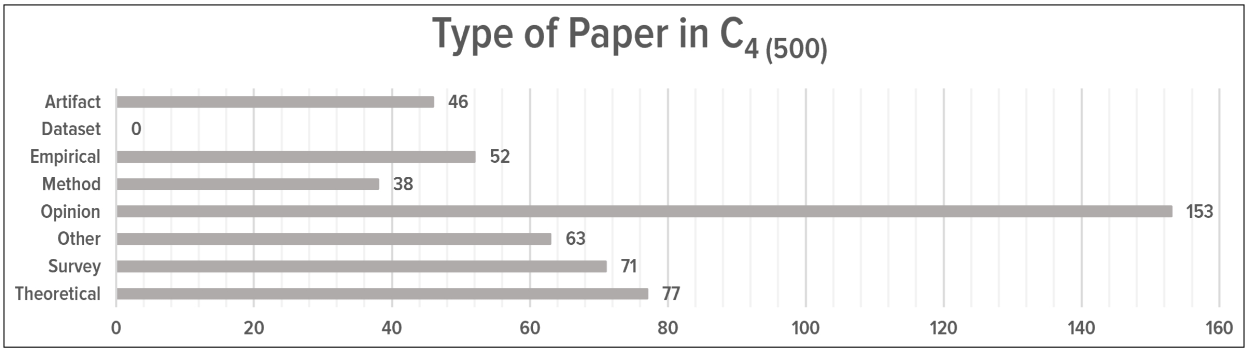


Figure 5.11: Type of Research Paper: $C_{4\ (500)}$

Figure 5.11 shows the frequency distribution of the type of research paper across $C_{4\ (500)}$. With almost one out of three papers (n=153, 31%), opinionated 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[23] (n=0), as visualized in Figure 5.11, were not found in $C_{4\ (500)}$.

5.5.4 Contextual Usage of the SF Referral: $C_{4\ (500)}$

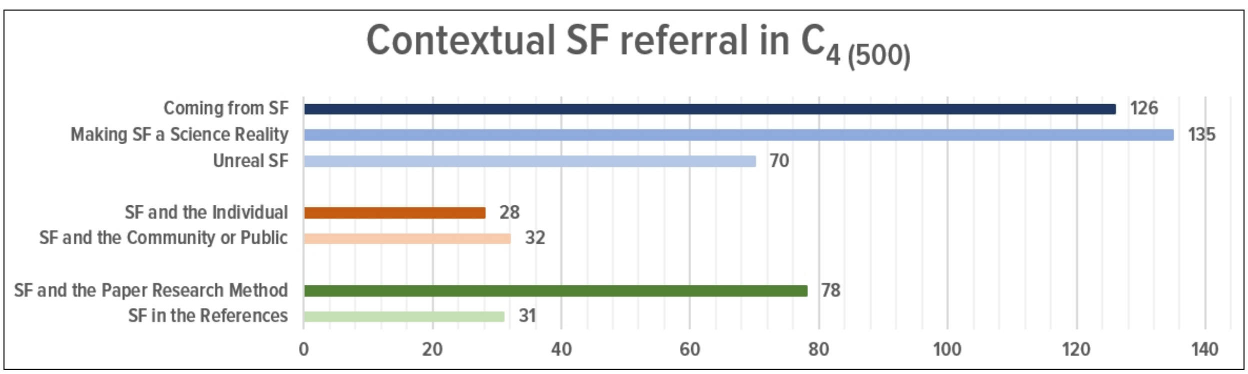


Figure 5.12: Contextual SF Referral: $C_{4\ (500)}$

Figure 5.12 shows the frequency distribution of the context of the SF referral across $C_{4\ (500)}$.

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, seen in, or known from

[23] As dataset contributions are quasi non existent in $C_{4\ (500)}$, this attribute of the variable type of research paper will be disregarded in the following analysis.

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[24] 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[25] out of 500 records, 66%).

5.5.5 Type of Research Paper / Contextual Usage of the SF Referral: $C_{4\ (500)}$

Figure 5.13 shows the frequency distribution of the type of research paper in relationship to the contextual usages of the SF referral (combination of Figure 5.11 and Figure 5.12).

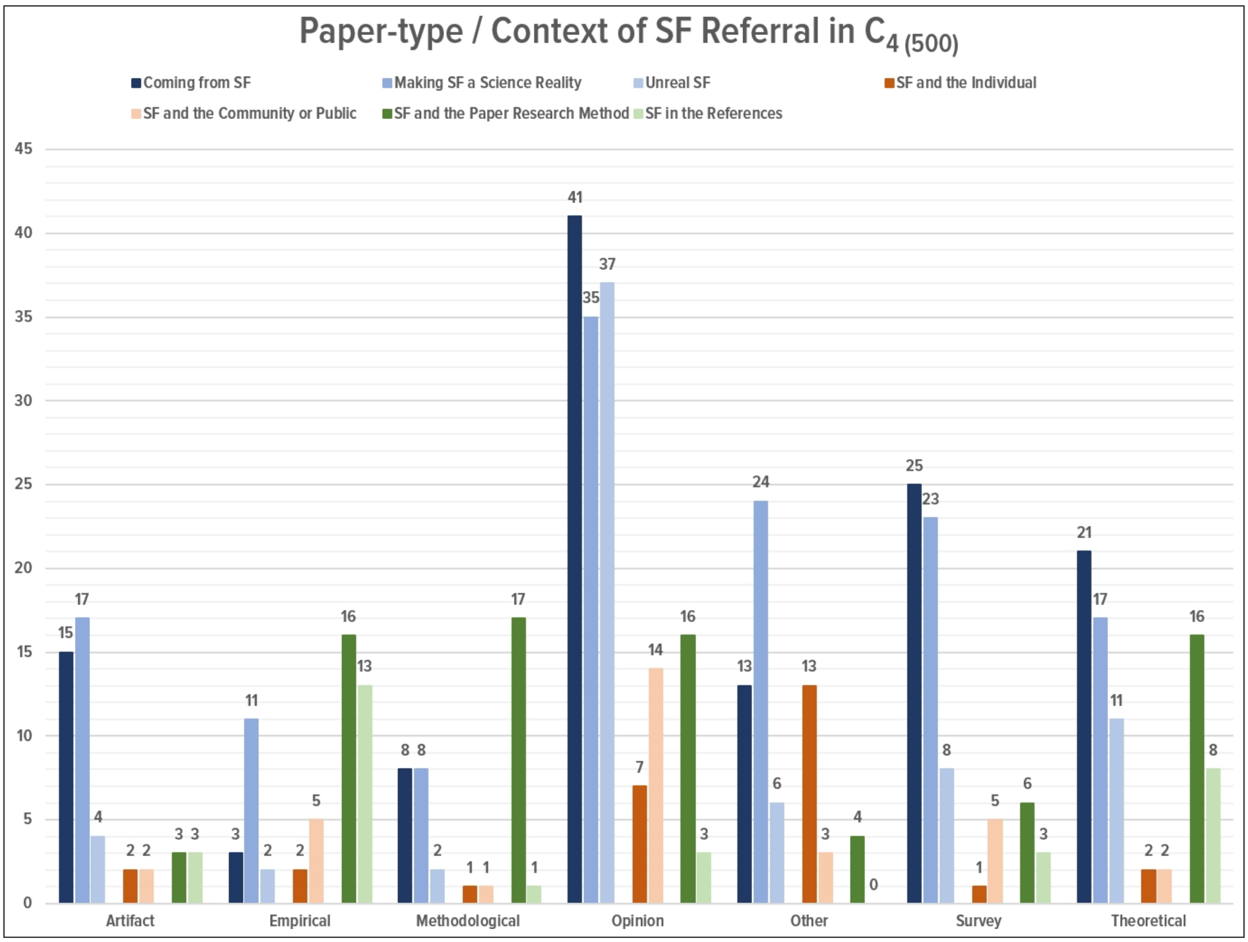


Figure 5.13: Type of Research Paper / Context of SF Referral: $C_{4\ (500)}$

An investigation of the most frequent contextual uses of SF references across the research paper types

[24] i) SF Referrals, with a focus on drawing innovation from SF in the research paper, ii) SF referrals, with a focus on individuals, the scientific community and / or the general public, iii) SF referrals, integrated as part of the research paper.

[25] 331 = Coming from SF (n=126) + Making SF a Science Reality(n=135) + Unreal SF (n=70).

reveals that in three categories of papers (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 paper types (Empirical, Methodological) use SF referrals most frequently as an integrated part of the research paper introduction, background, application, method or discussion. The 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 almost all seven paper types in Figure 5.13 (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 the least common type of referrals – relative to all referrals within the individual category under review.

5.5.6 SF Authors: $C_{4\ (500)}$

A total of 72 unique SF authors, spread across 528 full-text referrals, in 201 records were identified in vivo in the random sample of 500 records in $C_{4\ (500)}$. The full list of author names, frequencies of referral, and binary counts of records they appear in can be found in Table A.1 in Appendix A.

Table 5.6 shows the partial results of this analysis by means of a cut-off for the 14 most frequent SF authors for both, absolute and binary counts.

With regards to the absolute referrals, the results show that the most frequent SF author mentioned is Issac Asimov (n=111 referrals, 21%), followed by Norbert Wiener (n=80 referrals, 15%) and Arthur C. Clarke (n=37, 7%). Furthermore, the fourteen most frequent mentioned SF authors in Table 5.6 account for the majority (n=403 referrals, 76%) of the 528 full-text referrals of SF authors found in $C_{4\ (500)}$.

As far as the binary[26] counts of SF authors in $C_{4\ (500)}$, Table 5.6 shows that Issac Asimov (28 records, 13.9%) appears the most frequent in the research papers in $C_{4\ (500)}$, 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 5.6 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.

[26] 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.

Table 5.6: Most frequent SF Authors: $C_{4\ (500)}$

	Author Name	abs. ref.	% of abs. ref.
1	Isaac Asimov	111	21%
2	Norbert Wiener	80	15%
3	Arthur C. Clarke	37	7%
4	William Gibson	34	6%
5	Robert Heinlein	27	5%
6	Neal Stephenson	19	4%
7	Philip K. Dick	15	3%
8	Karel Čapek	14	3%
9	George Orwell	12	2%
10	J. R. Pierce	12	2%
11	Vernor Vinge	12	2%
12	H. G. Wells	10	2%
13	John Brunner	10	2%
14	Jules Verne	10	2%
	Subtotal (abs.)	**403**	**76%**
...	...	...	...
72	William F. Nolan	1	0.2%
	Total ref. (abs.)	**528**	**100%**

	Author Name	bin. ref.	% of bin. ref.
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 (bin.)	**123**	**61.2%**
...	...	...	...
72	William F. Nolan	1	0.2%
	Total records (bin.)	**201**	**100%**

5.5.7 SF Writings: $C_{4\ (500)}$

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 $C_{4\ (500)}$. The full list for these books, novels, short stories and magazines, as well as the frequencies of referral and binary counts of records they appear in can be found in Table A.2 in Appendix A.

Table 5.7 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 in the first order sorting, and by absolute referral frequency, as a second order sorting.

Table 5.7: Most frequent SF Writings: $C_{4\ (500)}$

	Books, Novels, Short Stories	**abs. ref.**	**bin. ref.**	**% of bin. ref.**
1	Neuromancer	16	10	4.5%
2	Astounding Science Fiction	8	7	3.1%
3	Runaround	7	7	3.1%
4	Snow Crash	9	6	2.7%
5	Hitchhikers' Guide to the Galaxy (novel)	14	4	1.8%
6	The Shockwave Rider	8	4	1.8%
7	R.U.R. (Rossum's Universal Robots)	5	4	1.8%
8	Do Androids Dream of Electric Sheep?	4	4	1.8%
9	I, Robot (novel)	4	4	1.8%
10	True Names	9	3	1.3%
11	From the Earth to the Moon	7	3	1.3%
12	Nineteen Eighty-Four	6	3	1.3%
13	The Diamond Age	6	3	1.3%
14	2001: A Space Odyssey (novel)	3	3	1.3%
	Subtotals	**106**	**65**	**29%**
...	...	...	...	...
162	Young Lady's Illustrated Primer	1	1	0.4%
	Totals	**328**	**224**	**100%**

With regards to the absolute referrals, the results show that the most frequent SF writings are Neuromancer (n=16 referrals), followed by the The Hitchhiker's Guide to the Galaxy (n=14 referrals) and Snow Crash / True Names (each with n=9 referrals). Furthermore, the fourteen most frequent mentioned SF tales in Table 5.7 account for a third (n=106 referrals, 32.3%) of the 328 full-text referrals found in $C_{4\ (500)}$.

The binary frequency analysis in Table 5.7 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 fourteen SF novels which appear the most often in research papers (binary counting) in Table 5.6 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.

5.5.8 SF Movies and Shows: $C_{4\ (500)}$

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 $C_{4\ (500)}$. The full list for these SF shows and movies, as well as the frequencies of referral and binary counts of records they appear in can be found in Table A.3 in Appendix A.

Table 5.8 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 in the first order sorting, and by absolute referral frequency, as a second order sorting.

With regards for the absolute referrals of SF movies and shows, the results display that Star Trek (n=62[27]) and Star Wars (n=58 referrals) referrals in $C_{4\ (500)}$ are the two most frequent SF franchises mentioned. Stanley Kubrick's film, 2001: A Space Odyssey, is the third most frequent (n=31 referrals) SF movie in $C_{4\ (500)}$.

The fourteen most frequent mentioned SF movies and shows (n=267 referrals) in Table 5.8 account for 62% of the 429 full-text referrals to all SF movies and shows, found in $C_{4\ (500)}$.

The binary frequency analysis in Table 5.8 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 fourteen SF movies and shows which appear the most often in research papers (binary counting) in Table 5.8 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.

[27] Although not explicit, often the Star Trek referrals implicitly referred to a Star Trek movie or one of the seven Star Trek shows (e.g. be referring the Star Trek Communicator or Mr. Data in context). It is noteworthy that there were referrals to specific Star Trek shows, counted separately (see Table A.3), which are: Star Trek: The Next Generation (n=13), Star Trek: The Original Series (n=1), Star Trek: Deep Space Nine (n=1), Star Trek: First Contact (n=1).

Table 5.8: Most frequent SF Movies and Shows: $C_{4\ (500)}$

	SF Movie, Show	abs. ref.	bin. ref.	% of bin. ref.
1	Star Trek	62	28	13.7%
2	2001: A Space Odyssey (movie)	31	23	11.2%
3	The Terminator	16	13	6.3%
4	Minority Report	18	12	5.9%
5	Star Wars	58	11	5.4%
6	The Matrix	14	9	4.4%
7	I, Robot (movie)	13	9	4.4%
8	Fantastic Voyage	14	8	3.9%
9	Star Trek: The Next Generation	13	7	3.4%
10	Blade Runner	9	7	3.4%
11	Gattaca	6	4	2.0%
12	Metropolis	5	4	2.0%
13	Forbidden Planet	5	3	1.5%
14	Battlestar Galactica	3	3	1.5%
	Subtotals	**267**	**141**	**68.8%**
...	...	...	...	...
103	Westworld	1	1	0.5%
	Totals	**429**	**205**	**100.0%**

5.5.9 SF Characters: $C_{4\ (500)}$

A total of 38 unique SF characters (humans, robots, androids, computers, AIs), spread across 100 full-text referrals, in 55 records were identified in vivo in the random sample of 500 records in $C_{4\ (500)}$. The full list for these SF characters, as well as the frequencies of referral and binary counts of records they appear in can be found in Table A.4 in Appendix A.

Table 5.9 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 in the first order sorting, and by absolute referral frequency, as a second order sorting.

Table 5.9: Most frequent SF Characters: $C_{4\ (500)}$

	SF Characters	abs. ref.	bin. ref.	% of bin. ref.
1	HAL 9000	31	11	20.0%
2	R2-D2	4	3	5.5%
3	Dick Tracy	3	3	5.5%
4	Captain Kirk	3	2	3.6%
5	Borg	2	2	3.6%
6	C-3PO	2	2	3.6%
7	Wintermute	11	1	1.8%
8	Princess Leia	8	1	1.8%
9	Waldo	3	1	1.8%
10	David	2	1	1.8%
11	Dr. Frankenstein	2	1	1.8%
12	Mr. Data	2	1	1.8%
13	Terminator (robot)	2	1	1.8%
14	Agent Smith	1	1	1.8%
	Subtotals	**75**	**31**	**56.4%**
...	...	...	...	...
38	Victor Frankenstein	1	1	1.8%
	Totals	**100**	**55**	**100.0%**

The results show for the absolute referrals of SF characters that HAL 9000, from the 1968 epic SF movie A SPACE ODYSSEY is the far most frequent mentioned SF character (n=31 referrals) in $C_{4\ (500)}$. The second and third most frequent characters mentioned are WINTERMUTE (11 referrals), another fictional AI appearing in William Gibson's 1984 SF novel Neuromancer, respectively PRINCESS LEIA (8 referrals), a main character appearing for the first time in the original Star Wars movie in 1977.

Furthermore, the fourteen most frequent mentioned SF characters in Table 5.9 account for $^3/_4$ (n=75 referrals, 75%) of the 100 full-text referrals found in $C_{4\ (500)}$.

The binary frequency analysis in Table 5.9 shows that Hal 9000 (11 records, 20%) appears the most frequent in the research papers in $C_{4\ (500)}$, followed by R2-D2, another Star Wars character (3 records, 5.5%) and Dick Tracey (3 records, 5.5%). Accordingly, the fourteen SF characters which appear the most often in research papers (binary counting) in Table 5.9 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.

5.5.10 SF Concepts: $C_{4\ (500)}$

A total of 284 records in $C_{4\ (500)}$ related an idea, concept, technology, device or interface in the context of the SF referral. As this variable is of a mutually exclusive nature, it can only appear once per record, hence the absolute and binary counts in this frequency analysis are identical. The full list of the SF concepts, technologies and devices can be found in Table A.5 in Appendix A.

Table 5.10 shows the partial results of this analysis by means of a cut-off for the 14 most frequent SF concepts for absolute / binary counts. The results show that AI (n=20, 7%) is the most frequent field of research, which co-occurs with SF referrals. Table 5.10 also shows that two Star Trek concepts (Communicator (n=6), Holodeck (n=3) are among the most frequent SF technologies in 284 records in $C_{4\ (500)}$.

The Table 5.10 indicates that concepts overlap. For example, Asimov's Three Laws of Robotics (n=7) share similarities with the concepts of Robotics (n=6), Humanoid Robots (n=5) and Killer Robots (n=3). Similarly, the Star Trek Communicator (n=6) is situated in the field of Speech Recognition (n=6) and Natural Language Processing (n=4).

The full results give a clear account of these terminology nuances, hence clear trends are difficult to extrapolate in this part of the analysis. This limitation will be addressed later on in the discussion and future work of this dissertation.

Table 5.10: Most frequent SF Concepts: $C_{4\ (500)}$

		abs. and bin. ref.	**% of bin. ref.**
1	Artificial Intelligence	20	7%
2	Asimov's Three Laws of Robotics	7	2%
3	Brain–computer Interfaces	7	2%
4	Communicator	6	2%
5	Robotics	6	2%
6	Speech Recognition	6	2%
7	Humanoid Robots	5	2%
8	Cyberspace	4	1%
9	Natural Language Processing	4	1%
10	Robots	4	1%
11	Artificial Life	3	1%
12	Exoskeletons	3	1%
13	Holodeck	3	1%
14	Killer Robots	3	1%
...	...	...	...
284	Wormholes	1	0.4%
	Total ref. (abs. and bin.)	**284**	**100.0%**

5.6 Chronological Trends: $C_{4\ (500)}$

This section presents an analysis of the papers types, contextual SF referrals and SF particulars in relationship to the publication years in $C_{4\ (500)}$. Such analysis over time can potentially identify chronological trends of the paper types, the SF referral types, and the mentioned SF particulars in $C_{4\ (500)}$.

5.6.1 Chronological Trends – Paper Types: $C_{4\ (500)}$

Figure 5.14 on page 101 shows the counts of the type of research paper (n=500) in relation to the publication year of the records in $C_{4\ (500)}$. As this variable is mutually exclusive, Figure 5.14 represents a view on both, the absolute and binary counts as the values are by definition identical. The related data table of this chart can be found in Table A.6.

Although small in count, Figure 5.14 indicates that early research contributions which refer SF (e.g. records published between 1948-1986) are frequently classified as other-type records (e.g. reader's letters, editors notes, interviews). In addition, before the year 1990, only three categories of research contributions (opinion-type, other-type, survey-type) occur in the analysis of $C_{4\ (500)}$. The first theoretical-type in $C_{4\ (500)}$ is published in 1990, the first methodological-type paper in 1994, the first empirical record in 1995 and the first artifact-type record, which refers SF in the full-text, in 1996.

In more recent years, Figure 5.14 shows an overall increase – with fluctuations between specific publication years – across all publications types in $C_{4\ (500)}$. In addition, other-type research papers become a less frequent paper type, proportionally.

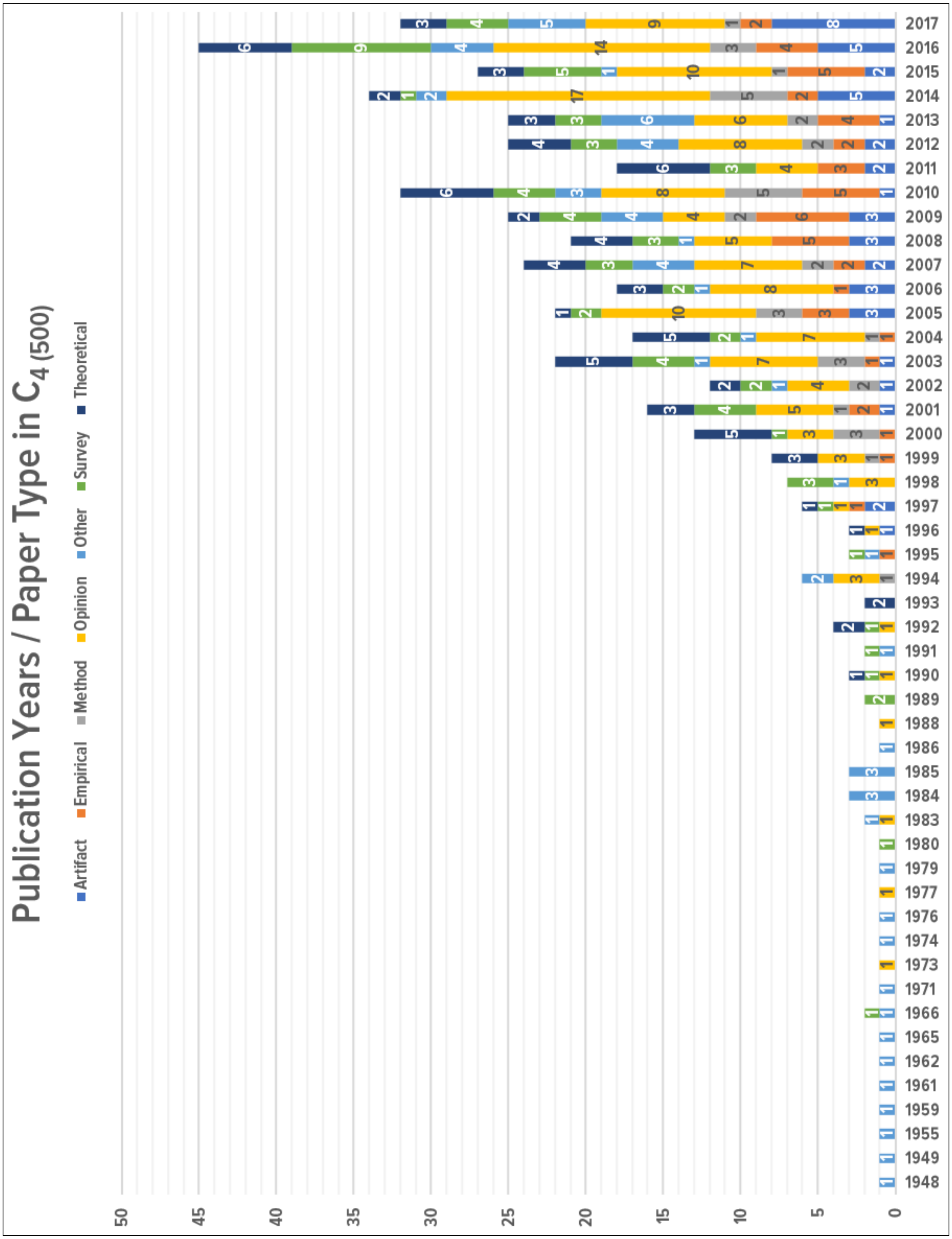


Figure 5.14: Publication Years / Type of Research Paper: $C_{4\ (500)}$

5.6.2 Chronological Trends – SF Referrals: $C_{4\ (500)}$

Figure 5.15 on page 103 shows the counts of the contextual SF referral (n=500) in relation to the publication year of the records in $C_{4\ (500)}$. As this variable is mutually exclusive, Figure 5.15 represents a view on both, the absolute and binary counts, as both values are by definition identical. The related data table of this chart can be found in Table A.7.

With regards to the contextual SF referrals in $C_{4\ (500)}$ over time, Figure 5.15 indicates that SF as part of the research method in a publication (n=7), SF in the references (n=1) as well as referrals of SF with a focus on the community or public (n=1) are not utilized often before the year 2000: From a total of 72 contextual referrals from 1948-1999, only 9 records, which refer SF, are classified into one these three referral categories.

Furthermore, Figure 5.15 shows that in the years from 2014-2017, the attribute 'Making SF a Science Reality' is more often found in $C_{4\ (500)}$ than the attribute 'Coming from SF'. This can potentially indicate that researchers focus more on referring aspects of SF concepts, technologies, ideas, devices and interfaces as a forthcoming reality, instead of a mere source of inspiration.

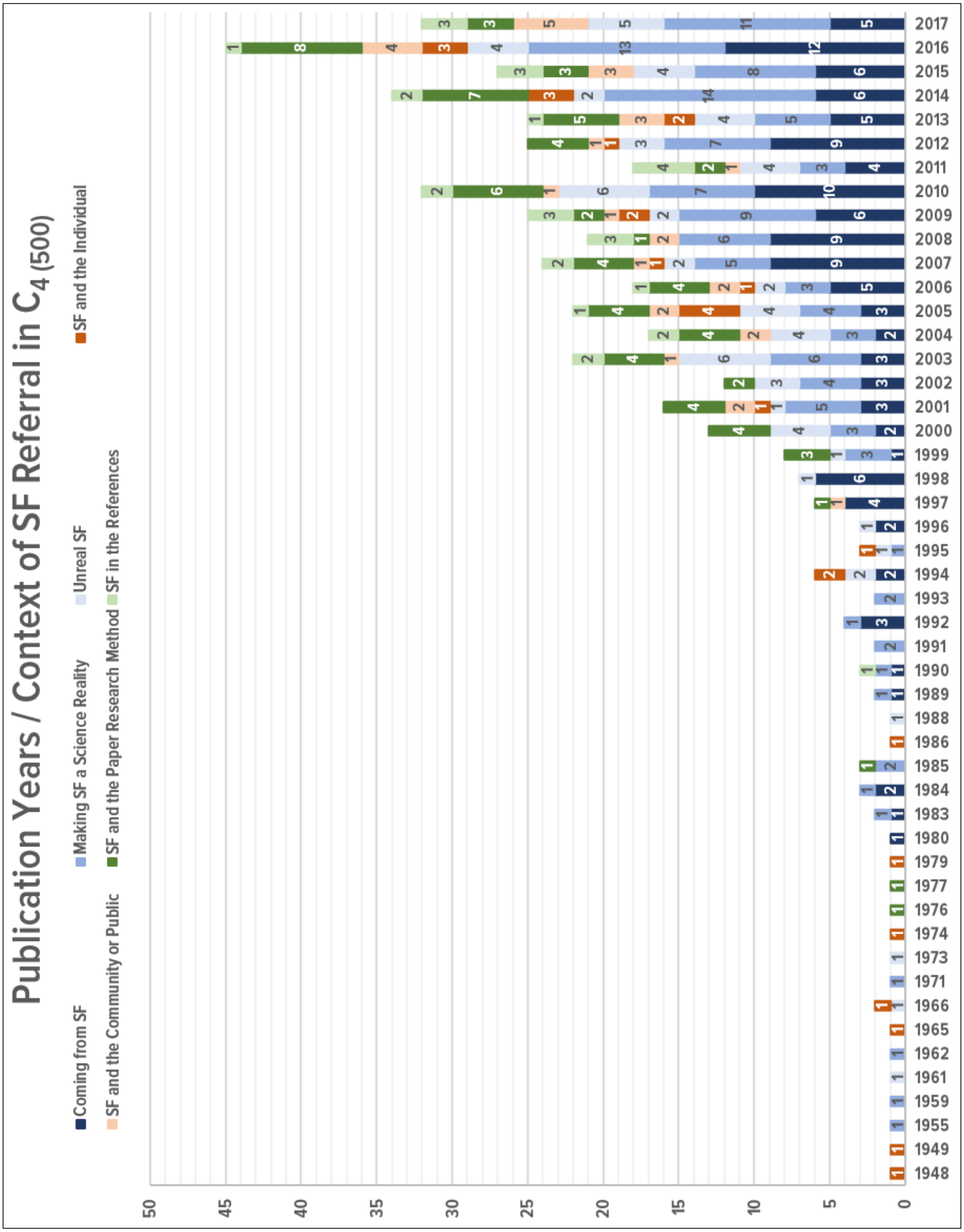


Figure 5.15: Publication Years / Contextual SF Referral: $C_{4\ (500)}$

5.6.3 Chronological Trends – SF Particulars: $C_{4\ (500)}$

Figure 5.16 on page 105 shows the binary counts of any records per year, which mention any of the prior introduced SF particulars[28]. As this variable is of non-mutually exclusive nature, e.g. multiple types of SF particulars (movies and shows) and multiple instances of the same SF particular (e.g. multiple times STAR TREK), Figure 5.16, shows records where a specific type of SF particular occurs at least once.

Furthermore, as the records are accumulated by publication year, Figure 5.16 does not show how many individual records refer a SF particular. For example, the two referrals in 1948 to a SF author and a SF writing stem from the analysis of one record. The related data table of this chart can be found in Table A.8.

In the span from 1948-1980 in Figure 5.16, only SF authors and writings are found in the analysis of the SF particulars in $C_{4\ (500)}$. The first SF movie – STAR TREK – is referenced in a other-type paper on CGI and special effects in 1984, and the first SF character – JAMES T. KIRK – is referenced in a paper on speech recognition in 1990.

Overall, more often a record in $C_{4\ (500)}$ refers a SF movie (n=155, red bars, Figure 5.16) than a SF novel (n=78, green bars, Figure 5.16). SF authors (n=112, blue bars, Figure 5.16) and SF writings seem to be a continuous resource in the papers reviewed in $C_{4\ (500)}$, appearing in nearly every publication year in the full range from 1948-2017. SF characters (n=78, yellow bars, Figure 5.16), most of them robots and AIs (see Table 5.9), are found more frequently in records from year 2000 onward.

In the years from 2013-2017, records refer more often (audio)-visual than written SF. This could be interpreted as a focus shift of researchers, away from written, interpretative SF toward explicit SF visualizations of concepts, technologies, devices, characters (especially robots), as they appear in SF movies.

[28] SF technologies, due to their ambiguity as explained in Section 5.5.10 are not considered in this analysis.

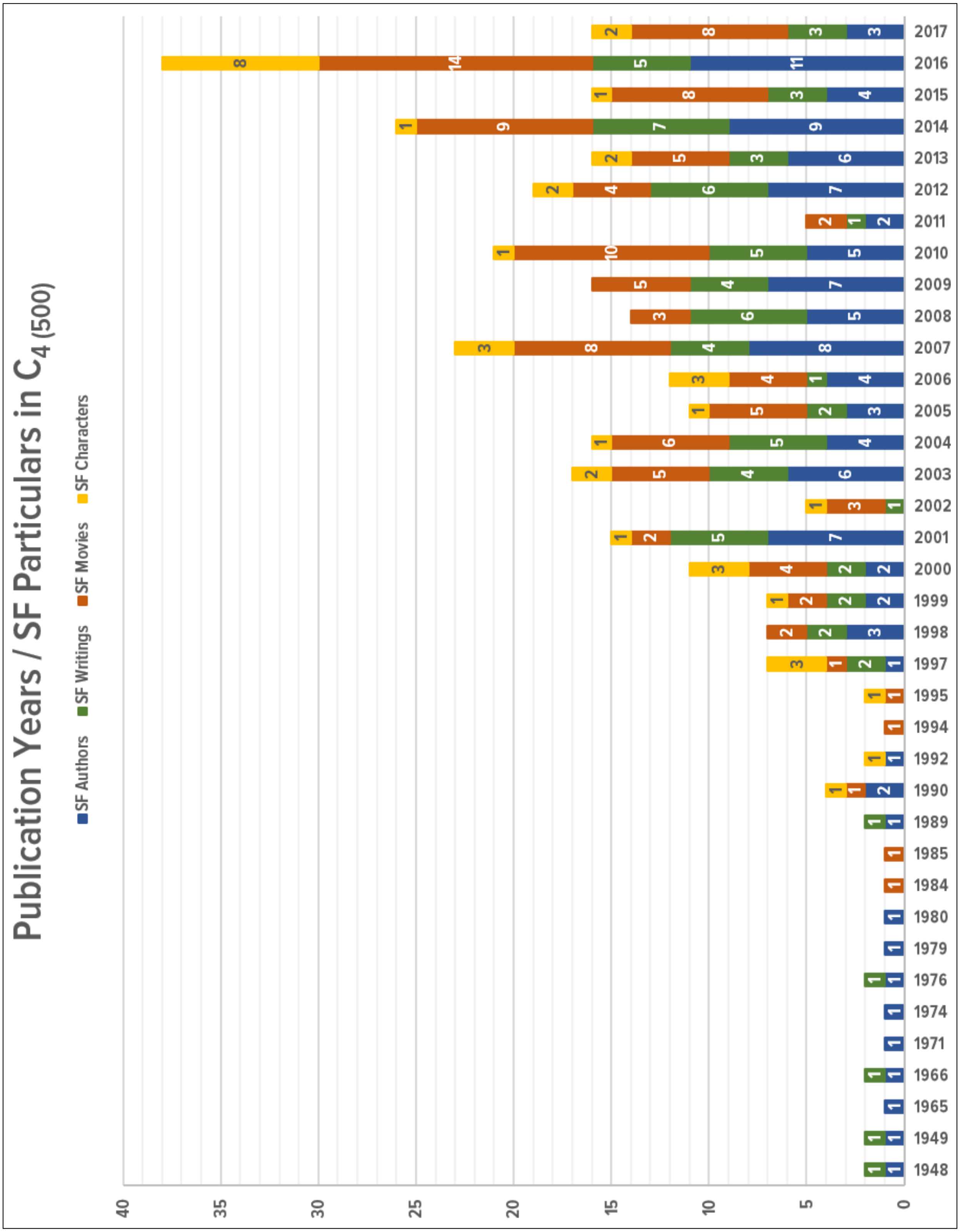


Figure 5.16: Publication Year / SF Particulars: $C_{4\ (500)}$

5.7 Selected Coding Examples: $C_{4\ (500)}$

In this section, selected examples, through quotes, of the most frequent contextual SF referrals for each paper type are presented. In total, 500 contextual SF referrals across all papers in $C_{4\ (500)}$ are coded. Therefore, this section can only provide highlights and partial results and attempts to provide a glimpse into the variety and depth of the uses of SF in each paper type.

5.7.1 $C_{4\ (500)}$: Artifact-type Papers

Figure 5.17 shows the contextual usage of the SF referral in the 46 artifact-type papers in $C_{4\ (500)}$.

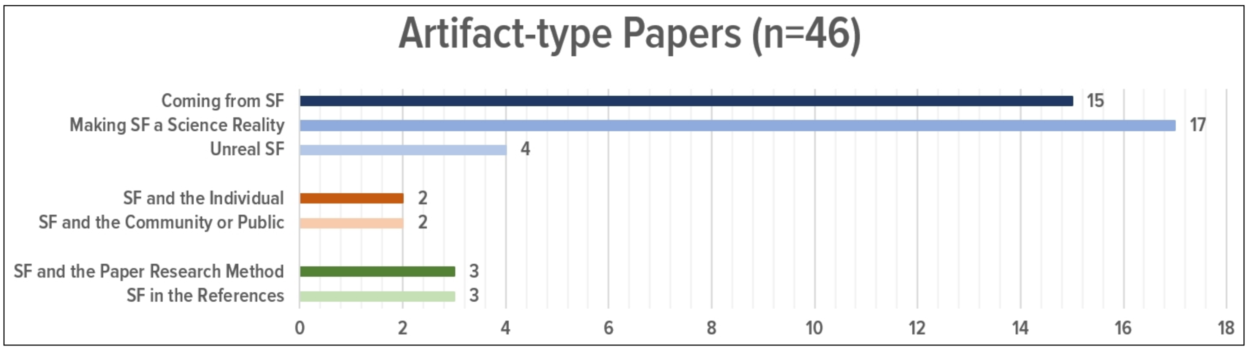


Figure 5.17: Artifact-type papers and contextual SF referral: $C_{4\ (500)}$

The results show that SF references are predominately used to draw innovation into the artifact-type research papers (Coming from SF (n=15), Making SF a Science Reality (n=17)). In comparison, the other remaining five attributes are rather small in count, with referrals ranging between $2 \leq n \leq 4$. Coding examples for the most frequent attributes in this paper category – Making SF a Science Reality and Coming from SF – are illustrated below:

Making SF a Reality (n=17): Instances of the most frequent category, SF referrals to concepts and ideas in artifact-type papers with a focus on turning them into a reality (or approximation therefore), as well as assessing them as being de facto existent, are presented below:

In discussing Augmented Reality (AR) applications, Reinhuber [267, p. 5] finds that:

> *"The gadgets which we are able to use nowadays resemble very closely that visionary device the obscure stranger used in Isaac Asimov's science-fiction story 'What if...?" – written more than sixty years ago – to provide an insight to a counterfactual reality."*

As an example, where SF writers allegedly 'get it wrong', Raghuvanshi, Fan, Woyke and Perkowski identify a discrepancy of the status quo of the field of quantum computing and its realization [263, p. 1]:

> *"Contrary to opinions of some 'popular science writers' quantum computing is not science fiction – quantum circuits are already used commercially for secure communication."*

More examples of this category – representing a varying degree of reality approximation of SF concepts, ideas, devices and technologies in real life and science – are listed below:

> *"This notion ultimately gives birth to the concept of the personal air vehicle (PAVE), which combines the performance elements of both ground and air transportation. In fact, such transportation means have been envisioned few decades ago in many futuristic, science-fiction movies, cartoons and books. To date, several design concepts for PAVE have already been researched in the United States and European countries."* [276, p. 60]
>
> *"Also, some smart TVs let users control their choices with a set of gestures, replacing the traditional remote control. Found only in science fiction movies a few years ago, the above-mentioned scenarios are now present in HCI."* [339, p. 303]
>
> *"Over the past two decades, several studies were performed towards the development of these BCI systems, which don't require muscle control. Although still in its infancy, BCI is no longer a realm of science fiction, but an evolving area of research and applications."* [102, p. 387]
>
> *"Nanorobots remain in the realm of science fiction, though robotics is beginning to approach these dimensions."* [230, p. 2155]

Coming from SF (n=15): In 2014, as a first example of an artifact-type paper (i.p. an input system, device or hardware toolkit), Miyazaki, Maeda and Maekawa [196, p. 211] propose a novel, 3-dimensional display system. The authors state at the beginning of their paper that:

> *"An aerial imaging display such as depicted in a science fiction movie has a great potential in the field of digital signage and entertainment."*

In a research project concerning a walking aid (exoskeleton) for the mobility-impaired, another type of artifact, Johnson, Repperger and Thompson [139, p. 67] find that such devices have been conceptualized and depicted by SF well ahead of the time :

> *"The concept for powered mobility devices, mechanical limbs, bionics, and exoskeletons have existed as far back as early science fiction."*

As a last example for a concept originating in SF, within an artifact-type paper, Mair [197, p. 118] mentions Telepresence:

> *"As an avid science fiction reader I first came across the concept of telepresence in the 1960s. The concept was contained in a short story by James Blish originally published in*

1952 and titled Bridge. Blish tells the story of a construction worker who is physically present on a base on one of Jupiter's moons. He uses a 'helmet' and control panel to be vicariously present on the 'surface' of Jupiter where he is involved in building an ice bridge. He experiences the forces, pressures, winds, and sound through the sensors on the construction vehicle that he remotely controls."

Other examples of artifact-type research papers, which primarily refer to concepts originating in SF are papers concerning robots (robots herein coded as artifacts) in conjunction with Issac Asimov Law's of robotics, holograms (e.g. [277]), perfect speech recognition interfaces, Brain-Computer Interfaces (BCI) and the prior mentioned exoskeletons (e.g. [119, p. 67], [19, p. 22]).

5.7.2 $C_{4\ (500)}$: Empirical-type Papers

Figure 5.18 shows the contextual usage of the SF referral in the 52 empirical-type papers in $C_{4\ (500)}$.

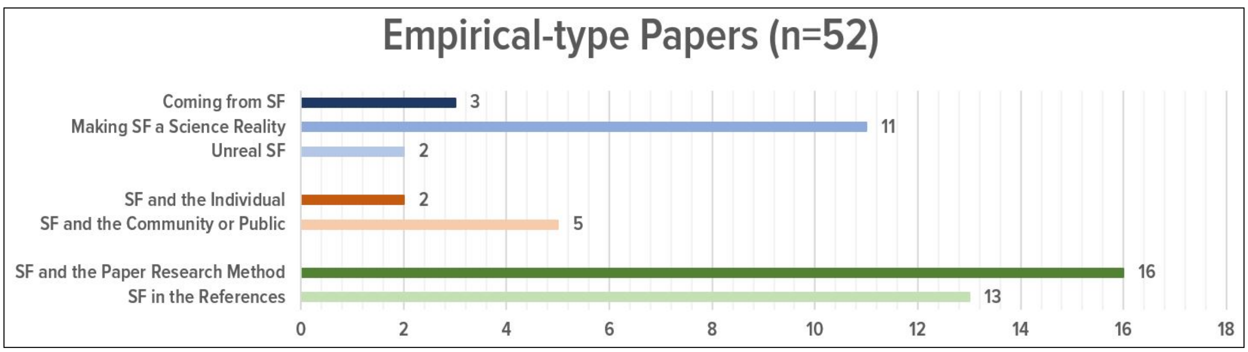


Figure 5.18: Empirical-type papers and contextual SF referral: $C_{4\ (500)}$

The results for empirical-type research contributions show that SF references are mostly used as part of the research paper or method itself (SF and the Paper Research Method (n=16)). With n=13 records, empirical-type papers also mention SF often in the bibliographies (SF in the References) of the research papers while the third most common attribute of contextual SF mentions are referrals to SF concepts, and their conversion from fiction into fact (Making SF a Science Reality (n=11)).

The remaining four attributes are in comparison rather small in count, with referrals ranging between $2 \leq n \leq 5$. Coding examples for the three most frequent attributes in this paper category, SF and the Paper Research Method, SF in the Reference and Making SF a Science Reality are presented below below:

SF and the Paper Research Method (n=16): Often, SF in empirical-type papers is utilized to assess the viability of a possible integration of SF into STEM education through prototypical university-level, introductory courses. For example, Wollowski used SF to foster student creativity as part of an undergraduate research course [353, p. S3A-2]:

"Just before the project proposals were due, my students had to write a science-fiction essay in which they had to create a future world that is dominated by the web. By employing the tool of a science fiction essay, I was hoping to put as few constraints on their imagination as possible and thereby stimulate it."

More examples where SF and STEM or Computer Science Education to advance innovative thinking and creative problem-solving intersect, can be found in engineering courses [246, p. T3H-8]:

"The substance of the course was literature in all its forms. Material was chosen from prose, short stories, science fiction, poetry, causerie, aphorism, drama and radio play."

Other instances of the relationship of SF and education, as part of the category of SF and the Paper Research Method, cover the assessment of the viability of SF as a means to sensitize STEM faculty toward (robot) ethics [241], the uses of SF to motivate highschool students in rural areas to pursue technical careers [208] as well as the reciprocal influence and uses SF film can offer in the field of biomedical instrumentation education and development [47].

A second group of referrals, as part of the empirical-type research papers in this group, utilize SF in a variety of contexts. For instance, SF movies are referred in studies on the popularity of baby names in relationship to the release years of (SF) movies [125]. Other studies where SF referrals are found involve involve qualitative research studies on, for instance children's attitudes and perceptions of robots [354] or questionnaire-type research with domestic robot owners [317] (i.p. owners of Roomba cleaning robots).

SF referrals and examples are furthermore also used as a dystopian story vehicle in studies on trust and fraud in online shopping as well as in papers, where study participants self-identified as SF fans, respectively where SF materials are used to create fictional robot characters and scenarios for a subsequent, empirical evaluation.

SF in the References (n=13) References to SF in the bibliography or sources section of the records in $C_{4\ (500)}$ represent the second most frequent attribute in this paper category. Three examples of SF in the References in this paper category are presented below:

"S. Pope. 'Fly by wire: Fact versus science fiction.' Flying, pp. 53–59, May 2014." [322, p. 8]

"N. G. Hockstein, C. G. Gourin, R. a. Faust, and D. J. Terris, 'A history of robots: From science fiction to surgical robotics,' J. Robot. Surg., vol. 1, pp. 113–118, 2007." [261, p. 6]

"C. Li, J. Cummings, J. Lam, E. Graves, W. Wu, 'Radar Remote Monitoring of Vital Signs – From Science Fiction to Reality', IEEE Microwave Magazine, vol. 10, issue 1, pp 47-56, February 2009." [358, p. 4839]

Making SF a Science Reality (n=11) As one example of an interplay of science and fiction, Ali and Tahir discuss the history of an iris-recognition system, which was envisioned by an ophthalmologist, later depicted by SF movies, and subsequently developed by a computer scientist [5, p. 328]:

> *"However, the idea of using iris patterns for personal identification was originally proposed in 1936 by ophthalmologist Frank Burch, MD. In the 1980's, the idea appeared in James Bond movies, but it remained science fiction. It was not until 1987, two American ophthalmologists, Leonard Flom and Aran Safir patented Burch's concept but they were unable to develop such a process. So instead they turned to John Daugman, who was teaching at Harvard University and now at Cambridge University, to develop actual algorithms for iris recognition. These algorithms, which Daugman developed in 1994, are the basis for all current iris recognition systems."*

Other examples for biometrics in connection with a contextual SF referral in this paper category range from the introduction of implantable Radio-frequency Identification (RFID) chips, [214], respectively large-scale fingerprint recognition and identification services, into real-world environments.

More ideas from SF in the papers categorized under this attribute are human-robot cooperation situations in work settings [256], as well as principal concepts and imaginations of technologies seen in SF. Examples range from the approximation of perfect cloaking / the creation of an invisibility cloak through radio antenna frequency modulation [169] or experimental studies on collective assembly using microrobots [207], a resemblance of the SF-typical depictions of swarm of artificial nanorobots.

5.7.3 $C_{4\ (500)}$: Methodological-type Papers

Figure 5.19 shows the contextual usage of the SF referral in the 38 methodological-type papers in $C_{4\ (500)}$.

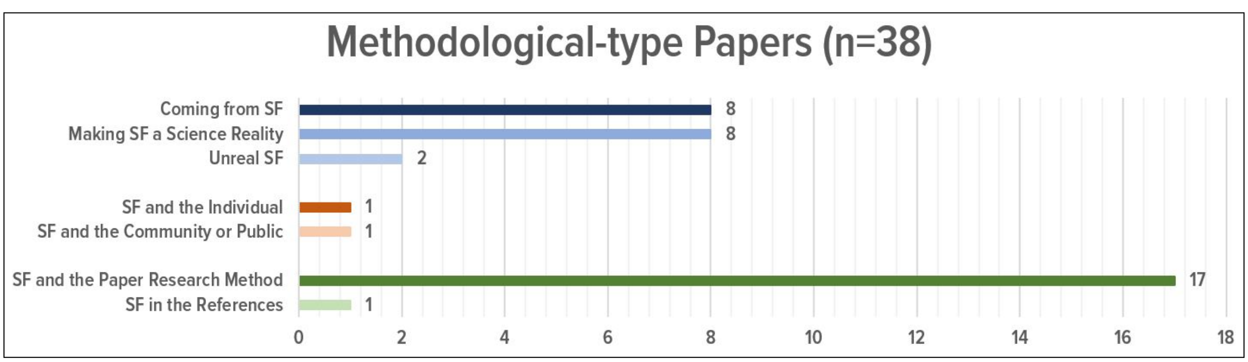


Figure 5.19: Methodological-type papers and contextual SF referral: $C_{4\ (500)}$

The three most frequent categories for the contextual usage of the SF referral in this paper category are SF and the Paper Research Method (n=17) and Coming from SF / Making SF a Reality (each with n=8 referrals).

SF and the Paper Research Method (n=17) In methodological-type papers, referrals of SF and the Paper Research Method occur in a variety of contexts, ranging from research connecting SF to Science Fiction Prototyping (SFP), SF to technology assessment and SF to technology forecasting, from innovative teaching methods as well as in the context of the research subject of the paper. Selected examples follow below:

Mendoza-Garcia and Cardella [213] present a method for design thinking – called 'alien-centered design' – for undergraduate design courses. Similarily, SF is mentioned in a 1999 paper by Stengel [310, p. 1272], who describes a method to teach an undergraduate seminar course on space flight through the partial utilization of SF:

> *"The space program is studied as portrayed in history and science fiction, and an understanding of the critical roles played by organizations, management principles, and budget is developed."*

In a paper introducing a method for adaptive contingency planning, Strong and many others [315, p. 4] differentiate SF and fantasy ideas:

> *"In general, good science fiction ideas are desired, fantasy ideas are not. But we prefer to err by including fantasy at this stage as long as it does not contain any of the three 'omnis' above."*

Another group of papers also refer SF as part of the research method used or applied in the paper itself. Examples are, for instance, the application of SFP [171]) as well as a variety of classification algorithms, ranging from semantic video scene identification [14], film sentiment analysis [126], the recommendation of books [244] or the clustering of book reviews [101]. More examples range from studies of text-classification systems, meta-tag analyses and video compression experiments, In all of the above examples in this group, SF referrals typically occur as part of the research method and data, the implementation of the method or the results presentation.

Coming from SF (n=8) Referrals to concepts Coming from SF in this paper category are presented below.

As an example of a methodological-type paper, which was inspired by a SF analogy, Ashlock and Ashlock [20, p. 1172] introduce new genetic programming technique in the field of AI :

> *"This study presents a new technique for use with genetic programming. It was inspired by a science fiction novel[29] about an all-male society in which children had only a father, and*

[29]Lois McMaster Bujold. Ethan of Athos. Baen Books, Riverdale, NY, 1986.

the female contribution came from artificial womb technology and egg cultures donated when the society was founded."

Similarily, in a 2010 paper on interactive clothing (e-fabric and fashion), researchers did use an SF analogy to extend the presented method and applicability [91, p. 210]:

> *"As mentioned earlier, the images that are substituted for the engrams may have three-dimensional structure and not merely be confined to the garment membrane. In his contraversial 1974 landmark science fiction novel Dhalgren, Samuel R. Delany described gangs that moved through the city with 'projectors' that created three-dimensional holograms around each person. Our concept will produce a similar effect."*

More example of SF concepts found in methodological-type research papers, consist of future outlooks to for example, immersive interfaces, as seen in SF [184], the anticipation of speech recognition in SF well ahead of its realization [227] or the conceptualization of Virtual Reality (VR) in SF [264].

As one final instance of a SF concept located in a methodological-type research paper, Bao and Pahlavan [27, p. 1] relate the idea of the ability to 'look inside the human body' to a popular science fiction novel and show :

> *"Wireless capsule endoscopy (WCE) has been in use for clinical procedure for 12 years. It provides a noninvasive imaging technology of examining the digestive system. Such capsules travel inside the human's gastrointestinal (GI) tract in almost the same way that the micro-spacecraft in the science fiction 'Fantastic Voyage' travels inside the human body."*

Making SF a Reality (n=8) Research, which refers SF and the transition of fictional concepts, technologies and devices into reality encompasses methodological-types from a diversity of topics.

To begin with, in a 2017 paper, scientists find that 'crime prediction', as conceptually described in SF in the mid 1950s, is in fact, a reality [25, p. 2]:

> *"The prediction of crime before it actually happens was highlighted by a 1956 science fiction story authored by Philip K. Dick: 'The Minority Report'. The story was later adapted to a well-known 2002 film with the same name. [...] Aside from fiction, the prediction of future urban crimes is actually possible. It can be done with some imprecision and by computer algorithms using available data from various sources."*

BCI, often dreamt of in SF,are as well approximated through scientific advances, two examples are listed below:

"Brain Computer Interfaces, a mere science fiction less than 20 years ago became reality in fastly growing diverse applications, pushing numerous attractive challenges to broader Artificial Intelligence." [82, p. 93]

"The Human Brain and its thoughts, actions, decisions, perceptions has been quite a scintillating field of study, and thus brain signals have found a growing research in the past two decades. Being able to control external devices with the help of brain signals has made science fiction closer to a reality today." [325, p. 1]

Other examples in this paper category involve SF referrals to nascent technologies, such as non-contact health monitoring and diagnosis [318], full automatic and seamless language translation [335] and autonomic computing.

5.7.4 $C_{4\ (500)}$: Opinion-type Papers

Figure 5.18 shows the contextual usage of the SF referral in the 153 empirical-type papers in $C_{4\ (500)}$.

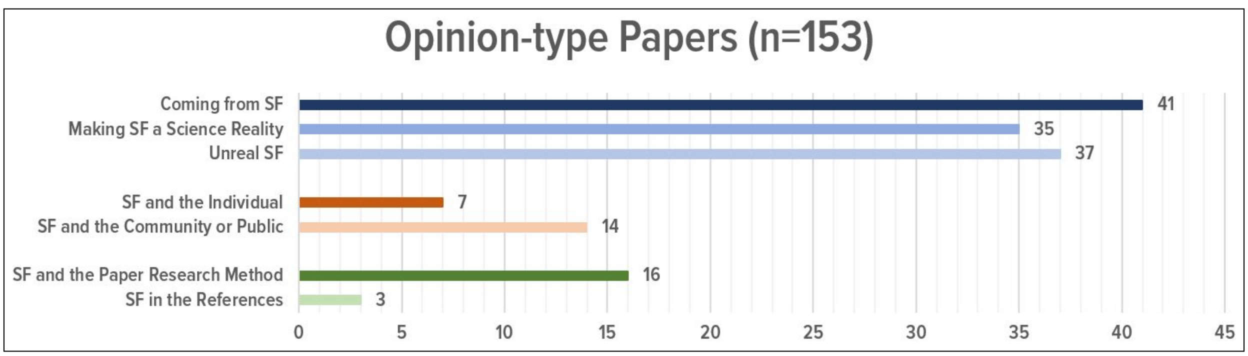


Figure 5.20: Opinion-type papers and contextual SF referral: $C_{4\ (500)}$

Opinionated papers represent the largest category in $C_{4\ (500)}$ and SF referrals mostly occur in research contributions, which integrate SF innovation or inspiration into the opinionated-type papers (Figure 5.18, blue bars).

Coming from SF (n=41) With a focus on the origin in SF literature or movies and shows, a broad selection of technologies, ideas and devices are mentioned in opinionated papers. Selected examples follow below:

The conceptualization, ethical issues and future potentials of AI and robotics are a re-occurring theme in opinion-type research papers. For example, AI ethics were an implicitly long discussed issue in SF, before they became a topic in (computer science) research according to Zheng [363, p. 3]:

"Research interest in AI ethics (broadly construed) is growing, but ethical studies of AI aren't actually new. Before the establishment of AI as an academic discipline, philosophers,

science fiction writers, and futurists were already discussing the ethical ramifications of machine intelligence. Such discussions are the precursors of AI ethics studies. In today's technological backdrop, old and new AI ethical discussion threads alike, to a large extent, are no longer fantasy pastimes. The legal, policy, and societal relevance and significance of AI ethics are now almost palpable."

Similarily, ambient, intelligent system were depicted long ahead of time in SF, for Harwig and Aarts [131, p. 4] state that

"[...] examples of early ambient intelligent systems are shown in science fiction movies. Well-known examples are Stanley Kubrick's 2001: A Space Odyssey, a classic movie from the 1960s in which an intelligent electronic world is depicted with humanlike characteristics. In Total Recall Paul Verhoeven envisions a digitally controlled world with large interactive screens and holographic images. Albert Brocolli uses in many of his James Bond movies examples of intelligent electronic devices integrated into ordinary objects."

SF referrals, which inspire real-world science are for instance, found in the Star Trek franchise [89, p. 677]:

"Gene Roddenberry's science fiction stories used a 'communicator' in the TV series Star Trek which has inspired real scientific work as well as made the general public aware of the usefulness of hand-held 'communicators'. His vision was about how people use technology rather than the technology itself."

More examples in this category are SF references to Isaac Asimov and his widely known three laws of robots [224], cyborgs and wearable computing [3], human augmentation and enhancement [347], virtual environments and VR [56], or more recently, the mixture videogames for military and or entertainment purposes [333].

SF referrals in opinion-type papers also extend from simple visions of future technologies or potential devices toward technologically determinist, ethically questionable utopian [253] or dystopian [71, 123] visions of society. For example, Pitt [253, p. 24] describes a dystopian future in the context of pervasive computing, through a SF novel:

"[...] its premise the 1970s science fiction novel This Perfect Day, by Ira Levin. This latter book imagined a (quasi-)utopian society based on simple provision and (ostensible) equality for all: there is limited individualism (there are only eight names, four for boys and four for girls); everybody is genetically engineered to look the same, and wears the same clothes; the act of choosing is socially unacceptable as a manifestation of selfishness; no one is violent or aggressive; and everyone's basic needs (as defined, for example, by the lowest level of Maslow's hierarchy) are met. However, underlying this perfectly

ordered society there is a central computer (called Uni, or UniComp) which makes every decision: for example, scanners are used to monitor physical actions, and permit or deny access to locations or resources; people are assigned to jobs, places, etc.; advisers are used to identify (and admit) 'selfish' behavior; compliance and docility are achieved by chemotherapeutic 'treatments'; and people die at the age of 65, more or less, for the sake of efficiency."

As a more realistic example, a direct contrast to the ideas of robots in SF is presented in a 2012 article on the contemporary impact of robots in worksettings [103, p. 1]:

"At science fiction literature it can find two basic aspects of the relationship between humans and robots: the destructive, proposed by Karel and Josef Capek in the first historical appearance of the word 'robot', and the constructive, strengthened by the novels of Isaac Asimov. Both are beginning to be assessed today in industry."

Unreal SF (n=37) The second most frequent category in opinion-type papers are referrals to impossible, unrealistic or - at the time of the research paper publication - not existent SF concepts, ideas, technologies or devices.

Examples of SF technologies, far from any realization at the present time, are teleportation or replication of (living) matter [195, 303], cryogenics [154], space exploration including visits to other planets in the solar system [288] and orbital warfare [80] and sentient, autonomous or intelligent robots (androids) and systems, including AI reaching the technological singularity [117].

In an early example from the April 1973 IEEE Electronics & Power magazine, microelectronics and liquid crystal displays are considered a SF [111, p. 135]:

"A lot of this mistrust is understandable when one considers the 'science-fiction' aspects of modern electronics: pinhead-sized circuits that perform complex switching functions; the apparent miracle of 3-dimensional holography; and the latest display techniques such as liquid crystals."

Contrasting dystopian and utopian (unreal) SF in with two separate examples, first, Mills and Fleddermann [217, p. 22] question in a 2005 opinion-type paper the viability of SF imaginations of utopian nanotechnologies:

"Another issue is the science-fiction nature of some nano-inventions. The carbon nanotube space elevator, or nanoreplicators, might well be rejected as being too far-fetched. But the rate of advance is such that the incredible might be realizable much sooner than we think, requiring a fine sense of judgment on the part of the United States Patent Office."

On the other hand, Schifo [286, p. 49] uses a dystopian SF example in an 2005 op-ed, targeted at recruiting talent in the power engineering sector:

> *"What compelling mission could the power industry hold out as inspiration to prospective engineers? In the 1985 science fiction film Mad Max – Beyond Thunderdome, actor Mel Gibson contends with a future plagued by an acute energy shortage. He battles a villain who maintains power over society by controlling its electrical resources. How telling was this dark vision of the future?"*

While both scenarios might or might not became reality to some degree sooner or later, they serve as examples of unreal, non-existent SF, which has not been realized at the time of the paper publication. Furthermore, it is worthwhile to note how a dystopian or dark scenario as described in Schifo is utilized as a motivator to recruit interest for a specific work domain.

As an example of the scientific advancement to human-like robots, androids and AIs (in relationship to SF) over time, a 1988 paper by Little [193, pp. 46-47] views characteristics of smart assistant systems and natural language user interfaces as nascent, at best:

> *"[...] AI investigations are beginning to see practical applications. In the areas of natural language, vision processing, and voice, researchers are providing solutions to problems that only a decade ago would have sounded like science fiction. Despite the activity and partial successes, however, current technology is these areas of human intelligence is limited. [...] Applications of AI in using language are limited to small vocabularies, recognition of isolated words rather than continuous speech, and speaker dependency, where each user's voice must be stored."*

Later on, in a 1994 paper, one of these AI features, speaker independent speech recognition, is assessed as advancing towards reality, though not a scientific fact yet, by Kirkland and Dean [159, p. 471]:

> *"Being able to talk interactively with a computer has been a dream for decades and, until recently, has been considered science fiction. With the advances in speaker independent speech recognition, this capability may soon become science fact."*

Nowadays, smart assistants, such as Apple's Siri, Amazon's Alexa or the Google Voice Assistant, utilize speech recognition and a natural language user interface effectively enabling complex 2-way conversations. These systems are used by millions of users at home and on their mobile devices, representing a class of AI-based virtual assistants, which eventually moved out of SF into reality.

Making SF a Science Reality (n=35) The prior section includes two examples of SF in the context of voice recognition, a 1988 paper by Little [193] and a 1994 paper by Kirland and Dean [159]. Either examples are coded as Unreal SF, at the time of the publications. Tracing this SF concept even further through time, Mulhauser [223, p. 24] in 2007 states that:

> *"In fact, natural language dialogues are a high priority challenge as, e.g., a look at IT centric science fiction can tell: most pertinent books and movies let humans talk to computer in unconstraint language. Such interfaces are still restricted to application domains since present NLP approaches are still far from human performance in 'sense-making'. Lately however, NLP based techniques for 'question answering' (as opposed to formal queries) improved considerably.*

Subsequently, in a 2014 paper on biometric analysis and voice recognition, Ricanek [270, p. 88] clearly sees this SF technology as matured:

> *"The notion of voice recognition, and hence control, dates back to early science fiction and TV programs like Star Trek, in which characters spoke commands into a system that, after authenticating the speaker, executed those hands-free commands. Systems are now being deployed that re-purpose the voice recognition process to better understand the speaker's emotional state, honesty, concentration level, and other attributes that define a person's character and personality."*

More examples in the category Making SF a Science Reality include, among others, opinionated research contributions discussing SF and wearables (i.p. wearable computing, e.g. [309]), human augmentation (biomotor [329] and cognitive [93]) enhancements as well as medical innovations (e.g. [74]).

5.7.5 $C_{4\ (500)}$: Other-type Papers

Figure 5.21 shows the contextual usage of the SF referral in the 63 other-type papers in $C_{4\ (500)}$.

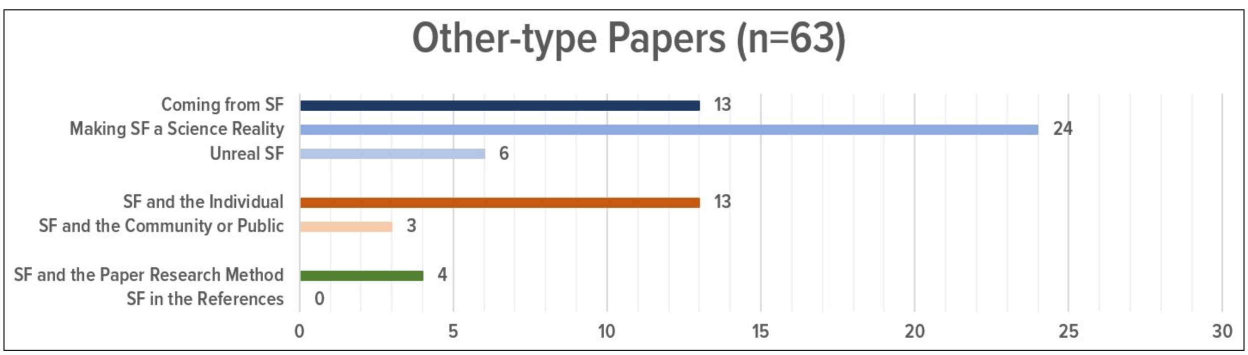


Figure 5.21: Other-type papers and contextual SF referral: $C_{4\ (500)}$

Making SF a Science Reality (n=24) A total of 24 referrals in other-type papers refers to concepts, described or visualized in SF, as being partially or fully realized.

An example from a 1973 paper [67, p. 41] discusses the coming of age of satellite relays, as envisioned by Arthur C. Clare roughly 30 years prior:

> *"As long ago as in 1945, Arthur C. Clarke, the well-known science fiction writer and a former Chairman of the British Interplanetary Society, first put forward the idea of using satellites as relays for communication. An international corporation, International Telecommunications Satellite Consortium (Intelsat) was established in 1964 and Intelsat now has a series of satellites above the Atlantic, Pacific and Indian Oceans providing near-global coverage for all forms of communications transmissions."*

An intriguing instance where a SF reality inspired a researcher (And research) is found in an account of an 2009 IEEE Spectrum interview with James Oberg, a vetereran NASA space engineer:

> *"James Oberg was 11 in 1955 when his grandfather gave him a copy of Jules Verne's classic From the Earth to the Moon. He was hooked by the 19th-century fantasy and dreamed of building spaceships—someday. Two years later, he sat on a sidewalk next to a stack of newspapers intended for his paper route and devoured the front-page stories: The Soviets had just launched Sputnik. No longer was space exploration the stuff of science fiction. It was happening, right now. [...] Oberg went on to work as an aerospace engineer at NASA for 22 years.*

The concept of the Internet of Things, where all devices in our lives are connected, is discussed in three different records in other-type papers:

> *"Our world is becoming increasingly virtual and accessible. The Internet enables dissemination of information on a scale that, not too long ago, was found only in science fiction."* [129, p. 16]
>
> *"Thirty years ago, the idea of 'Connecting Every-Thing' was just a topic of science fiction, but with the introduction and technological advancements and introduction of the Internet, the fiction has become reality."* [331, p. xxxiii]
>
> *"Things once considered as ingredients to the science fiction movies are quickly becoming a reality. The future Internet will be capable of connecting & communicating with almost all physical and virtual objects around us to the existing Internet."* [168, p. 1]

More examples of SF referrals in other-type research contributions, with focus on their realization, include the area of human-like androids [237], robots and autonmous systems [70], including the potential utilization for such systems for warfare and military contexts [296].

Coming from SF (n=13) A diversity of concepts originating from, or being traced back to SF, are referenced in this category.

As one example, the Metaverse, a concept which refers to 3D interactions in virtual environments, is rooted in a science fiction novel according to 2007 IEEE Editor's Note by Nikolaidis [235, p. 2]:

> *"Ample speculation surrounds the extent to which Metaverses will have (are having) an impact as the next big thing in networked applications. The origins of the word Metaverse is rooted in science fiction[30], but the term applies collectively to existing immersive virtual worlds ('Meta'-Universes). A less exotic definition is that Metaverses are essentially the extension of web-based interaction from "2-D web' to '3-D web."*

In 2016, Smith [305, p. 84] describes the origins of the research field of AI in 1956 of AI was a successor to SF conceptualizations in SF writings:

> *"We all feel that we understand AI to some degree because it is something that has come out of popular culture. Science-fiction writers were addressing this a long time before the technical field itself was formalized as its own discipline in 1956."*

Other SF references in this category mention SF visions of pervasive computng [78], genetic engineering visualized in the SF film GATTACA [106] and visions of human spaceflight [77], written about by Jules Verne and visualized through early filmmakers, such as Georges Méliès.

SF and the Individual (n=13) Examples of SF references, which focus on a person, researcher or SF author in the context of the SF referral cover mostly scientists, who were inspired by SF to pursue a technical career, who are engaged in both, SF writing and traditional research [136, p. 1040], who are hobby SF enthusiasts [327, p. 636] or report on honorary awards, dedicated to SF authors in the context of their influence on technical domains (e.g. Hugo Gernsback [232, p. 136] or Marvin Minsky or Marvin Minsky [60, p. 22]).

As an early example, representing the earliest retrieved record in $C_{4\ (500)}$ dating back to 1948, J.R. Pierce's accomplishments as both researcher and SF author are described [249, p. 195], who:

> *"[...] has written articles for both popular and technical engineering magazines and [...] writes for the magazine Astounding Science Fiction under the pen name of J. J. Coupling."*

70 years later, when asked for the reason in pursuing his professional carrer in a 2016 IEEE Control System Magazine interview Aaron D. Ames, a renowned Professor in Mechanical and Civil Engineering at CalTech, replied that SF was the seed of inspiration [1, p. 21]:

> *"It probably started with reading science fiction. I read every book I could get my hands on, most notably the works of Asimov, and these painted a picture of technology—and especially robots—that I found deeply compelling. During my undergraduate work, while studying mechanical engineering and mathematics, I started to see how math must underlie this idea of the future."*

[30] N. Stephenson, 'Snow Crash,' Bantam Spectra Book, Bantam Books, 1992, New York.

5.7.6 $C_{4\ (500)}$: Survey-type Papers

Figure 5.22 shows the contextual usage of the SF referral in the 71 survey-type papers in $C_{4\ (500)}$.

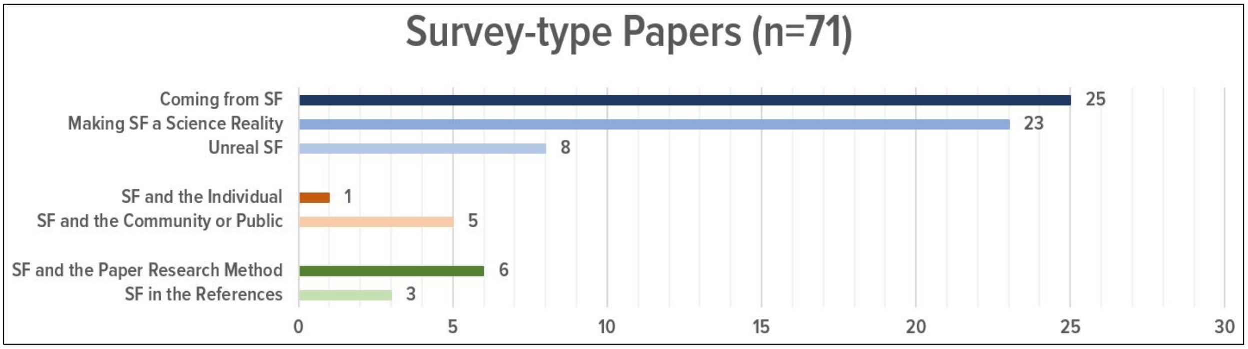


Figure 5.22: Survey-type papers and contextual SF referral: $C_{4\ (500)}$

Coming from SF (n=25) Instances of survey-type paper which discuss SF concepts as known from written fiction or movies occur on a range of topics, among those references to Asimov's Three Laws of Robotics [242], computer viruses able to paralyze large-scale weapon systems [297] or multi-modal augmentation and skill enhancement of either, people with disabilities [2] or soldiers [127] in military settings.

An intriguing example is a the below excerpt from a 2004 paper on context-aware systems by Brézillon [52, p. 7], who describes a french SF novel from 1969:

> *"In 1969, Frederik Pohl*[31] *wrote a science fiction novel called 'The Era of the Satisfactor'. In the story, each person possess a mobile device – called Satisfactor – by which the person can order and buy a product, pay something in a store, have news, communicate with another person, command the TV channel, control what the children are doing, and even can receive (or send on someone) some chemical drugs (e.g. a relaxing drug). As a corollary, if a person loses his satisfactor, this person is anymore a person recognized by the society, cannot buy food, etc. This is a novel of science fiction. However, some research is in the realm of this story: identification of a person entering a room, location of a person from his cellular phone, payment through internet, etc. The focus is now on mobile devices, and the hardware aspect of such devices would be soon under control."*

Another great example, where concepts from SF are utilized as a pop-cultural device, is demonstrated in Sterritt's 2012 paper on apoptotic computing [312, p. 1]:

> *" 'Scientists fear a revolt by killer robots' was a headline in the UK's Sunday Times reporting on scientists who presented their findings at the International Joint Conference*

[31] Pohl, F., "L'ère du Satisfacteur". Paris: Librairie des Champs Elysées, Série Science Fiction, 1969.

for Artificial Intelligence in Pasadena, California, in July 2009, feared that nightmare scenarios, which have until now been limited to science fiction films, such as the Terminator series, The Matrix, 2001: A Space Odyssey and Minority Report, could come true."

Making SF a Science Reality (n=23) A broad variety of topics, technologies and devices are found in association with SF referrals in survey-type papers.

One topical area in the late 2000s in survey-type papers is that of nanotechnology in medical applications. Examples, which are associated with Making SF a Science Reality in surveys range from nano-robotics in biomedical applications [321], non-contact health monitoring through radio waves [185] or health diagnosis using medical nanotechnologies [6].

As two examples of the topic of speech recognition and natural language user interfaces, Wilpon and Mikkilineni [350, p. 23] resort in 1990 to the Star Trek depiction of human-machine communication through two-way conversations:

"Conversing with a computer is commonplace in science fiction, for instance, Captain Kirk of Star Trek talking to the computer of the Starship Enterprise. But practical systems for conversing with computers about elementary tasks are no longer just science fiction; they are an emerging reality. As speech recognition technology progresses, we will see the evolution of systems – simple at first but becoming more powerful – that let us talk to machines as easily as we converse with other people."

Bolei and Semwal [42, p. 212] mention in 2012 general SF writings and movies in the context of voice-only control of a system:

"Sound can be used to control devices in a number of ways. Full control of a system using only natural language speech has been featured in science fiction novels and movies for a long time. Though actual technology has a long way to go before such a system is possible, limited versions now exist which are capable of performing different actions based on spoken phrases."

SF and the Community or Public (n=5) Examples from the attribute SF and the Community or Public, which, due to their overall scarcity in $C_{4\ (500)}$ have not been presented in the preceding categories, are concerning media effects of SF and the consequences on the public understanding, expectations and fears of science and future technologies.

For instance, SF and the relationship to robots, as outlined in prior examples earlier, also has a larger effect on the greater public according to [120, p. 144]:

"On the societal side, robotics differs from other ICT areas in that it designs machines that are frequently used to represent the hopes and fears of humankind. When a robot

leaves the laboratory to interact with people in a social context, it ceases to be a mere physical object and becomes a sociotechnical system. Oftentimes these hopes and fears, amplified by media and science fiction, resound in a vague or excessive manner."

5.7.7 $C_{4\ (500)}$: Theoretical-type Papers

Figure 5.23 shows the contextual usage of the SF referral in the 77 theoretical-type papers in $C_{4\ (500)}$.

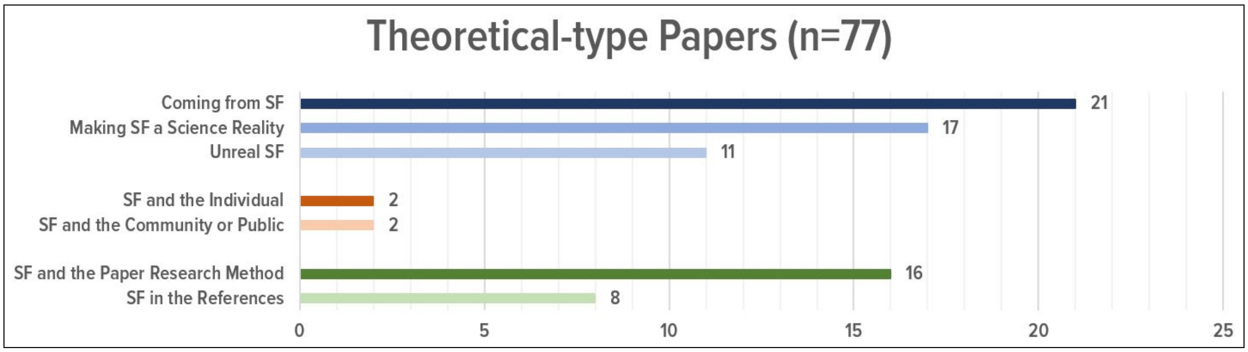


Figure 5.23: Theory-type papers and contextual SF referral: $C_{4\ (500)}$

Coming from SF (n=21) Examples, in the category Coming from SF range in theoretical-type papers frequently discuss SF and AI, robots, as well as the prior mentioned Three Laws of Robotics from Issac Asimov (e.g. [24, 28, 269, 218]), for example [50, p. 470]:

"The most popular approach among technologists has been to envision equipping such systems with social laws that would encourage "good" actions and discourage "bad" ones [9[32]]. The idea of building strong social laws into intelligent systems can be traced at least back as far as the 1940s to the science fiction writings of Isaac Asimov [2[33]].

More examples, where direct concepts from SF are cited in theory-type research contrubtions in $C_{4\ (500)}$ are presented below:

" 'Worms', introduced in [1[34]] and inspired by a science-fiction novel [2[35]], are self-replicating, segmented, distributed systems." [11, p. 403]

" The cyberspace as a term was first introduced to the world by the science fiction 'Neuromancer' Novel's author, William Gibson in 1984 [12[36]]. According to Gibson,

[32] Bradshaw J.M. et al. (2004) Making Agents Acceptable to People. In: Intelligent Technologies for Information Analysis. Springer, Berlin, Heidelberg.

[33] Asimov, I. (1942). Runaround. Astounding Science Fiction, 29(1), 94-103.

[34] John F. Shoch and Jon A. Hupp. 1982. The "worm" programs—early experience with a distributed computation. Commun. ACM 25, 3 (March 1982), 172-180.

[35] Brunner, J. (1975). The shockwave rider. New York: Harper & Row.

[36] Gibson, W. (1984). Neuromancer.

Cyberspace is a network space of digital data stores with connectivity for access and interaction through a computer connection." [336, p. 107]

Making SF a Science Reality (n=17) More of SF referrals approximating science reality in theory-type papers with a focus algorithmic modelling are located in topics including, but not limited to, robot-supported rehabilitation of humans [349],nanotechnology [278] and nanobiology [254], natural language interfaces [167, 100] and autonomous driving [62] and roadway systems [283].

In a example paper from 2012 proposing the utilization of biological principles in technical fields, Ackovska, Bozinovski, Bozinovska [4, p. 1] find that:

"Although the term "genetic engineering" was coined 1951 in a science fiction novel by Williamson (reprinted in [1[37]]), it was not until 1970s when the first achievements in DNA modification showed that genetic engineering is actually happening. However, for us, as computer engineers, the most important discovery that molecular biology offered, was the moment when biology data was recognized as information processing data."

In a second example of a theory-type paper, which introduces a kinematic model for underwater gliders, a SF novel is credited with imagining such a concept ahead of its actual realization [359, p. 1]:

"After Henry Stommel first described the concept of underwater gliders in his science fiction article 'The Slocum Mission' published in Oceanography in 1989, some outstanding gliders, such as Spray, Seaglider, Soclum02, ALBAC, the XRay, Deepglider, STERNE, USM and PETREL-II, appeared and had been applied in many fields."

SF and the Paper Research Method (n=16) Examples of SF referrals, integrated as part research contribution, range from methodological approaches, for instance Science Fiction Prototyping (SFP) in learning and creativity settings (e.g. [84, 247, 245]) to SF in formal education and classroom environments.

For instance, on the topic of SF and undergraduate computer science education, Sedlet [293, p. 252] finds in his 1999 paper on computer ethics, laws and society that:

"[...] course material can be tailored to the interests of the students. Homework assignments and discussion that involve movies and science fiction novels are quite relevant to the subject matter and invoke interest in most students. Anecdotes and professional 'war stories' are usually entertaining and can be used to convey key points".

In a similar instance, Piepmeier, Bishop and Knowles [252, p. 37]identify multimedia functions – namely SF films – as one of three basic principles in innovative robotic engineering instruction:

[37] Williamson, J. (2002). Dragon's Island and other stories. Waterville, Me: Five Star.

"Hollywood produces an ever-increasing number of (SF) films that explore the possible roles of robotics within our society. These include Metropolis, 2001:A Space Odyssey, Short Circuit, the Star Wars films, Bicentennial Man, and the recent A.I. During the advanced robotics course at the United States Naval Academy, students view a set of selected scenes from such films, including scenes where intelligent robots are bought and traded, discriminated against, express emotions,are treated with affection,or are used to perform special tasks, including combat. After the video presentation, the instructor initiates a class discussion on robotic issues and ethics."

5.7.8 Summary

This section presented the main results of this dissertation in a consecutive manner, from the initial identification of potential candidate repositories, to the testing of multiple variations and iterations of metadata or full-text search and retrieval queries for SF in these candidate repositories.

The results presented next the steps and reasoning, which lead to the identification and retrieval of four candidate sets via a 2*2 retrieval approach (full-text or metadata-based) in either, the ACM and IEEE *Xplore* Digital Libraries.

After the decision to move forward with C_4, a descriptive analysis of its characteristics – among those publication years, venues and keywords – before ($C_{4\ (2784)}$), and after ($C_{4\ (1647)}$) the application of search facets, is presented. In addition two subsets, the random subset of 500 papers ($C_{4\ (500)}$) and the inter-rater set ($C_{4\ (125)}$) are analyzed with regards the location and frequency of the SF referral(s).

An inter-rater reliability review of $C_{4\ (125)}$ for two interpretative variables, the type of the research paper under review and the contextual usage of the SF referral resulted in substantial agreement for cohen's κ, respectively allowed tentative conclusions in the case for Krippendorff's α.

In the remainder of the results, the usages of SF referrals across paper types in $C_{4\ (500)}$ are highlighted. Among others, the results showed a tendency of researchers to mention SF primarily in opinionated research papers, most often for reasons to draw innovation and inspiration from SF into science. The results also indicated that researchers, who referenced SF, focused predominantly on a narrow, seminal, Western selection of well-known SF novels, authors, movies and characters.

A descriptive trend analysis of $C_{4\ (500)}$ showed that SF was early on found mostly in other- or opinion-type research contributions, with a 'diversification' of referrals across paper types from the 1990s onward. In the years from 2013-2017, the investigated records in $C_{4\ (500)}$ refer more often (audio)-visual than written SF, potentially indicating a shift of researchers toward utilizing SFMS instead of literary SF in the future in CS / HCI research science communication.

To substantiate the presented, descriptive results, the SF—science relationship in research communication is highlighted via 50 representative example quotes, as outcomes of the content analysis of $C_{4\ (500)}$, which concludes the resutls chapter.

CHAPTER 6
DISCUSSION

This chapter will provide a discussion of selected results of this dissertation, divided into two main parts. First, a critical examination of the key results of this dissertation is presented. Second, the limitations of the study design and results are addressed.

In the former part, the discussion will cover the i) SF referral frequencies and locations, the ii) paper types the SF referrals appear in and, iii) the utilization of the SF referrals in the context of the publications in $C_{4\ (500)}$. Next, the discussion will focus on the SF specifics, in particular, the most often retrieved iv) SF authors and writings, v) SF movies and characters and vi) SF technologies. Finally, the discussion will engage with trends over time identified in $C_{4\ (500)}$, including a chronological analysis of vii) paper types, viii) contextual SF referrals and ix) SF Particulars. At the end of the first part of the discussion, a critical, synoptic assessment of x) SF in HCI and computer science concludes the section.

In the latter part, the discussion addresses discrete limitations of the presented study, among those methodological shortcomings and validity considerations with regards to the the study results and analysis.

6.1 Selected Results

i) SF Referral Frequency and Location: With regards to the frequency and location of the SF referrals in $C_{4\ (500)}$, the study outcome demonstrates that SF referrals occur in the majority of cases one single time in the full-text of the 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 $C_{4\ (500)}$).

At face value, this can be interpreted as such that the majority of authors, who refer to some sort of SF, at the end do not focus on SF in their research contributions per se. Instead, most often scientists 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 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, as well via the qualitative codes presented in the results chapter of this dissertation. Furthermore, this finding conforms to the results found in pilot study 2 [151], in which the majority of the reviewed records (30%) did as well refer one single time, one (of six possible) SF search term(s).

ii) Types of Paper: In cases where researchers resort to SF, the analysis of $C_{4\ (500)}$ shows clearly that opinionated research papers are *the* preferred outlet of research contributions for (computer) scientists, who publish in the IEEE *Xplore* Digital Library. In other words, opinionated research dominates in cases when authors decide to mention and refer to SF. This finding confirms the results in pilot study 3 on the topic of the usage of SF robots in HRI research [222], which identified philosophical and opinionated papers as the most frequent category of research contribution type.

Unsurprisingly, this dominance of opinionated 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, with a focus on a SF-link in traditional computer science and STEM research, SF was often utilized via its main intended function, a commentary and envisionment on future, socio-technical possibilities.

In fact, one of the earliest mentions of the term SF can be found in Wilson's [351, pp. 137-139] A Little Earnest Book upon a Great Old Subject: With the Story of the Poet-Lover from 1851. Wilson wrote almost 170 years ago that, SF can 'reveal the truth of science' by means of an 'interwoven story', which may be both imaginative and accurate thus finding SF to be of 'complementary nature' for science:

> *"We hope it will not be long before we may have other works of Science-Fiction, as we believe such books likely fulfill a good purpose, and create an interest were, unhappily, science alone might fail."*

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

In addition, methodological-type papers – after dataset-type papers with n=0 referrals – are the least frequent type of research paper of referring SF. This result is reasonably explainable due to the fact, that the contextual SF referral in methodological-type papers is in majority stemming from a practical integration of SF into the research method or application, such as a method to recommend entertainment content, among those 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, opinionated (n=153 records) and dataset contributions (n=0), another interesting observation with regards to the totality of paper types in $C_{4\ (500)}$ is the somewhat evenly distribution of the remaining five paper types, ranging between n=38-77 records per category. Perhaps this indicates that SF is furthermore a 'jack-of-all-trades', as scientists utilize it 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. As such, emphasizing some aspects of SF and understating others might lead to a fallacy of incomplete evidence. This observation can be exemplified in a contemporary, ethically strained research topic, identified in the SF concepts found in $C_{4\ (500)}$; autonomous military robots, drones and unmanned aerial vehicles.

One hand hand, theoretical and survey-type articles on the topic (e.g.[28, 8]) outline the proliferation and beneficial technology outcomes of smart, autonomous drones as the coming-of-age of SF dreams. For instance, Barfield [28, p. 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' is not presented, nor any sort of explanation what would happen in such case. As a reminder, 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. [296, 123], 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.

Further thoughts inevitably lead to the notion of Institutional Review Boards (IRBs), established in the 1970s in the United States in response to gone awry psychological, behavioural, and medical studies. For almost a semi-centennial time period, IRBs ensure that humans are not harmed in the context of a scientific research project, directly or indirectly, immediately or longitudinally. A pertinent question arises: What about technological harm? Should Technological Review Boards implement standards for the ethical, complete and consequential conduction and presentation of research accordingly?

To name one example effort, the relatively new Center for Human Technology, a non-profit organization, founded by former Silicon Valley leaders in 2012 has been called the 'closet things Silicon Valley has to a conscience' [45]. Maybe the efforts undertaken by the Center for Human Technology and alike will lead in the near future to a more critically evaluation of devices, interfaces and technologies, which are developed and brought to market at an incredible pace, integrated in virtually every aspect of life.

While 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.

iii) Contextual SF Referral: The analysis of the contextual usage of the SF referrals in $C_{4\ (500)}$ 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 in $C_{4\ (500)}$. Herein, SF is the 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 found in $C_{4\ (500)}$, as part of this coding group, 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 meshed-in 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 science fiction prototyping and, iii) SF as a means to forecast future technological developments.

These results clearly show that SF in $C_{4\ (500)}$ 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 $C_{4\ (500)}$.

This is both, a remarkable result and powerful display of the inherent strength and advantage SF can provide to scientists. While certain key technologies seem to be more often associated with SF than others, e.g. robots, AI, NLI, or BCI, Table A.5) provides the reader an uncurated list of nearly 300 SF ideas, concepts, technologies, devices and interfaces, found in the analysis of $C_{4\ (500)}$. This diversity of SF imaginations identified in $C_{4\ (500)}$ 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, franchise or concept.

vi) 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 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 $C_{4\ (500)}$.

An interesting relationship of the effect of pop-culture in science communication in the analysis of $C_{4\ (500)}$ is the following observation: A 'SF triumvirate' held by Isaac Asimov, Arthur C. Clarke, and Robert Heinlein in the first golden age of SF [179, p. 81]:

> *"[...] 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. In addition, Roberts [272, p. 31] finds that:

> *"[...] the so-called 'Golden Age' of science fiction, from the late 1930s through to the early 1960s, the term 'Science Fiction' [...] 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 communication, 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 conjecture is plausible and supported by anecdotal evidence, for instance, by Carl Sagan, who stated in a New York Times essay in 1973 [279] that SF had been a seminal factor and forerunner to pursue his scientific career as astronomer, science communicator and SF author:

> *"Such ideas, when encountered young, can influence adult behavior. Many scientists deeply involved in the exploration of the solar system (myself among them) were first turned in that direction by science fiction. And the fact that some of that science fiction was not of the highest quality is irrelevant. Ten year-olds do not read the scientific literature."*

v) SF Movies 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: The Next Generation and others, see Table A.3), was assumed a given in pilot study 2 [149], which investigated exclusively Star Trek references in the ACM Digital Library. The overall broad creative offering of Star Trek technologies in both, pilot study 2 and this dissertation provides evidence of the potential effect on scientists this specific SF franchise offers.

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, serving as both, utopian imaginations of future human-robot cooperation and dystopian horrors of technological disobedience and men-versus-machine scenarios, are providing full-fledged examples, highly relevant to computer science research. As a matter of fact, pilot study 3 [222] 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.

vi) SF Technologies: With regards to the SF ideas, concepts, devices, technologies and interactions found in the context of the SF referral in $C_{4\ (500)}$, the results, in the current state, do not permit a clear interpretation. Due to the ambiguity of the coding and the sheer diversity of the 284 attributes in this variable, a second-level content analysis seems warranted first, a limitation addressed in Section 6.2 and Chapter 7.

vii) Chronological Analysis of Paper Types: The analysis of paper types in $C_{4\ (500)}$ over time shows that SF referrals occur as early as in 1948 in the analysis of $C_{4\ (500)}$. As SF referrals are used by authors in their research papers over a time frame of more than 6 decades, this indicates that computer science researchers resort to SF referrals since the (prior introduced) first 'golden age' of SF. In addition, the chronological trends of paper types (which refer SF in the full-text) in the IEEE *Xplore* Digital Library show that other-type research contributions are found more often than any of the alternative types research contributions in a period from approximately 1984-1986.

As such, a possible explanation could be a 'convergence' of SF and real-world science, from an initial utilization in mostly unconventional, non-research contributions from the mid 1950s first, toward, from the 1990s onward, a later a later usage in essentially all possible types research contributions. This potentially suggests, that authors and researchers did use SF in early years as a 'trope' or 'gimmick' in alternative contributions, until SF in computer science research matured into a more viable topic, with however, a clear focus on opinionated research, ever since.

viii) Chronological Analysis of Contextual SF Referrals: With regards to the analysis of the contextual SF referral across publication types as well as over time, the results show that in the time period of 2014-2017, 'Making SF a Science Reality' represents the most frequent attribute $C_{4\ (500)}$ per year. Possibly, this represents a slight swing toward a utilization of SF examples, concepts, device and ideas, which are more founded in real world scientific achievements, away from an accreditation the inspiration SF can provide.

ix) Chronological Analysis of SF Particulars: The analysis of the four SF particulars[38] – i.e. the SF authors, SF writings, SF movies and SF characters – shows that more records refer SF movies (n=115 binary referrals) than SF novels (n=78 binary referrals). Surprisingly, 112 records (binary counts) refer at least one of the SF authors found in $C_{4\ (500)}$ while SF characters (n=39 binary referrals), represent the most scare type of SF particular.

Furthermore, SF authors and novels are the most frequent type of SF referral per record from 1948 until the turn of the millennium, which is the point in time when SF movies are more frequently referenced going forward: From 1948 to 1999, 11 records refer a SF writing, while 10 publications mention a SF movie. From 2000-2017, this equal referral of written and audio-visual fiction changes considerably: 67 records refer a SF novel, short story or book, while 105 papers mention a specific SF movie or show.

While SF authors seem everlastingly popular across publication years and time in the records analyzed in $C_{4\ (500)}$, SF novels, in direct comparison to SF movies, seem to be less often utilized in computer science research.

A detailed view of the most often referenced SF films and shows, refereed in the records in $C_{4\ (500)}$, shows a production date of most SF films and shows in the late 1970s[39] or later. On the other hand, the SF novels found in $C_{4\ (500)}$ were published as early as 1942, for instance Isaac Asimov's RUNAROUND. Another case is the popular SF magazine ASTOUNDING SCIENCE FICTION, which printed its first issue in 1932, and later published Asimov's influential I, ROBOT in 1950.

Clearly, SF writing had head start before SF film was introduced to the general public, including scientists and researchers. A possible explanation for this observation can be the technological advances (i.p. CGI) in SF film production (see Johnston's [142] epochal classification of the SF

[38]The SF ideas, concepts, technologies, interfaces and devices variable is not considered in this part of the analysis, a decision which is addressed in the limitations (see Section 6.2 and Chapter 7).

[39]Only the the original STAR TREK TV show (first aired in 1966), Stanley Kubrick 2001: A SPACE ODYSSEY (released 1958) and the SF / fantasy movie FANTASTIC VOYAGE (released 1966).

film in Chapter 1). The usage and appropriation of SF in $C_{4\ (500)}$ over time , indicates a reflection and influence of popular culture in computer science communication, and as such computer science research and development.

x) SF in Computer Science: This dissertation did aspire to investigate the usage of SF in computer science research for many reasons, one of them being the fact, that no other studies were found, which provide a clear view on this interdisciplinary linkage of art and science, in the context of research communication.

Even though sources and studies on the general distribution of research study types in the IEEE *Xplore* DL are not accessible, the simple fact that the database lists in April 2019 around 4.85 million records in total, and retrieves at the same time, 3859 records for a full-text search for "science fiction" shows that SF, in the IEEE *Xplore* DL is mentioned in less that 0.1% of the indexed records.

In contrast, a full-text search for "algorithm" returns 1.8 million records (40%), a full-text search for "artificial intelligence" returns 233,000 records (5%), hence in the grand scheme of things, SF referrals might appear negligible and insignificant at first glance. While it needs to be noted, however, that the IEEE *Xplore* DL self-identifies as a resource for electrical engineering, computer science and electronics research articles and not English literature or poetry[40], there is more to the story of SF than the analysis quantitative frequency distributions.

It still can be reasonably assumed that a different full-text search for a more technical term[41] would retrieve more methodological-type papers and probably less opinion-type contributions, however, this assumption can not be verified in the presented study.

6.2 Limitations

As any other research study, this dissertation has its unique limitations, which range from the chosen, exploratory research design, targeted at evaluating science communication, the search and retrieval approach, the sampling of records, the utilized coding scheme and subsequent IRR evaluation and lastly, the interpretability of the results. These limitations are addressed in this section.

i) The analysis of science communication: First, the study and interpretation of science communication is a subjective matter. While the evaluation of quantitative results in science might be less prone to interpretation bias, case in point controlled laboratory experiments in contrast to field research, any review and analysis of peer-reviewed work might be prone to researcher bias and misjudgment.

[40] Fields listed in, for instance, the EBSCO humanities source or Gale's LitFinder.

[41] For example search terms stemming from a computer programming or software engineering vocabulary, such as 'algorithm, 'source code or 'operators'.

In this dissertation, both, quantitative and qualitative data is presented. The quantitative data analysis consists in essence of in vivo frequency counts of references to specific keywords in the metadata of $C_{4\ (500)}$ and frequency distributions of SF referrals over a subset of scientific records. In addition, the study provides descriptive, quantifiable counts on the relative presence (binary counts) and absolute referral (absolute counts) of SF authors, SF literature works, SF movies, SF characters and SF technologies.

With regards to the quantitative frequency counts of the SF technologies, one limitation is the fact that it is vague, *what* a SF technology or concept constitutes in the first place. This is limitation is born out of the fact, that SF itself is an ambiguous term. This limitation was addressed in this dissertation with a simple convention. If a technology occurred in the context of the SF referral, it was coded in vivo as an concept, technology, idea, device or interaction, associated with that referral. The future work outlines a follow-up study of this sub-result of this dissertation.

ii) Search query: Yet another limitation is the deliberate choice to use a singular search term in the retrieval of C_4 – "science fiction" – instead of a search for different, suitable SF synonyms (e.g. space opera, futurism or science imagination) or specific SF authors, movies or books. The decision to use one singular retrieval term was based on creating an inclusive and relevant candidate set, which does not give preference to a specific SF book or franchise.

Said 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". As the query for "science ficiton" in C_4 was a full-text retrieval returning the largest cache of records — about 2784 for $C_{4\ (1647)}$ — it was expected (and later on confirmed) that specific SF terms and concepts will be identified when utilizing a singular search term.

iii) Search and retrieval approach: 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 fully not 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%.

iv) Sampling method: 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, as for instance, the comparative publication year analysis of all C_4 sets (see Figure 5.3) shows, the distribution of records of $C_{4\ (500)}$ does principally re-ensemble the distributions of records per year in both, $C_{4\ (1647)}$ and $C_{4\ (2784)}$.

v) Inter-rater reliability: In order to ensure a basic appropriateness in the measurement of the two interpretative variables in this study – the type of research paper and the contextual SF referral – a IRR evaluation of agreement of $C_{4\ (125)}$, a subset 125 randomly selected publications from $C_{4\ (500)}$ was conducted.

The results of the IRR were calculated through Cohen's κ and Krippendorff's α coefficients. The variable type of research paper retrieved a κ of 0.71 and an α of 0.71, the variable contextual SF referral retrieved a κ of 0.65 and an α of 0.68. These values are acceptable, indicating a substantial agreement for cohen's κ and allowance for tentative conclusions for Krippendorff's α. However, the agreement/disagreement coefficients in all four variations did not reach a level of almost perfect agreement in the case of Cohen's α, and more importantly, the threshold for good reliability with regards to Krippendorff's α.

With regards to the paper type, Wobbrock and Kientz [352] state that very often multiple paper types co-occur and as such, could apply to a research contribution, hence, complicating the assessment of a specific paper type. While an initial training and two check-ins with the second Rater were conducted before and during the independent assessment of $C_{4\ (125)}$, the desired thresholds for both co-efficient could not be reached.

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 $C_{4\ (500)}$.

Indeed, initial thoughts on code consolidations were ultimately not pursed in this category. For instance, example calculations for a consolidation of the 8 attributes in the contextual SF referral into the three larger application domains – SF referrals, i) with a focus on drawing innovation from SF in the research paper, ii) with a focus on individuals, the scientific community and / or the general public and iii) integrated as part of the research paper – were conducted.

Such a reduction and consolidation of 7 attributes into 3 resulted κ and α values of 0.8, a noteworthy improvement. However, such a consolidation also entails a loss of information and detail, for instance, a differentiation between unrealistic SF and making SF a reality would have been abandoned in such a reducing coding. As a trade-off, and in the light of acceptable IRR coefficients in the analysis of $C_{4\ (125)}$, the decision was made to proceed with the remainder of $C_{4\ (500)}$ without a code consolidation, maintaining a higher degree of differentiation the coding of the contextual SF referral.

In the end, it has to be acknowledged that full review of $C_{4\ (500)}$ by R1 and R2 in addition to more accurate coding instructions and variable definitions, could have potentially increased the agreements for both interpretative variables.

CHAPTER 7
CONCLUSIONS

First-of-a-kind study: This dissertation – based on qualitative data on the utilization of SF, over time, across subfields and repositories of peer-reviewed science communication – provides a compelling account of the explicit relationship of science and art in the case of computer science research. As such, the work provides, through a broad and in-depth investigation, exploration, and analysis of SF in computer science research a novel view and understanding of the utility of SF for STEM domains, specifically computer science and HCI. The work, including the three pilot studies [148, 151, 222], shows that SF is used in a broad range of topics, across two main computer science repositories, the ACM and IEEE *Xplore* Digital Libraries, over more than 60 years of research.

Although SF is clearly a niche in the large of arena of computer science R&D in the IEEE *Xplore* Digital Library, 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, professional 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.

One limitation in the chosen study design, the analysis of science communication, is that it allows only limited interpretation of the importance or impact of SF in a specific research contribution. To remedy this disadvantage, a convenience sample of researchers or, alternatively, a targeted sample of the authors found in $C_{4\ (500)}$, could be recruited for follow-up empirical studies, such as in-depth interviews or survey research on the role, utilization, opportunities and hindrances SF represents for them. Supplementing the data and results in the presented content analysis with such empirical data seems like a logical, next step to better comprehend SF and computer science / HCI research and could shed light on the reasons scientists write, or do not write, about SF in their publications.

SF and real-world science relationship over time: The study was also targeted at identifying a correlation of SF concepts, technologies or devices with regards to their advancement in actual reality. Such a linear relationship, describing the transition from fiction into reality could not be identified, attributable due to the broad range of SF concepts investigated in the study. SF, especially 'hard SF', is known to be anchored to some degree in real-world state-of-the-art. While most of the SF concepts found in this dissertation stem from this category (i.p. 'Coming from SF' and 'Making SF a Science Reality'), the broad variety of 'Unreal SF' concepts complicate a universal conclusion for the transition from fiction to fact. It is conceivable that an investigation of a specific concept, for instance, SF and speech recognition, could be scrutinized toward a breaking point, where scientists begin to assess such a technology as mature enough to be described as science fact.

An integrated science fiction–science–research communication framework: In Section 3.1.5, four SF—science frameworks are presented and contrasted. Each of the frameworks seems to focus on one singular aspect of the multi-faceted SF—science relationship, including a focus on audio-visual SF or the recognition of the geopolitical climate at the time. Other factors which determine the quality, quantity and distribution of e.g. a SF production are the availability of Special Effects and budget in addition to the technological readiness of the audiences and greater public.

While all these factors and concepts do evidently play a role in the SF—Science link, one result in this dissertation for further investigation is the effect exposure to popular cultures can have on the lives and works of all of us, including scientists. The analysis of $C_{4\ )500)}$ reveled multiple instances where scientists where inspired to start a research career based on the exposure to a SF novel or movie.

This leads to two implications. First, the recognition of the potential of SF for CS education, which will be addressed in separate section in the next paragraph and second, a potential consolidation of the four introduced frameworks in Section 3.1.5, through data from this dissertation and future empirical studies with scientists, would allow the creation of a meaningful model describing the interplay and intricacies of SF and science in the context of creativity, R&D and science communication.

SF as an opportunity in CS education: This dissertation provides a compelling case of the benefits and opportunities SF provides across computer science research and education - ranging from ethics to ideation. SF is used to inspire middle school students to aspire toward a technical career, as well as to teach university students fundamental issues of forthcoming challenges in the realm of STS. The question arises if, how, and when SF could be integrated into specific computer science curricula, for instance AI ethics. Prior work [150] explored the benefits of SF for Student Learning and Innovation, namely Creativity and Problem-solving, part of the larger Partnership for 21_{st} Century Skills (P21).

Technical skills are certainly the foundation of future computer science engineers and HCI researchers, however, a broad understanding of the potential opportunities and drawbacks of such a focus on technical solutions seems to be warranted – SF can provide a source of inspiration, education and most importantly, a case study of detrimental technology outcomes in a compelling, easy to understand, audio-visual format, or in a less constrained, literary medium.

Maybe the time to introduce comprehensive SF-based courses into computer science curricula is not now, perhaps it will never be the case, however, the analysis presented in this work clearly shows the potential benefits such an opening toward philosophy of technology and society in computer science edition could result in – which is a better, perhaps more nuanced understanding, of the entire consequences of the introduction of new technology.

For example, the data generated in this dissertation could be used to create a reading and viewing list of foundations SF literature and movies, relevant for specific topics and context in computer science research. The ACM-supported K–12 Computer Science Framework [69] provides five core concepts and seven core practices, among those the concept of 'Computing Impacts' and the practice of 'communication about computing, which could guide subtle curriculum modification, eventually leading to a widely-adopted and accepted utilization of SF materials in distinct aspects of SF education.

Regardless of the bias toward Western SF material, It seems reasonable that the most common SF particulars identified in this study, can provide a useful starting point of a selection of written or audio-visual SF, which can be integrated into educational or research aspects of current and future CS and HCI works.

Methodological contribution and validation: This dissertation furthermore provides a method, which allows to identify this link of science art through searching for generic SF referrals. Specifically, the work shows how the applied methodology enables to i) gather a set of relevant publications, ii) develop and apply a coding scheme identifying temporal patterns and cultural characteristics of the SF referrals and iii), mapping out the appropriation and usage of specific SF concepts, over time, by researchers and scientists.

As this method has been used in three prior pilot studies and the dissertation study, through different terms, search facets and repositories, the method has shown to be adaptive and re-configurable to identify the emergence of specific SF concepts across computer science disciplines.

Additional potential directions to extend the presented dissertation would be to investigate if the most frequent SF particulars, found in this study, are representative of the distribution within the collections investigated in the course of this dissertation. Direct searches for specific SF authors, literature or movies could then be cross-referenced with results for the inclusive search for SF in this dissertation and, as a consequence, validate the methodology.

This, in turn, implies that the method itself could be improved for future studies. For example, a combination of generic and specific SF terms via a logical OR would cast a wider net (as in improved recall) in the retrieval step. However, great caution has to be given to homonyms, such as THE TERMINATOR SF franchise or the SF movie *A.I. Artificial Intelligence*, which can greatly impact precision in such retrieval queries.

A focus on Western SF: The SF particulars identified in this dissertation 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. Science and culture indeed are indeed linked, see for instance Chapter 1. However, the transition of this linkage into actual scientific appropriation through research communication, the core of this dissertation, seems to be mediated through pre-dominantly Western, popular SF.

Fictional and factual technologies: Finally, this dissertation tackles the usage of fiction in science, specifically computer science. In Chapter 1, contrasting definitions of the term and conceptualizations of SF are presented where terminology nuances, such as 'fantasy SF' or 'hard SF' are discussed.

The in-vivo coding of the SF technologies in $C_{4\ (500)}$ allowed the generation of an uncurated list of more than 290 SF ideas and technologies. Is a 'Dyson sphere', originally described by Olaf Stalpeton in his SF novel Star Maker, later on discussed by Freeman Dyson in a 1960 paper [90] a SF technology? In a 1966 paper, Townsend [328] described flat-panel television as a SF proposal of a technology. Certainly today, flat-panel televisions are consumer products, available globally, at affordable acquisition costs.

However, when exactly was the point in time this SF proposal of a technology became a real-world technology? When a flat-panel screen was for the first time realized? When it had a certain resolution? Colors? When it was en par with cathode -ray television, the leading screen technology at the time of Stapleton's paper?

The 284 SF concepts, technologies, interactions, devices and interfaces found in this dissertation (see Table A.5) would benefit from a categorization into specific application areas, either thematic (e.g. robots/AI, implantables/human-body-modification) or conceptually (e.g. interfaces, devices or technologies), which could then, in turn, indicate for what specific area SF is potentially useful computer science and HCI R&D. Such a semantic and ontological analysis could trace

Maybe it is reasonable to assume that, if a SF referral occurs in the context of a scientific paper, for the reason of drawing inspiration into the contribution (coded as either i) Coming from SF, ii) Making SF a Science Reality or iii) Unreal SF), a specific aspect of the respective concept, idea, device, technology or interface, re-ensembles parts of its SF counterpart, instead of a 'carbon copy' of the fictional blueprint.

For example, the Qualcomm Medical Tricoder is now a 'science reality' [357]. But is it really an 'equivalent device' compared to the sleek, light Star Trek Tricorder, which seem to be able to diagnose a variety of health conditions, contact-free. Perhaps the device is just deemed close enough to its advanced, fictional template, it aspires to be. Certainly, realizing a full-fledged SF vision of a device or technology is a challenging endeavour. It seems scientists won't run out of ideas any time soon and SF will continue to provide endless resources to inspire, caution and enlighten us.

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APPENDIX A
FULL RESULTS

A.1 SF Authors in $C_{4\ (500)}$

Table A.1 shows the full results of the retrieved SF authors in $C_{4\ (500)}$. The left side of Table A.1 shows the retrieved SF authors, sorted by absolute referral frequency, in descending order. The right side of Table A.1 shows the retrieved SF authors, sorted by binary referral frequency (at least one referral in one paper) in descending order, as well as the relative binary referral percentages of each SF author referral, over the total amount of binary SF author referrals (n=201) in $C_{4\ (500)}$.

Table A.1: Full list of SF Authors: $C_{4\ (500)}$

	Author Name	**abs. ref.**		**Author Name**	**bin. ref.**	**% of C4$_{4\ (500)}$**
1	Isaac Asimov	111	1	Isaac Asimov	28	5.6%
2	Norbert Wiener	80	2	Arthur C. Clarke	19	3.8%
3	Arthur C. Clarke	37	3	William Gibson	15	3.0%
4	William Gibson	34	4	Robert Heinlein	9	1.8%
5	Robert Heinlein	27	5	Jules Verne	7	1.4%
6	Neal Stephenson	19	6	Karel Čapek	7	1.4%
7	Philip K. Dick	15	7	Neal Stephenson	7	1.4%
8	Karel Čapek	14	8	Philip K. Dick	7	1.4%
9	George Orwell	12	9	John Brunner	5	1.0%
10	J. R. Pierce	12	10	Vernor Vinge	5	1.0%
11	Vernor Vinge	12	11	George Orwell	4	0.8%
12	H. G. Wells	10	12	Ray Bradbury	4	0.8%
13	John Brunner	10	13	Frank Herbert	3	0.6%
14	Jules Verne	10	14	H. G. Wells	3	0.6%
15	Marvin Minsky	9	15	J. R. Pierce	3	0.6%
16	Thomas J. Ryan	9	16	Norbert Wiener	3	0.6%
17	Frank Herbert	6	17	Olaf Stapledon	3	0.6%
18	Fritz Lieber	5	18	Orson Scott Card	3	0.6%
19	Ray Bradbury	5	19	Aldous Huxley	2	0.4%
20	Harlan Ellison	4	20	E .E. Smith	2	0.4%
21	James Blish	4	21	Frederik Pohl	2	0.4%
22	Mary Shelley	4	22	Harlan Ellison	2	0.4%

Continued on next page

Table A.1 continued from previous page

	Author Name	abs. ref.		Author Name	bin. ref.	% of bin. ref.
23	Olaf Stapledon	4	23	Harry Kleiner	2	0.4%
24	Bruce Sterling	3	24	Hugo Gernsback	2	0.4%
25	E. M. Forster	3	25	Jack Williamson	2	0.4%
26	Harry Kleiner	3	26	James Blish	2	0.4%
27	Jack Williamson	3	27	Larry Niven	2	0.4%
28	Larry Niven	3	28	Marvin Minsky	2	0.4%
29	Orson Scott Card	3	29	Mary Shelley	2	0.4%
30	Vannevar Bush	3	30	Vannevar Bush	2	0.4%
31	Aldous Huxley	2	31	Alfred Bester	1	0.2%
32	Ambrose Bierce	2	32	Ambrose Bierce	1	0.2%
33	Douglas Adams	2	33	Arthur Conan Doyle	1	0.2%
34	E .E. Smith	2	34	Bruce Sterling	1	0.2%
35	Frederik Pohl	2	35	Charles Dickens	1	0.2%
36	Fredric Brown	2	36	Chris Hables Gray	1	0.2%
37	Howard Fast	2	37	Douglas Adams	1	0.2%
38	Hugo Gernsback	2	38	Duncan H. Munro	1	0.2%
39	Ira Levin	2	39	E. M. Forster	1	0.2%
40	Michael Crichton	2	40	Everett Edward Hale	1	0.2%
41	Michael Flynn	2	41	Fredric Brown	1	0.2%
42	Philip Frances Nowlan	2	42	Fritz Lieber	1	0.2%
43	Alfred Bester	1	43	Genrich Altshuller	1	0.2%
44	Arthur Conan Doyle	1	44	George O. Smith	1	0.2%
45	Charles Dickens	1	45	Harry Harrison	1	0.2%
46	Chris Hables Gray	1	46	Henry Stommel	1	0.2%
47	Duncan H. Munro	1	47	Howard Fast	1	0.2%
48	Everett Edward Hale	1	48	Ian Watson	1	0.2%
49	Genrich Altshuller	1	49	Ira Levin	1	0.2%
50	George O. Smith	1	50	J. G. Ballard	1	0.2%
51	Harry Harrison	1	51	J. J. Coupling	1	0.2%
52	Henry Stommel	1	52	Jerry Pournelle	1	0.2%
53	Ian Watson	1	53	John Anderton	1	0.2%
54	J. G. Ballard	1	54	Josef Čapek	1	0.2%
55	J. J. Coupling	1	55	L. Jerome Stanton	1	0.2%

Continued on next page

Table A.1 continued from previous page

	Author Name	abs. ref.
56	Jerry Pournelle	1
57	John Anderton	1
58	Josef Čapek	1
59	L. Jerome Stanton	1
60	Lester del Rey	1
61	Lois McMaster Bujold	1
62	Marge Piercy	1
63	Murray Leinster	1
64	Nancy Kress	1
65	Samuel R. Delany	1
66	Stanislaw Lem	1
67	Steven Barnes	1
68	Timothy Zahn	1
69	Ursula Le Guin	1
70	Voltaire	1
71	Wil McCarthy	1
72	William F. Nolan	1
	Total	**528**

	Author Name	bin. ref.	% of bin. ref.
56	Lester del Rey	1	0.2%
57	Lois McMaster Bujold	1	0.2%
58	Marge Piercy	1	0.2%
59	Michael Crichton	1	0.2%
60	Michael Flynn	1	0.2%
61	Murray Leinster	1	0.2%
62	Nancy Kress	1	0.2%
63	Philip Frances Nowlan	1	0.2%
64	Samuel R. Delany	1	0.2%
65	Stanislaw Lem	1	0.2%
66	Steven Barnes	1	0.2%
67	Thomas J. Ryan	1	0.2%
68	Timothy Zahn	1	0.2%
69	Ursula Le Guin	1	0.2%
70	Voltaire	1	0.2%
71	Wil McCarthy	1	0.2%
72	William F. Nolan	1	0.2%
	Total	**201**	**100%**

A.2 SF Writings in $C_{4\ (500)}$

Table A.2 shows the full results of the retrieved SF books, novels, short stories or magazines in $C_{4\ (500)}$. Table A.2 shows the SF writings, sorted first by binary referral frequency (at least one referral in one paper) in descending order) and second, by absolute referral frequency in descending order. Table A.2 shows also the relative binary referral percentage of each individual SF writing referral, over the total amount of binary SF referrals (n=224) of SF books, short stories, novels or magazines found in $C_{4\ (500)}$.

Table A.2: Full list of SF Writings: $C_{4\ (500)}$

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
1	Neuromancer	16	10	4.5%

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Table A.2 continued from previous page

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
2	Astounding Science Fiction	8	7	3.1%
3	Runaround	7	7	3.1%
4	Snow Crash	9	6	2.7%
5	Hitchhikers' Guide to the Galaxy (novel)	14	4	1.8%
6	The Shockwave Rider	8	4	1.8%
7	R.U.R. (Rossum's Universal Robots)	5	4	1.8%
8	Do Androids Dream of Electric Sheep?	4	4	1.8%
9	I, Robot (novel)	4	4	1.8%
10	True Names	9	3	1.3%
11	From the Earth to the Moon	7	3	1.3%
12	Nineteen Eighty-Four	6	3	1.3%
13	The Diamond Age	6	3	1.3%
14	2001: A Space Odyssey (novel)	3	3	1.3%
15	Ender's Game (novel)	3	3	1.3%
16	Frankenstein	3	3	1.3%
17	Brave New World	3	2	0.9%
18	Fahrenheit 451	3	2	0.9%
19	I Have No Mouth and I Must Scream	3	2	0.9%
20	Robbie	2	2	0.9%
21	Star Maker	2	2	0.9%
22	Stranger in a Strange Land	2	2	0.9%
23	The Fountains of Paradise	2	2	0.9%
24	Micromégas	7	1	0.4%
25	A Scientist Reappears	6	1	0.4%
26	The Moon is a Harsh Mistress	6	1	0.4%
27	The Adolescence of P-1	5	1	0.4%
28	The Brain	5	1	0.4%
29	The Day of the Dead	5	1	0.4%
30	Starship Trooper (novel)	4	1	0.4%
31	Flowers for Algernon	3	1	0.4%
32	Johnny Mnemonic	3	1	0.4%
33	The Time Traveler's Wife	3	1	0.4%

Continued on next page

Table A.2 continued from previous page

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
34	A Bad Day for Sales	2	1	0.4%
35	Answer	2	1	0.4%
36	As We May Think	2	1	0.4%
37	Burning Chrome	2	1	0.4%
38	Destination: Void	2	1	0.4%
39	Dream Park	2	1	0.4%
40	Men Like Gods	2	1	0.4%
41	Moxon's Master	2	1	0.4%
42	Prey	2	1	0.4%
43	Slaughterhouse Five or the Children's Crusade	2	1	0.4%
44	The 64-Square Madhouse	2	1	0.4%
45	The Bridge	2	1	0.4%
46	The City and the Stars	2	1	0.4%
47	The Difference Engine	2	1	0.4%
48	The Era of the Satisfactor	2	1	0.4%
49	The Evitable Conflict	2	1	0.4%
50	The Godmakers	2	1	0.4%
51	The Machine Stops	2	1	0.4%
52	The Martian Shop	2	1	0.4%
53	The Miracle of the Broom Closet	2	1	0.4%
54	The Nanotech Chronicles	2	1	0.4%
55	This Perfect Day	2	1	0.4%
56	Under the Stone	2	1	0.4%
57	20,000 Leagues Under the Sea	1	1	0.4%
58	A Canticle for Leibowitz	1	1	0.4%
59	A Clockwork Orange	1	1	0.4%
60	A Feeling of Power	1	1	0.4%
61	Amazing Stories	1	1	0.4%
62	American Gods	1	1	0.4%
63	Animal Farm	1	1	0.4%
64	Armageddon: 2419 A.D.	1	1	0.4%
65	Assignment in Eternity	1	1	0.4%

Continued on next page

Table A.2 continued from previous page

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
66	Bloom	1	1	0.4%
67	Blowups Happen	1	1	0.4%
68	Bu-Sab	1	1	0.4%
69	Cat's Cradle	1	1	0.4%
70	Cities in Flight	1	1	0.4%
71	Cobra	1	1	0.4%
72	Computer Connection	1	1	0.4%
73	Contact	1	1	0.4%
74	Count Zero	1	1	0.4%
75	Cryptonomicon	1	1	0.4%
76	Cyberspace (novel)	1	1	0.4%
77	Dhalgren	1	1	0.4%
78	Doomsday Book	1	1	0.4%
79	Dragon's Island and other stories	1	1	0.4%
80	Dragonflight	1	1	0.4%
81	Dune (novel)	1	1	0.4%
82	Ethan of Athos	1	1	0.4%
83	Extra-terrestrial Relays	1	1	0.4%
84	First Contact	1	1	0.4%
85	Foundation	1	1	0.4%
86	Four Steps to Salvation	1	1	0.4%
87	Gardens of the Moon	1	1	0.4%
88	Going Postal	1	1	0.4%
89	Habit	1	1	0.4%
90	He, She and It	1	1	0.4%
91	Heir to the Empire	1	1	0.4%
92	Homeland	1	1	0.4%
93	I Am Legend	1	1	0.4%
94	I'm Working on That	1	1	0.4%
95	Journey to the Center of the Earth	1	1	0.4%
96	Kushiel's Dart	1	1	0.4%
97	Last and First Men	1	1	0.4%

Continued on next page

Table A.2 continued from previous page

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
98	Lensmen	1	1	0.4%
99	Life, the Universe, and Everything	1	1	0.4%
100	Martian Chronicles	1	1	0.4%
101	Matrix (novel)	1	1	0.4%
102	Methuselah's Children	1	1	0.4%
103	Mostly Harmless	1	1	0.4%
104	Nightflyers	1	1	0.4%
105	Nothing Ever Happens on the Moon	1	1	0.4%
106	Oath of Fealty	1	1	0.4%
107	Outlander	1	1	0.4%
108	QRM - Interplanetary	1	1	0.4%
109	Ringworld	1	1	0.4%
110	Round the Moon	1	1	0.4%
111	Saviour	1	1	0.4%
112	Science Fiction World	1	1	0.4%
113	Small Gods	1	1	0.4%
114	So Long, and Thanks for all the Fish	1	1	0.4%
115	Something Wicked This Way Comes	1	1	0.4%
116	Space Cadet	1	1	0.4%
117	Sunjammer	1	1	0.4%
118	The Age of the Pussyfoot	1	1	0.4%
119	The Book of the New Sun	1	1	0.4%
120	The Brick Moon	1	1	0.4%
121	The Complete Chronicles of Conan	1	1	0.4%
122	The Cyborg Handbook	1	1	0.4%
123	The Dark Tower	1	1	0.4%
124	The Embedding	1	1	0.4%
125	The Eyre Affair	1	1	0.4%
126	The Great Escape	1	1	0.4%
127	The Handmaid's Tale	1	1	0.4%
128	The Invisible Man	1	1	0.4%
129	The Last Unicorn	1	1	0.4%

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Table A.2 continued from previous page

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
130	The Left Hand of Darkness	1	1	0.4%
131	The Man Who Japed	1	1	0.4%
132	The Minority Report (novel)	1	1	0.4%
133	The Mists of Avalon	1	1	0.4%
134	The Once and Future King	1	1	0.4%
135	The Princess Bride	1	1	0.4%
136	The Pseudo-People: Androids in Science Fiction	1	1	0.4%
137	The Puppet Masters	1	1	0.4%
138	The Restaurant at the End of the Univer	1	1	0.4%
139	The Road	1	1	0.4%
140	The Sentinel	1	1	0.4%
141	The Simulacra	1	1	0.4%
142	The Slocum Mission	1	1	0.4%
143	The Stand	1	1	0.4%
144	The Subliminal Man	1	1	0.4%
145	The Tactful Saboteur	1	1	0.4%
146	The Tempter	1	1	0.4%
147	The Turing Option	1	1	0.4%
148	The War of the Worlds	1	1	0.4%
149	The Way of Kings	1	1	0.4%
150	Things To Come	1	1	0.4%
151	Triplanetary	1	1	0.4%
152	UBIK	1	1	0.4%
153	U-Turn	1	1	0.4%
154	VALIS	1	1	0.4%
155	Watchmen	1	1	0.4%
156	Watership Down	1	1	0.4%
157	What if...?	1	1	0.4%
158	Wicked	1	1	0.4%
159	World Brain: The Idea of a Permanent World Ency.	1	1	0.4%
160	World War Z	1	1	0.4%
161	Year 2889	1	1	0.4%

Continued on next page

Table A.2 continued from previous page

	SF Books, Novels, Magazines and Short Stories	abs. ref.	bin. ref.	% of bin. ref.
162	Young Lady's Illustrated Primer	1	1	0.4%
	Totals	**328**	**224**	**100%**

A.3 SF Movies and Shows in $C_{4\ (500)}$

Table A.3 shows the full results of the retrieved SF movies and shows in $C_{4\ (500)}$. Table A.3 shows the results first, by binary referral frequency (at least one referral in one paper) in descending order and second, by absolute referral frequency in descending order. Table A.3 shows also the relative binary referral percentage of each individual SF movie or show, over the total amount of binary SF movie / show referrals (n=205) in $C_{4\ (500)}$.

Table A.3: Full list of SF Movies and Shows: $C_{4\ (500)}$

	SF Movie, Show	abs. ref.	bin. ref.	% of bin. ref.
1	Star Trek	62	28	13.7%
2	2001: A Space Odyssey (movie)	31	23	11.2%
3	The Terminator	16	13	6.3%
4	Minority Report	18	12	5.9%
5	Star Wars	58	11	5.4%
6	The Matrix	14	9	4.4%
7	I, Robot (movie)	13	9	4.4%
8	Fantastic Voyage	14	8	3.9%
9	Star Trek: The Next Generation	13	7	3.4%
10	Blade Runner	9	7	3.4%
11	Gattaca	6	4	2.0%
12	Metropolis	5	4	2.0%
13	Forbidden Planet	5	3	1.5%
14	Battlestar Galactica	3	3	1.5%
15	Iron Man	3	3	1.5%
16	Terminator 2: Judgment Day	3	3	1.5%
17	Frau im Mond	1	3	1.5%
18	Her	9	2	1.0%
19	Alien	8	2	1.0%

Table A.3 continued from previous page

	SF Movie, Show	abs. ref.	bin. ref.	% of bin. ref.
20	A.I.: Artificial Intelligence	3	2	1.0%
21	Conquest of Space	3	2	1.0%
22	E.T. the Extra-Terrestrial	3	2	1.0%
23	Knight Rider	3	2	1.0%
24	Transformers	3	2	1.0%
25	Aliens	2	2	1.0%
26	Avatar	2	2	1.0%
27	Doctor Who	2	2	1.0%
28	Ender's Game	2	2	1.0%
29	Harry Potter (movie)	2	2	1.0%
30	James Bond	2	2	1.0%
31	RoboCop	2	2	1.0%
32	Sleeper	2	2	1.0%
33	Stargate	2	2	1.0%
34	Starship Troopers	2	2	1.0%
35	The Man from U.N.C.L.E	2	2	1.0%
36	Total Recall	2	2	1.0%
37	Dark Star	8	1	0.5%
38	Self/Less	6	1	0.5%
39	Black Mirror	5	1	0.5%
40	Frankenstein (movie)	5	1	0.5%
41	Hollow Man	3	1	0.5%
42	Jurassic Park	3	1	0.5%
43	Men into Space	3	1	0.5%
44	Blake's 7	2	1	0.5%
45	Chrysalis	2	1	0.5%
46	Demon Seed	2	1	0.5%
47	The Abyss	2	1	0.5%
48	The Martian	2	1	0.5%
49	Wonder Woman	2	1	0.5%
50	2010: The Year We Make Contact	1	1	0.5%
51	Abre Los Ojos	1	1	0.5%
52	Airwolf	1	1	0.5%
53	Animatrix	1	1	0.5%

Table A.3 continued from previous page

	SF Movie, Show	abs. ref.	bin. ref.	% of bin. ref.
54	Automan	1	1	0.5%
55	Bicentennial Man	1	1	0.5%
56	Blue Thunder	1	1	0.5%
57	Brazil	1	1	0.5%
58	Capricorn 1	1	1	0.5%
59	Countdown	1	1	0.5%
60	Dark City	1	1	0.5%
61	Deep Impact	1	1	0.5%
62	Destination Moon	1	1	0.5%
63	Dinner for One	1	1	0.5%
64	Dr. Jekyll and Mr. Hyde	1	1	0.5%
65	Dragnet	1	1	0.5%
66	Elysium	1	1	0.5%
67	Ex Machina	1	1	0.5%
68	Farscape	1	1	0.5%
69	Firefox	1	1	0.5%
70	Innerspace	1	1	0.5%
71	Interstellar	1	1	0.5%
72	Mad Max - Beyond Thunderdome	1	1	0.5%
73	Max Headroom	1	1	0.5%
74	Modern Times	1	1	0.5%
75	Pacific Rim	1	1	0.5%
76	Predator	1	1	0.5%
77	Short Circuit	1	1	0.5%
78	Solaris	1	1	0.5%
79	Species	1	1	0.5%
80	Star Trek: Deep Space Nine	1	1	0.5%
81	Star Trek: First Contact	1	1	0.5%
82	Star Trek: The Original Series	1	1	0.5%
83	Strange Days	1	1	0.5%
84	Terminator: The Sarah Connor Chronicles	1	1	0.5%
85	The Andromeda Strain	1	1	0.5%
86	The Avengers	1	1	0.5%
87	The Bionic Woman	1	1	0.5%

Table A.3 continued from previous page

	SF Movie, Show	abs. ref.	bin. ref.	% of bin. ref.
88	The Bride of Frankenstein	1	1	0.5%
89	The Cabinet of Dr. Caligari	1	1	0.5%
90	The Day the Earth Stood Still	1	1	0.5%
91	The Hitchhiker's Guide to the Galaxy	1	1	0.5%
92	The Jetsons	1	1	0.5%
93	The Lawnmower Man	1	1	0.5%
94	The Matrix 2	1	1	0.5%
95	The Matrix 3	1	1	0.5%
96	The Net	1	1	0.5%
97	The Prisoner	1	1	0.5%
98	The Twilight Zone	1	1	0.5%
99	The X-Files	1	1	0.5%
100	Tripping the Rift	1	1	0.5%
101	VR.5	1	1	0.5%
102	WALL-E	1	1	0.5%
103	Westworld	1	1	0.5%
	Totals	**429**	**205**	**100.0%**

A.4 SF Characters in $C_{4\ (500)}$

Table A.4 shows the full results of the retrieved SF characters in $C_{4\ (500)}$. Table A.4 shows the results, sorted first by binary referral frequency (at least one referral in one paper) in descending order and second, by absolute referral frequency in descending order. Table A.4 shows also the relative binary referral percentage of each individual SF character referral, over the total amount of binary SF character referrals (n=55) of SF characters in $C_{4\ (500)}$.

Table A.4: Full list of SF Characters: $C_{4\ (500)}$

	SF Characters	abs. ref.	bin. ref.	% of bin. ref.
1	Hal 9000	31	11	20.0%
2	R2-D2	4	3	5.5%
3	Dick Tracy	3	3	5.5%
4	Captain Kirk	3	2	3.6%

Continued on next page

Table A.4 continued from previous page

	SF Characters	**abs. ref.**	**bin. ref.**	**% of bin. ref.**
5	Borg	2	2	3.6%
6	C-3PO	2	2	3.6%
7	Wintermute	11	1	1.8%
8	Princess Leia	8	1	1.8%
9	Waldo	3	1	1.8%
10	David	2	1	1.8%
11	Dr. Frankenstein	2	1	1.8%
12	Mr. Data	2	1	1.8%
13	Terminator (robot)	2	1	1.8%
14	Agent Smith	1	1	1.8%
15	Ava	1	1	1.8%
16	Baymax	1	1	1.8%
17	Commander Spock	1	1	1.8%
18	Deep Thought	1	1	1.8%
19	Gort	1	1	1.8%
20	James Bond (character)	1	1	1.8%
21	Jean-Luc Picard	1	1	1.8%
22	KITT	1	1	1.8%
23	Maria	1	1	1.8%
24	Moxon	1	1	1.8%
25	Neo	1	1	1.8%
26	Obi-Wan Kenobi	1	1	1.8%
27	Proteus	1	1	1.8%
28	Robbie the Robot	1	1	1.8%
29	Samantha / OS1	1	1	1.8%
30	Skynet	1	1	1.8%
31	T-1000	1	1	1.8%
32	T-800	1	1	1.8%
33	TARS	1	1	1.8%
34	Teddy	1	1	1.8%
35	The Love Bug	1	1	1.8%
36	Uhura	1	1	1.8%
37	UniComp	1	1	1.8%

Continued on next page

Table A.4 continued from previous page

	SF Characters	abs. ref.	bin. ref.	% of bin. ref.
38	Victor Frankenstein	1	1	1.8%
	Totals	**100**	**55**	**100.0%**

A.5 SF Concepts in $C_{4\ (500)}$

Table A.5 shows the full results of the retrieved SF technologies, ideas, concepts, devices and interfaces in $C_{4\ (500)}$. Table A.5 shows the results, sorted by absolute / binary referral frequency first, and then in alphabetical order. Note that this code is mutually exclusive, it therefore can only occur once per record (if at all). Table A.5 shows the total amount of absolute / binary SF referrals (n=284) to technologies, ideas, concepts, devices and interfaces found in $C_{4\ (500)}$.

Table A.5: Full list of SF Concepts: $C_{4\ (500)}$

	SF ideas, concepts, technologies, devices and interfaces	abs. and bin. ref.
1	Artificial Intelligence	20
2	Asimov's Three Laws of Robotics	7
3	Brain–computer Interfaces	7
4	Communicator	6
5	Robotics	6
6	Speech Recognition	6
7	Humanoid Robots	5
8	Cyberspace	4
9	Natural Language Processing	4
10	Robots	4
11	Artificial Life	3
12	Exoskeletons	3
13	Holodeck	3
14	Killer Robots	3
15	Nanotechnology	3
16	Space Exploration	3
17	Teleportation	3
18	Universal Language Translators	3

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	**abs./bin. ref.**
19	Biometrics	2
20	Brain-machine Interface	2
21	Cyborgs	2
22	Dyson sphere	2
23	Electromagnetic Cloaking	2
24	Exoskeleton	2
25	Invisibility Cloak	2
26	Low Cost Wireless Power Transfer	2
27	Medical Tricorder	2
28	Metaverse	2
29	Mobile Computing	2
30	Pervasive Computing	2
31	Replicator	2
32	Smart House	2
33	The Borg	2
34	The Singularity	2
35	Tiny Surgical Robots	2
36	Transporters	2
37	Tricorder	2
38	Virtual Environments	2
39	Virtual Reality	2
40	Viruses and Worms	2
41	3D Holographic Telephones	1
42	3D Holography	1
43	3D Volumetric Projection	1
44	Ad Astra Diplomacy	1
45	Advanced Nanotechnology	1
46	Aerial Drones	1
47	Aerial Imaging Display	1
48	Affective Computing	1
49	Alternate Universes	1
50	Ambient Intelligent Systems	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	abs./bin. ref.
51	Anthropomorphic Robots	1
52	Artifical Neural Networks	1
53	Artificial Consciousness	1
54	Artificial Intelligence Ethics	1
55	Artificial Microrobots	1
56	Artificial Muscles	1
57	Artificial Neural Networks	1
58	Atomic Clock	1
59	Augmented Reality	1
60	Augmenting Cognition	1
61	Automated Assessment	1
62	Automatic Computing System	1
63	Automatic Language Translating Devices	1
64	Automatic Sliding Doors	1
65	Automatons	1
66	Autonomic Computing	1
67	Autonomous Vehicles and Versatile Robots	1
68	Beaming	1
69	Bioastronautics	1
70	Bio-Energy Conversion	1
71	Bioengineering	1
72	Bio-inspiration	1
73	Biomedical Instruments	1
74	Biometric personal Identification	1
75	Borgification	1
76	Brain Implants	1
77	Brain-body Transfer	1
78	Brain–Neural Machine Interfaces	1
79	Calculator with Speech Recognition	1
80	Carbon Nanotube Space Elevator	1
81	CG Technology	1
82	Cloud Service Brokers	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	abs./bin. ref.
83	Commercial Satellite Communications	1
84	Computer Technology	1
85	Computer Virus	1
86	Computer-based Surveillance of Individuals	1
87	Contextual Awareness (Satisfactor)	1
88	Continuous Speech Recognition	1
89	Cryogenic Methods	1
90	Cultured Cells	1
91	Cyber Warfare	1
92	Cyber-Physical Systems	1
93	Cyberspace or Self-Developing Information Systems	1
94	Cyborgs / Wearable Computing	1
95	Dark Scenarios	1
96	Dirac Transmitter	1
97	Directed Energy Planetary Defense	1
98	Domestic Robotics	1
99	Ear bud radios / seashells	1
100	Earth-Satellite Communication	1
101	Emergent Holonic Autonomous Agent System	1
102	Emotional Machines	1
103	Emotional Robots	1
104	Experiences of Remote Environments	1
105	Extracting Power from Thin Air	1
106	Flat-panel Television	1
107	Force Field	1
108	Free Telephone Calls	1
109	Full-immersion Virtual Reality	1
110	Fully Autonomous Systems	1
111	Fully Conversational Computer	1
112	Fully Immersive Technology	1
113	Genetic Engineering	1
114	Geosynchronous satellites	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	**abs./bin. ref.**
115	Gesture-based Human Computer Interface	1
116	Global Artificial Intelligence of Cyberspace	1
117	Global Telepresence	1
118	Handheld Programmable Calculator	1
119	Handy Home Computers	1
120	High-quality Chatterbots	1
121	Hive Mind	1
122	Holograms	1
123	Holographic Printer	1
124	Home Computer	1
125	Human Augmentation	1
126	Human Enhancement Engineering	1
127	Human Exploration of Space	1
128	Human Gesture Recognition	1
129	Human-like chatterbot	1
130	Human-robot Cooperation	1
131	Hyperwave	1
132	Immersion in Virtual Reality	1
133	Immersive Metaphorical VR interfaces	1
134	Impact of Large Near-earth-orbit Objects	1
135	Implantable Medical Devices	1
136	Implantable Microchips	1
137	Implants for Communications	1
138	Information Fusion	1
139	Integration of Man, a Protective Suit, a Computer	1
140	Intelligent Devices	1
141	Intelligent Fabrics	1
142	Intelligent Interfaces	1
143	Intelligent Systems	1
144	Intelligent Vehicle Highway System	1
145	Interactive Virtual Worlds	1
146	Internet of Things	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	**abs./bin. ref.**
147	Internet of Things / IoT	1
148	Interplanetary Travel	1
149	Interstellar Exploration	1
150	Intimacy with Robots	1
151	Intra and Inter-body Cognitive Communication System	1
152	Intracellular Robotic Micro-manipulators (IRMs) / Cytobots	1
153	Invisibility	1
154	In-vitro fertilization and Pre-implantation	1
155	Ionic Propulsion	1
156	Iris Scanning	1
157	Jumping Into Hyperspace	1
158	Knowledge Download	1
159	Language Identification (LID)	1
160	Large-scale Online Elections	1
161	Light Speed Travel	1
162	Machine Rights	1
163	Machine Translation	1
164	Magneto-caloric Materials	1
165	Man vs. Machine competition	1
166	Material by Design	1
167	Medical Nanotechnology	1
168	Microbots	1
169	Micromachined Neural Probe	1
170	Micro-spacecraft	1
171	Mid-air or 3D Displays	1
172	Mobile Augmented Reality	1
173	Mobile Internet	1
174	Mobile Phone / Pocketphone	1
175	Mobile Software Agents	1
176	Multi-octave Traveling-wave Tube	1
177	Nanites	1
178	Nanoreplicators	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	**abs./bin. ref.**
179	Nano-Robotics	1
180	Networked Answering Machine	1
181	Networked White Boards	1
182	Neural Interfaces	1
183	Neurocontrollers	1
184	Non-Anonymous Money	1
185	Noncontact Health Monitors	1
186	Non-contact Health Monitors	1
187	Nuclear Fusion	1
188	Online laboratories	1
189	Pattern Recognition	1
190	Perfect Artificial Lover	1
191	Personal Access Data Display (PADD)	1
192	Personal Air Vehicle	1
193	Personalized News Feed	1
194	Personalized Television	1
195	Personally Identifiable Information	1
196	Pervasive Environments	1
197	Phaser	1
198	Power Over Society by Controlling its Electrical Resources	1
199	Prediction of Crimes	1
200	Programmable Matter	1
201	Public Wireless Access Point	1
202	Quantum Computer	1
203	Quantum Computing	1
204	Quantum Cryptography	1
205	Rehabilitation Robots	1
206	Relationship between Humans and Robots	1
207	Replicate Human Thought	1
208	Robot	1
209	Robot Autonomy	1
210	Robot Consciousness	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	**abs./bin. ref.**
211	Robot Warfare	1
212	Robotics Revolution	1
213	Robots as Caregivers	1
214	Satellite Communication Links	1
215	Satellite Communications	1
216	Satellites as Relays for Communication	1
217	Seamless Metacomputer	1
218	Selective Silicon Etching Technology	1
219	Self-driving Cars	1
220	Self-replicating, Segmented, Distributed Systems	1
221	Semantic Web and Semantic Grid of agents	1
222	Semantic Web of agents	1
223	Sensory Immersion in the Net	1
224	Sentient Cars	1
225	Sentient Tools	1
226	Shape-memory Materials	1
227	Singularity	1
228	Smart Dust	1
229	Smart Houses	1
230	Smartclothing	1
231	Solar Sailing	1
232	Solar-system-wide Communication Network	1
233	Space Arrows	1
234	Space Drives	1
235	Space Elevator	1
236	Space Rockets	1
237	Space Solar Power	1
238	Space Solar Power Plants	1
239	Space Weapons	1
240	Space-based Lasers	1
241	Spatial Displays	1
242	Speaker Recognition	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	**abs./bin. ref.**
243	Superconducting Quantum Interference Device	1
244	Superhuman Strength	1
245	Surveillance Video Combined with Television	1
246	Swarm Robots	1
247	Telecommunication	1
248	Telepresence	1
249	Terraforming	1
250	The Ansible	1
251	The Long Tail	1
252	The Perceiving Robot	1
253	The Sentient Web	1
254	The Sprawl	1
255	Three-dimensional Holograms	1
256	Transistor	1
257	Tribble	1
258	UbiComp	1
259	Ubiquitious Computing	1
260	Ultra-wave Communication	1
261	Underwater Gliders	1
262	Unmanned Aerial Vehicles	1
263	Video Calls / Telephot / Phonotelephote	1
264	Virtual Emotional Human System	1
265	Voice Activation	1
266	Voice Communication	1
267	Voice Recognition	1
268	Vulcan Mind Meld	1
269	Walking and Climbing Robotics	1
270	Warp drives	1
271	Wearable Computing	1
272	Wearable Computing Environment	1
273	Wearable Devices	1
274	Wireless Capsule Endoscopy	1

Continued on next page

Table A.5 continued from previous page

	SF ideas, concepts, technologies, devices and interfaces	abs./bin. ref.
275	Wireless Communication / Ear Discs	1
276	Wireless Intelligent Sensor Networks	1
277	Wireless Power Transmission	1
278	Wireless Sensor Network	1
279	Wireless Sensor Networks	1
280	Wireless World	1
281	Wireless Wrist Radio	1
282	World Controlled By Computers	1
283	World Wide Web	1
284	Wormholes	1
	Total	**284**

A.6 Paper Types by Year in $C_{4\ (500)}$

Table A.6 shows the data table for Figure 5.14 on page 105. Table A.6 shows the counts of the type of research paper (n=500) in relation to the publication year of the records in $C_{4\ (500)}$.

Table A.6: Data table for Figure 5.14

Year	Artifact	Empirical	Method	Opinion	Other	Survey	Theoretical
1948	0	0	0	0	1	0	0
1949	0	0	0	0	1	0	0
1955	0	0	0	0	1	0	0
1959	0	0	0	0	1	0	0
1961	0	0	0	0	1	0	0
1962	0	0	0	0	1	0	0
1965	0	0	0	0	1	0	0
1966	0	0	0	0	1	1	0
1971	0	0	0	0	1	0	0
1973	0	0	0	1	0	0	0
1974	0	0	0	0	1	0	0
1976	0	0	0	0	1	0	0

Table A.6 continued from previous page

Year	Artifact	Empirical	Method	Opinion	Other	Survey	Theoretical
1977	0	0	0	1	0	0	0
1979	0	0	0	0	1	0	0
1980	0	0	0	0	0	1	0
1983	0	0	0	1	1	0	0
1984	0	0	0	0	3	0	0
1985	0	0	0	0	3	0	0
1986	0	0	0	0	1	0	0
1988	0	0	0	1	0	0	0
1989	0	0	0	0	0	2	0
1990	0	0	0	1	0	1	1
1991	0	0	0	0	1	1	0
1992	0	0	0	1	0	1	2
1993	0	0	0	0	0	0	2
1994	0	0	1	3	2	0	0
1995	0	1	0	0	1	1	0
1996	1	0	0	1	0	0	1
1997	2	1	0	1	0	1	1
1998	0	0	0	3	1	3	0
1999	0	1	1	3	0	0	3
2000	0	1	3	3	0	1	5
2001	1	2	1	5	0	4	3
2002	1	0	2	4	1	2	2
2003	1	1	3	7	1	4	5
2004	0	1	1	7	1	2	5
2005	3	3	3	10	0	2	1
2006	3	1	0	8	1	2	3
2007	2	2	2	7	4	3	4
2008	3	5	0	5	1	3	4
2009	3	6	2	4	4	4	2
2010	1	5	5	8	3	4	6
2011	2	3	0	4	0	3	6
2012	2	2	2	8	4	3	4
2013	1	4	2	6	6	3	3
2014	5	2	5	17	2	1	2

Table A.6 continued from previous page

Year	Artifact	Empirical	Method	Opinion	Other	Survey	Theoretical
2015	2	5	1	10	1	5	3
2016	5	4	3	14	4	9	6
2017	8	2	1	9	5	4	3
Subtotal	**46**	**52**	**38**	**153**	**63**	**71**	**77**
Total	**500**						

A.7 SF Referrals by Year in $C_{4\ (500)}$

Table A.7 shows the data table for Figure 5.15 on page 103. Table A.7 shows the binary referral frequency of any given SF particular (either a SF author, writing, movie or character) per record, sorted by year of publication.

Table A.7: Data table for Figure 5.15

Year	Coming from SF	Making SF a Science Reality	Unreal SF	SF and the Ind.	SF and the Com. or Pub.	SF and the Paper Research Method	SF in the Ref.
1948	0	0	0	1	0	0	0
1949	0	0	0	1	0	0	0
1955	0	1	0	0	0	0	0
1959	0	1	0	0	0	0	0
1961	0	0	1	0	0	0	0
1962	0	1	0	0	0	0	0
1965	0	0	0	1	0	0	0
1966	0	0	1	1	0	0	0
1971	0	1	0	0	0	0	0
1973	0	0	1	0	0	0	0
1974	0	0	0	1	0	0	0
1976	0	0	0	0	0	1	0
1977	0	0	0	0	0	1	0
1979	0	0	0	1	0	0	0
1980	1	0	0	0	0	0	0

Table A.7 continued from previous page

Year	Coming from SF	Making SF a Science Reality	Unreal SF	SF and the Ind.	SF and the Com. or Pub.	SF and the Paper Research Method	SF in the Ref.
1983	1	1	0	0	0	0	0
1984	2	1	0	0	0	0	0
1985	0	2	0	0	0	1	0
1986	0	0	0	1	0	0	0
1988	0	0	1	0	0	0	0
1989	1	1	0	0	0	0	0
1990	1	1	0	0	0	0	1
1991	0	2	0	0	0	0	0
1992	3	1	0	0	0	0	0
1993	0	2	0	0	0	0	0
1994	2	0	2	2	0	0	0
1995	0	1	1	1	0	0	0
1996	2	0	1	0	0	0	0
1997	4	0	0	0	1	1	0
1998	6	0	1	0	0	0	0
1999	1	3	1	0	0	3	0
2000	2	3	4	0	0	4	0
2001	3	5	1	1	2	4	0
2002	3	4	3	0	0	2	0
2003	3	6	6	0	1	4	2
2004	2	3	4	0	2	4	2
2005	3	4	4	4	2	4	1
2006	5	3	2	1	2	4	1
2007	9	5	2	1	1	4	2
2008	9	6	0	0	2	1	3
2009	6	9	2	2	1	2	3
2010	10	7	6	0	1	6	2
2011	4	3	4	0	1	2	4
2012	9	7	3	1	1	4	0
2013	5	5	4	2	3	5	1
2014	6	14	2	3	0	7	2

Table A.7 continued from previous page

Year	Coming from SF	Making SF a Science Reality	Unreal SF	SF and the Ind.	SF and the Com. or Pub.	SF and the Paper Research Method	SF in the Ref.
2015	6	8	4	0	3	3	3
2016	12	13	4	3	4	8	1
2017	5	11	5	0	5	3	3
Subtotal	**126**	**135**	**70**	**28**	**32**	**78**	**31**
Total	**500**						

A.8 SF Particulars by Year in $C_{4\ (500)}$

Table A.8 shows the data table for Figure 5.16 on page 105. Table A.8 shows the binary referral frequency of any given SF particular (either a SF author, writing, movie or character) per record, sorted by year of publication.

Note that this calculation consolidates SF referrals of SF particulars of the same type (e.g. 2 SF movies are mentioned in one record), into binary yes (1).

For example, Table A.8 shows in the year 1948 2 referrals, one to a SF author and one to a SF writing. The two referrals appear in the same record, hence representing each one binary referral in a record for the year 1948 of two categories of SF particulars.

Furthermore, it is important to note that multiple types SF particulars of the same type can occur in the same record. For example, a record, published in a given year, can name multiple SF movies in the full-text. Therefore, the total amount of binary referrals for each SF particular is smaller than the explicit binary counts in Tables A.1, A.2, A.3 and A.4.

Table A.8: Data table for Figure 5.16

Year	SF Authors	SF Writings	SF Movies	SF Characters
1948	1	1	0	0
1949	1	1	0	0
1965	1	0	0	0
1966	1	1	0	0
1971	1	0	0	0
1974	1	0	0	0

Continued on next page

Table A.8 continued from previous page

Year	SF Authors	SF Writings	SF Movies	SF Characters
1976	1	1	0	0
1979	1	0	0	0
1980	1	0	0	0
1984	0	0	1	0
1985	0	0	1	0
1989	1	1	0	0
1990	2	0	1	1
1992	1	0	0	1
1994	0	0	1	0
1995	0	0	1	1
1997	1	2	1	3
1998	3	2	2	0
1999	2	2	2	1
2000	2	2	4	3
2001	7	5	2	1
2002	0	1	3	1
2003	6	4	5	2
2004	4	5	6	1
2005	3	2	5	1
2006	4	1	4	3
2007	8	4	8	3
2008	5	6	3	0
2009	7	4	5	0
2010	5	5	10	1
2011	2	1	2	0
2012	7	6	4	2
2013	6	3	5	2
2014	9	7	9	1
2015	4	3	8	1
2016	11	5	14	8
2017	3	3	8	2

Total	**112**	**78**	**115**	**39**

APPENDIX B
SCHOLARLY WORK 2015-2019

This appendix includes the scholarly work conducted from late 2015 to early 2019 in the context of this dissertation. Table B.1 lists these activities in a chronological fashion.

Table B.1: Overview of prior work, awards and earned press

Nr	When	What	Where	Reference
1	Fall 2015	Workshop Paper	OZCHI	[147]
2	Summer 2016	Grant	WSU	[219]
3	Summer 2016	Poster / Short Paper	HCII	[149]
4	Fall 2016	Full Paper	ACE	[220]
5	Summer 2017	Full Paper	AHFE	[148]
6	Winter 2017	Proposal Defense	UHM	*N/A*
7	Spring 2018	Blog Post	ACM IX	[145]
8	Spring 2018	Earned Press	MIT TR	[95]
9	Summer 2018	Short paper	HCII	[151]
10	Summer 2018	Scholarship	BPM	[143]
11	Fall 2018	Presentation	FF	[146]
12	Spring 2019	Doctoral Consortium	HICSS	[144]
13	Spring 2019	Full Paper	ISHI	[150]
14	Spring 2019	Journal Article	THRI	[222]
15	Summer 2019	Dissertation Defense	UHM	*N/A*

In summary, the prior work on SF/SFMS and computer science research represents an incremental approach to the topic discovery and initial analysis of SF/SFMS in HCI/computer science publications and serves as an antecedent for the dissertation study in the context of the *IEEE* Xplore Digital Library.

The earlier publications from 2016 [147, 149, 220] serve as an introduction to the significance of the topic and represent the results of the literature study and topic discovery of the author.

The latter publications from 2017–2018 [148, 151] present two pilot studies to assess the viability and methodology of this dissertation. The two pilot studies further present descriptive measures on specific usages of SF, such as research themes over time where SFMS and computer science research intersect, among those, the cultural origin of the SF material and the usage, characterization, and referral of SF technologies and devices in computing literature.

The most recent publications from 2019 [150, 222] extend the topic on specific foci, for instance, education, effectively 'branching out' the groundwork of this dissertation in the prior years. A 2019 position paper [150] proposes the 'serious' integration of SF/SFMS into HCI/CS curricula and education. A third article [222] focuses on SF/SFMS and HRI and analyzes the uses of SF robots in the ACM Digital Library.

Additionally, an external research grant [219] for $3500 at the University of Western Sydney was awarded and utilized to conduct the third pilot study [222]. Furthermore, this dissertation was awarded with a $3000 honorary fellowship [143] in 2018. An ACM IX Blog post was published in 2018 [145] and one paper [151] has been featured in the MIT Technology Review [95]. Lastly, in late 2018, an online presentation on the topic of SF/SFMS and Design Fictions was held [146].