Reflecting on the Presence of Science Fiction Robots in Computing Literature

OMAR MUBIN and KEWAL WADIBHASME, Western Sydney University, Australia

PHILIPP JORDAN, University of Hawai'i at Mānoa, USA

MOHAMMAD OBAID, Department of Information Technology, Uppsala University, Sweden and UNSW Art and Design, University of New South Wales, Australia

Depictions of robots and AIs in popular science fiction movies and shows have the potential to showcase visions of Human-Robot Interaction (HRI) to the general public and computer science researchers alike. In contrast, studies on the referral, usage, and appropriation of these portrayals by computer scientists in their research publications is an academic void at present. However, such investigations are critical to better understand the potential utility and latent shortcomings of science fiction robots for future HRI research, innovation, and education. To address this research gap, this study investigates the overall presence, nature, and frequency of referrals of 18 popular science fiction robots in the Association for Computing Machinery (ACM) Digital Library. These robots were either portrayed in various movies and subsequently inducted into the Robot Hall of Fame, created by Carnegie Mellon University in 2003, or were top-ranked in a user-curated Internet Movie Database (IMDB) list. To do so, we performed full-text search and retrieval queries of all 18 robots in the ACM Digital Library. In total, we identified 121 relevant mentions, across 102 individual publications, in a time span from 1973 to 2017. These 121 mentions were then qualitatively analysed to determine the nature of the robot mentions. Our results indicate that the robot attributes of voice or dialogue were emerging as a popularly mentioned element. In addition, we find that research papers of philosophical nature mention sci-fi robots more frequently than papers of technical or theoretical nature. We also observe that the dystopian element of science fiction is under-utilised, with the majority of robot mentions exhibiting neutral or utopian characteristics. In conclusion, we speculate on our results and present possible avenues of future HRI research on the topic.

CCS Concepts: • **General and reference** → **Surveys and overviews**; • **Human-centered computing** → *Empirical studies in HCI*; • **Applied computing** → *Media arts*;

Additional Key Words and Phrases: ACM digital library, AI, computing literature, robots, science fiction, text mining, visions of the future

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Authors' addresses: O. Mubin, Western Sydney University, Parramatta Campus, Sydney, Australia; email: o.mubin@westernsydney.edu.au; K. Wadibhasme, Western Sydney University, Sydney, Australia; P. Jordan, University of Hawai'i at Mānoa, USA; email: philippj@hawaii.edu; M. Obaid, Department of Information Technology, Uppsala University, Uppsala, Sweden and UNSW Art and Design, University of New South Wales, Sydney, Australia; email: mohammad.obaid@it.uu.se. Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

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1 INTRODUCTION

The depiction of emerging technologies in science fiction media (sci-fi) has played a key role in the advancement of technology in the real world [39, 44]. As a medium of expression and creativity, visions portrayed in sci-fi film and television have been incorporated by computer science researchers in various domains, for instance, as inspiration for novel user interfaces or innovative gesture interaction [18, 70, 75] in the field of Human-Computer Interaction (HCI). In addition, sci-fi film is also thought of a mechanism that promotes technological awareness in society [22], not only allowing both researchers and movie directors to showcase their imagination to the public [43] but also informing them of the “perils of Artificial Intelligence and sci-fi” [4, 8]. A bi-directional cycle of influence between sci-fi and interactive technology has allowed both fields to progress in unison [52]. Among others, the field of robots and robotics is an important theme of contemporary sci-fi and, as such, robots have a long-lasting tradition and history of being promoted and exhibited in sci-fi [57]. In fact, the word robot is also derived from sci-fi literature [9]. Some researchers [6, 77] claim that the attributes of social robots (such as extreme levels of intelligence or human likeness) portrayed in sci-fi are the “Holy Grail” as far as robotics research is concerned. Furthermore, it is well known that the individual perception and understanding of robots is commonly governed by a person’s socio-cultural context as well as the access and knowledge of sci-fi and the vision promoted in such content [64, 68]. Due to limited exposure of the general public to a wide variety of robots, their definition and understanding of robots is likely more determined by what they know from sci-fi and moulded by the vision presented in movies. Even in countries where sci-fi and manga are highly popular and appreciated, such as Japan, research [54] has shown that the public has questioned the morality of cyborg technology.

Technological visions and innovations portrayed in sci-fi are inevitably of inspirational importance to researchers and scientists in the field of robotics as well, such as the design of Fujitsu’s robot RoboPin being inspired by “Eve” from the movie “Wall-E” [11]. However, the quantification or measurement of the transformation or utilization of this inspiration into scientific research, such as peer-reviewed publications, has not been investigated. Ergo, the association between sci-fi and the advancement of robotics research is either merely an assumption or, in individual instances, based on anecdotal evidence. In extension, general studies on the usage and appropriation of these fictional robot portrayals or sci-fi technology by computer scientists in their research publications are scarce as well. While science fiction is understood to not only provide positive highlights and utopian visions of future Artificial intelligence (AI) and HRI (for example, the fictional android Lt. Commander Data in *Star Trek*), but through dystopian view-points (e.g., the mixed depiction and transformation of HAL 9000 in *2001: A Space Odyssey* or other similar rogue AI’s or killer humanoids such as the Terminator), it can also provide ethical lessons and reflective guidelines for scientists and humans alike [7, 24, 37]. In summary, sci-fi robots can be thought of not only as an inspiration to scientists but also as a means of promoting discussion and discourse on delicate issues, among those the future role, agency, and usage of robots in society [25, 26, 50, 74]. However, as we emphasized earlier, for now this remains a theoretical assumption, as there is little concrete evidence due to an absence of scientific studies on measuring the utilization of sci-fi robots in Computing and HRI literature at present. Such research can, for instance, identify which robots are utilized by scientists in their research publications, what social attributes of these robots are emphasized, and last, if robots from sci-fi are portrayed from an either utopian or dystopian stance, all in the aim of providing implications for future research in the area of Human-Robot Interaction.

In this study, we set out to determine the frequency and nature of mentions of sci-fi robots within Robotics and Computing literature, particularly to decipher the specific nature of the contribution

of such robots on research through both qualitative review and quantitative analysis. In addition, we aimed to reflect on the presence of sci-fi robots in academic literature in the field of Computing to understand what aspects of sci-fi robots are highlighted more often in research and what are the nature and purpose of the different mentions. We also aimed to understand if the type or theme of research papers had any effect on the likelihood of sci-fi robots being mentioned in Robotics research. For example, we investigated if particular types of research articles were more conducive to cite examples of robots from sci-fi than others. Last, we also aimed to identify citing and referral patterns by studying individual case studies of the mentions of sci-fi robots.

In summary, we aimed to comprehensively understand how sci-fi robots are portrayed and framed in HRI and Computing scholarship, specifically academic literature. Our method of choice to carry this out was a rigorous content analysis of the contextual referrals of sci-fi robots in computing literature. We believe that our results indicate that robots from fiction can be used as an effective tool to promote and guide the uptake and design of robots in the real world. Ultimately, by deducing the presence of fictional robots in HRI and computing literature, we can gauge their popularity and acquire a sense of the past and potential future usage of robot visions. Our trends can contribute to upcoming research in the area of robotics by showcasing how the community has utilised sci-fi visions in the past, provide recommendations to research on the topic of social robots, and chart the contribution of sci-fi to robotics research.

2 BACKGROUND

Within computer science literature, a number of overview papers have been presented that discuss the synergy of interactive technology in sci-fi and HCI [46, 69], a closely related field to HRI. Numerous HCI panels, workshops and discussions have also been held on the topic [47, 48, 52]. In general, the community acknowledges that HCI and sci-fi have an important relationship.

However, most of these reviews are either, individual case studies or examples and most importantly, are restricted to a meta-level analysis with insufficient quantitative data to articulate linkages between the two disciplines of interactive technology and sci-fi. In addition, we believe that most of the above reviews are highly selective as they only highlight the utopian or positive vision of sci-fi content toward the advancement of technology, whilst ignoring the lessons that can be learned from dystopian portrayals of sci-fi media. Robots are an important element of advanced interactive technology, however none of the afore-mentioned reviews focus on how sci-fi has particularly contributed to the advancement of the field of research in robotics. Instead their focus has been on areas such as gesture interaction, wearables or mobile devices. Other review articles have analyzed the different sources and types of technology presented in sci-fi or attempted to create taxonomies of AI as depicted in movies [43, 71]. Such reviews have also presented an outlook on the various robots illustrated in sci-fi ranging from androids to mechanical creatures to zoomorphic robots. Yet again, how these different types of robots are reflected in academic literature in the fields of HRI, HCI or Computing Technology in general is not known. To the best of our knowledge, we provide herein the first study which charts and categorizes the overall presence of sci-fi robots in academic computing literature through specific keyword searches and a subsequent contextual analysis. Thus, in this research, we contribute to the HRI community with an investigation that provides an analysis of the overall presence, nature and frequency of 18 popular sci-fi robots in a representative computer science repository.

In continuation of recent prior work, for example [33, 34], our research methodology is based on content analysis and text mining of the presence of sci-fi-based robots in literature, a technique that emerges from the field of Scientometrics [38]. A similar method also applied by others, for instance de Souza [14], who currently explores the usages of the words and concepts of “human” or “user” within theoretical computer science repositories. We find only limited examples of text

mining or keyword search-based analyses to decipher sci-fi's relationship with specific domain areas in research, however they are not focused on robotics, or computing literature. Nevertheless, Levin and De Filippo [42] provides us with a positive exemplar of undertaking qualitative content analysis to disentangle sci-fi mentions in academic articles. Our method comprised further, as a first step, of searching for academic publications in the ACM Digital Library, which referred to sci-fi robots. As a second step, we reviewed the context of the referrals in each retrieved publication.

In recap, our methodology consists of a search and retrieval process and a subsequent, independent qualitative coding of the retrieved publications. Therefore, in some ways our methodology is similar to that of [42]; however, we focus particularly on the presence of robots and the nature of these mentions and references in academic articles found in a Computing repository of papers. Given that robotics and AI are key sub-topics within the Computing discipline, we focused on directing our search broadly across Computer Science. We also introduce a range of quotes obtained in our sample to allow an unfiltered view on the raw referrals and mentions of sci-fi robots in HRI and Computer Science research. In summary, having acknowledged the importance of specifically studying the relationship of sci-fi robots with computing literature, we identified the following research aims of our empirical study (within the boundaries of our dataset of academic publications):

- (1) Are there sci-fi robots that are more popular than others within robotics literature (*Research Aim 1—part a*) and in extension, what nature of referrals (*Research Aim 1—part b*), particular attributes (*Research Aim 1—part c*), and purpose of mention of those robots are mentioned (*Research Aim 1—part d*)?
- (2) Are there dissemination venues (*Research Aim 2—part a*) and paper types (*Research Aim 2—part b*) that are more popular than others within the robotics research community when it comes to mentioning sci-fi robots in their papers?
- (3) By associating both the nature of the referrals (*Research Aim 3—part a*) and robot attributes (*Research Aim 3—part b*) to the type of paper, purpose of sci-fi robot mentions and the robots themselves, can we determine the contributions that sci-fi robots may have had on the development of (interactive) technology as described in our data set?

3 METHOD AND DATA COLLECTION

In the following section, we outline the main four aspects of our research method. We begin by explaining the decision to conduct our search and retrieval process in the ACM Digital Library (Section 3.1), followed by the research team's determination of the 21 sci-fi robot characters, which served as the basic search terms (Section 3.2). We then provide details on the specific full-text searches we conducted in the ACM DL, including the facets and exclusion criteria we applied (Section 3.3). Last, through a variety of examples, we introduce the final coding scheme for the retrieved papers and mentions of the sci-fi robots that we searched for (Section 3.4).

3.1 Choice of Repository

As with any search strategy, our data collection phase commenced with first identifying an appropriate database or repository of academic literature and, second, a list of sci-fi robots and associated search keywords. The Association of Computing Machinery (ACM) is perhaps the most renowned and long standing organization supporting Computing and Information Technology research. Its Digital Library (ACM DL) indexes a wide variety of venues comprising more than 300 conferences and 50 journals dating back to 1950. It also provides access to a powerful search-engine facility. All these attributes made it the database of our choice for this particular study.

Table 1. List of Robots from Sci-Fi Inducted in the CMU Hall of Fame Alongside the Movie They Appear in and List of Science Fiction Robots Ranked by IMDB Rating

CMU Robot Hall of Fame			
#	Robot Name	Movie Name	Inducted in Year
1	Astro Boy	<i>Astro Boy</i>	2004
2	C-3PO	<i>Star Wars</i>	2004
3	Data	<i>Star Trek</i>	2008
4	David	<i>Artificial Intelligence</i>	2006
5	Gort	<i>The Day the Earth Stood Still</i>	2006
6	HAL 9000	<i>2001: A Space Odyssey</i>	2003
7	Huey Dewey Louie	<i>Silent Running</i>	2010
8	Maria	<i>Metropolis</i>	2006
9	R2-D2	<i>Star Wars</i>	2003
10	Robbie, the robot	<i>Forbidden Planet</i>	2004
11	T-800	<i>Terminator</i>	2010
12	Wall-E	<i>Wall-E</i>	2012
Top 10 IMDB Robots			
#	Robot Name	Movie Name	IMDB rating
13	Smith	<i>The Matrix Series</i>	8.7
14	Oracle	<i>The Matrix Series</i>	8.7
15	Tars	<i>Interstellar</i>	8.6
16	Jarvis	<i>Avengers</i>	8.1
17	Terminator	<i>Terminator Series</i>	8.0
18	Sentinel	<i>X-Men: Days of Future Past</i>	8.0
19	Skyнет	<i>Terminator Series</i>	8.0
20	Gerty	<i>Moon</i>	7.9
21	Baymax	<i>Big Hero 6</i>	7.8
22	Ava	<i>Ex Machina</i>	7.7

3.2 Robots and Search Terms

The choice of robots, or search terms, was less straightforward. It is commonly acknowledged that there are hundreds of sci-fi films that portray robots as one of the main characters. It would have been logistically impossible to search for all such robots in the ACM DL. To attain some coverage, we initially identified two (slightly tangential) sources of sci-fi robots. First, we included the 12 sci-fi robots of the Carnegie Mellon University (CMU) Robot Hall of Fame [13] within our search criteria (see Table 1). We had confidence that the Robot Hall of Fame would be representative of the larger body of sci-fi robots for a number of reasons. To begin with, the Robot Hall of Fame from CMU has been used in other research in HRI [53]. In addition, it is drafted based on the opinions of a wide range of experts in science and cinema. Furthermore, the CMU Robot Hall of Fame recognizes excellence in robotics technology worldwide and honors the fictional and real robots that have inspired and made breakthrough accomplishments in the field of robotics.

In contrast, our second source of sci-fi robots considers the opinions of the general public and those who were not experts in the area of robotics per se. Using the list of 28 popular sci-fi robots provided in Reference [71], we first sorted them on the basis of user ratings available on the Internet Movie Database (IMDB). To have a manageable set of robots similar in number to our sample from the CMU Hall of Fame, the top 10 in terms of IMDB rating from the total of 28 robots were

then shortlisted for further analysis (see Table 1) and hence became our second source of data. Terminator was discarded from the list of 10 robots ranked on the basis of their IMDB rating since it was already listed in the CMU Hall of Fame. Therefore, our final sample comprised a total of 21 robots.

3.3 Search Strategy and Inclusion Criteria

Data for the robots from the CMU Hall of Fame was searched, collected, and filtered in a single week in the second half of April, 2017, whereas data for the robots from the IMDB was searched, collected, and filtered in a single week in the second half of November, 2017. We employed the advanced search in the ACM Digital Library to perform our case insensitive, full-text search. Papers from periodicals and conferences in the ACM Guide to Computing Literature were searched as long as the full-text comprised of our provided keywords. Due to the nature of our intended analysis, we also constrained the search to records where PDF files of source text were directly available through our institutional subscriptions, hence papers from IEEE or other databases that were showing up in our search were not considered. As our search focused on PDF files only, we also excluded other files types, such as HTML or video records.

The initial search for each robot name in the ACM Digital Library was quite simple and uncomplicated as we used the known or commonly used name of the robot (e.g., “Gort”). If the name of the searched robot involved more than one word, then quotation marks (e.g., “Astro Boy”) were employed in the search term to reduce false positives and to ensure that all terms occurred in unison. Regardless, some of our searches had to be abandoned due to extensive false positives, for example a simple full-text search for “Data” from Star Trek or “Maria” from Metropolis returned more than hundred-thousand records each. These results of these searches are indicated as NA in the second column of Table 2). Therefore, for each robot, we also employed an additional range of keywords in advanced search queries to minimize the possibility of false positives by either appending the word “robot,” “name of the movie,” and both (see third, fourth, and fifth column in Table 2), wherever applicable. This was particularly helpful in the case of robots such as “David,” “Maria,” and “Data” (homonyms) but not so in the case of “Oracle” and “Smith,” which we had to exclude from further analysis due an excessive amount of false-positives. This brought our sample of robots down to 19. Cells with “NA”—see Table 2) refer to a search that was not considered due to either extensive false positives or due to redundancy, resulting in a total of 47 search results that were collated. In the case of spaces or punctuation in the robot name or movie name (such as “R2-D2”), we preferred to use double quotes to ensure an exact search was found. PDF’s for each search query were downloaded and thereafter, duplicate papers for each keyword search across each robot were removed.

A final check was performed on all mentions to ensure that the robot in question was being referred to. In the instance that the name of the movie and the robot was identical, papers from that robot were included in our final sample only if the mention was in context of the robot and not the movie (applied to Wall-E and Astro Boy only). A number of exclusions were carried out in which the search term did not refer to the robot per se (such as in the case of David and Maria when they were used as names of people or other researchers or in the case of Gerty, which was used to refer to the movie featuring an animated dinosaur). It is worth mentioning that we could not find a single relevant mention for David (from the movie *A.I.*), bringing our list of robots down to 18 (see Table in Appendix A). A table is provided that summarizes the number of papers retrieved for each search per robot and the final list of included papers (see last column in Table 2), which in total amounted to 121 mentions spread across 102 unique papers for 18 robots (excluding David), as in some cases a paper mentioned more than one robot and therefore appeared multiple times.

Table 2. The Extracted Papers per Search Query, Where “Finalized Inclusions” Is the Final Set of Papers Extracted per Robot

Robot	Robot_Name	Robot_Name + “Robot”	Robot_Name + Movie_Name	Robot_Name + Movie_Name+“Robot”	Finalised inclusions
Astro Boy	4	3	NA	NA	2
Ava	NA	NA	6	4	4
Baymax	12	6	6	6	6
C-3PO	7	5	2	2	5
Data	NA	NA	384	106	12
David	NA	NA	NA	51	0
Gerty	75	9	4	2	1
Gort	65	9	4	4	5
HAL 9000	15	5	8	0	15
Huey Dewey Louie	2	0	0	0	2
Jarvis	NA	NA	3	0	3
Maria	NA	NA	29	5	5
R2-D2	130	17	10	8	13
Robbie, the Robot	10	NA	3	NA	9
Sentinel	NA	NA	84	26	1
Skynet	55	16	21	8	12
T-800	NA	5	20	2	2
Tars	NA	NA	15	5	4
Wall-E	76	32	NA	NA	20

3.4 Coding Scheme

From the set of 121 retrieved mentions of robots, we then performed content analysis on each one of them as per our coding scheme. In the cases where the same robot was mentioned multiple times in a paper, we counted this as a single data point; i.e., our sample comprised of 121 papers (PDF’s) not 121 sentences. Therefore, coding was completed by assessing the overall contribution of the mention(s) within the paper. Two researchers independently coded 25% of the sample with a particular focus on the subjective elements of the coding scheme. Moderate agreement was observed on those subjective elements (where $0.65 < \kappa < 0.75$). Disagreements were resolved after consultation and one researcher finalized the coding for the entire data set. Each mention was coded as per the following categories:

- (1) Title of Paper.
- (2) Year of Publication.
- (3) Which robot is mentioned (a code from 1 to 18).
- (4) The number of times the robot was mentioned in the paper.
- (5) Venue of the paper (with edition or year removed to allow for aggregation with other editions). For example, HRI2015 and HRI2014 were both coded as HRI. We did not aggregate regional editions of the same conference, such as SIGGRAPH Asia was not combined with SIGGRAPH.
- (6) The type of the paper that was extracted from the typical call for papers of any Computing or Robotics conference; a taxonomy is suggested in Reference [51]. The possible codes within this category were mutually exclusive and included:

- (a) Empirical/User study based: Empirical- or user-study-based papers were, where some form of data was acquired from human subjects (qualitative or quantitative), typically in relation to their perception of some form of robotic technology. For example, we coded Reference [21] as an empirical study, because in it an ethnographic study was presented on the Roomba vacuum cleaner and where its participants gave Roomba the name Robbie.
 - (b) Technological Advancements: Technological Advancement papers were studies whose focus or main contribution was a new piece of technology, an algorithm, an interaction technique or artifact. Typical papers in this category would be algorithmic attempts to improve human-robot interaction. In some papers, human data was collected but only as a means of testing or benchmarking the technology and not gauging human perception. These papers were also placed in Technological Advancements. For example, we coded Reference [79] as a paper discussing technological advancements, because HAL9000 was referred to inspire the design of empathetic virtual agents.
 - (c) Theoretical Framework or Model based: Theoretical papers introduced new frameworks, models; in summary had a conceptual contribution with no testing or evaluation. An example being the paper entitled “*Unity in Multiplicity: Searching for complexity of persona in HRI*” [67, p. 1], where the plausibility of designing social robotic personas is discussed, analysed and modelled whilst mentioning Wall-E.
 - (d) Philosophical or Opinionated pieces: Last, philosophical papers were papers that were reflective and controversial in nature written with the main aim of convincing the reader. An example of an opinionated paper was Reference [49], where the consequences of autonomous agents was debated upon whilst discussing the “passive and obese outlook” of humans in the movie *Wall-E* and how Wall-E the robot helps them regain a sense of being.
- (7) Nature of reference or referral of the robot, which was coded as neutral, positive, and negative, where this code was also treated as mutually exclusive. If a robot was mentioned on more than one occasion, then we attributed a single value to this code based on our interpretation of the nature of reference across the entire paper. The following give examples of the nature of reference codes:
- (a) Neutral reference (0): “For example, if one sees an R2-D2 from a StarWars movie this can be recognizable, but few have actually seen a real one” [40, p. 20].
 - (b) Positive reference (1): essentially an *utopian* reference such that the robot was being praised and considered as an inspiration or a highlight to base future research on. For example, “WHAT IS A SOCIALLY INTELLIGENT ROBOT? It is a difficult concept to define, but science fiction offers many examples. There are the mechanical droids R2-D2 and C-3PO from Star Wars” [6, p. 19].
 - (c) Negative reference (−1): such that the robot was criticized or implied as a *dystopian* element to society or future technological development. For example, “If the HAL 9000 kills its crewmates to avoid being deactivated, it is because its designers failed to prioritize its goals properly” [35, p. 38].
- (8) By analyzing the context of the specific mentions and the overall theme and aim of the paper, we were also able to code the purpose of the mention of the robot by the authors. This was coded into five possible mutually exclusive categories; namely:
- (a) Inspiration to Authors themselves (such that this was explicitly mentioned or established by for e.g., mention of a new prototype or technique or vision—as in the case

of Reference [60] where they clearly state how their research in hologram projection is inspired by that of R2-D2).

- (b) Communication or Clarification to readers (as a means of comparing current technology with sci-fi technology or to set the scene of what to/what not to aspire for in terms of technological development for society or researchers—as was the case in many of the ACM Communication opinion pieces or in the case of Reference [63] where Baymax was mentioned so that readers could visualise the existence of a hypothetical robot).
 - (c) Factual Mention (the robot within the movie is specifically mentioned such as within a scene as in the case of various overview papers [46]).
 - (d) Research Tool or methodology (such as the image or video of the robot was used as a means to collect data from participants by inclusion in a survey or questionnaire as in Reference [58]).
 - (e) Instances when the sci-fi robot was mentioned by a participant of the research through an interview or qualitative remark. Typically this occurred when participants wanted to give examples of how they imagined or anticipated real world robots to look like or behave [36].
- (9) Which attribute of the sci-fi robot is being mentioned, with six possibilities that were *not* mutually exclusive. Whichever category was thought to being referred was coded as 1. If we felt that none of the categories were being referred, then this code was left empty. Since sci-fi robots interact with humans and can be considered as social robots, we extracted these attributes from a taxonomy available on the topic of social robotics [20]. The following list describes the six attribute codes with examples from our sample:
- (a) Emotions/Facial expressions, such that the sci-fi robot was stated to express some form of emotional behaviour (a basic emotion) or there was a clear mention of facial expressions. For example, “...the HAL 9000 computer, which could speak, reason, see, play chess, plan and express emotions” [72, p. 3].
 - (b) Intelligence, such that the robot exhibited some form of social awareness and rationality—“Lt. Commander Data in *Star Trek: the Next Generation*, was humanoid in form, and was capable of interacting with his environment and learning from it with a positronic brain” [12, p. 1].
 - (c) Voice/Dialogue/Speech, where the robot’s ability to interact and communicate through vocalization of any kind for example, “Movie portrayals of robots such as R2-D2 and WALL-E are reflected in recent approaches with regards the creation of non-verbal sounds by several authors as a means to replace or augment synthetic speech lacking paralinguistic cues” [31, p. 257].
 - (d) Embodiment/Physical Appearance, such that the robot could interact with the environment through its physical appearance; for instance, C-3PO, the humanoid robot character from the *Star Wars* franchise is contrasted to real-world, HRI expectations by Wright in his 2012 ACM Communications review on robots and anthropomorphism [78, p. 13]:

“The science fiction robots of our youth always looked reassuringly familiar. From the Iron Giant to C-3PO, they almost invariably sported two arms, a torso, and some type of metallic head. Real-world robots, alas, have largely failed to live up to those expectations. Roombas, factory assembly arms, and even planetary rovers all seem a far cry from the Asimovian androids we had once imagined.”

- (e) Movement/Physical Actions, such that the sci-fi robot conveyed meaning through body movement; for instance [15, p. 30]:
“In this sequence from ‘The Day The Earth Stood Still,’ the U.S. Army sends drone aircraft to attack the sinister robot Gort, who aims lasers at them and crashes them spectacularly into the ground.”
- (f) Personality, where certain behavioural and character-based traits were mentioned, such as friendliness or shyness—for example, Rose and Björling’s participatory design study on teenager expectations of robots finds that [66, p. 5]:
“When participants discussed social robots from popular culture (BB-8, Baymax, Wally¹) they described unanimous likability, cuteness, and good hearted-ness.”

4 RESULTS

In this section, we summarize some of the main results and trends observed based on our coding scheme in relation to our research aims. We first describe our set of descriptive results through overviews of accumulated robot referrals (Section 4.1), followed by significant testing on the associations between codes (Section 4.2).

4.1 Descriptive Results

Consolidation and filtration upon the retrieved papers provided us with a final sample of 121 records across the 18 robots, ranging from 1973 to 2017. We found the most records when searching for Wall-E, HAL 9000, R2-D2, Skynet, and Data (in descending order, see last column of Table 2) [Research Aim 1—part a]. We charted the number of papers retrieved per publication year and, as shown in Figure 1, there was a peak in recent times, particularly in 2015 and 2016. We speculate on the plausible causes of this peak in the discussion section (see Section 5) and attribute it to the current rise in voice-based digital assistants.

The average mentions per robot in each paper was 1.86, with the maximum being 11. Utopian references dominated the nature of reference count with 60 (almost 50% of all mentions), followed by neutral with 40 and dystopian or negative mentions with 21 [Research Aim 1—part b]. Robots such as HAL9000 and Skynet were interesting case studies, offering a rich distribution of both utopian and dystopian quotes. For example, in 2017, representing the most recent mention, Kaplan outlines the negative sides of HAL in light of contemporary HRI research and public perception of AI, a dystopian example [35, p. 38]:

“Good products, including increasingly autonomous machines and applications, don’t go haywire unless we design them poorly. If the HAL 9000 kills its crewmates to avoid being deactivated, it is because its designers failed to prioritize its goals properly.”

When coding which aspects or attributes of the robots were being referred to, we noticed that Intelligence was the most popular with 41 mentions [Research Aim 1—part c]. Specifically, the intelligence of robots such as HAL9000 and Lt. Cmdr. Data was mentioned:

“A problem of the conversational chat bot interface is that they don’t have a HAL 9000 level of intelligence and there is ambiguity in how the computer interprets what the human is trying to convey” [19, p. 23].

“The field of Artificial Intelligence is a recent incarnation of an age-old quest or dream, the dream of building an image of the human in the machine. It is this dream, fueled

¹This particular quote illustrates as well the issue of heterography in the case of “Wall-E,” here spelled as “Wally.”

Fig. 1. Graph of papers retrieved per publication year.

by science fiction representations of AI such as Hal 9000 or Commander Data, which is the initial inspiration for many researchers entering the field” [32, p. 91].

Voice was also a popular design attribute with 27 mentions, in particular the non-linguistic utterances of R2-D2 and Wall-E:

“In the present research, we studied nonverbal sound emblems rather than verbal interjections or affect bursts, because we aimed to interlink these emblems with verbal utterances of a robotic tutor that can be seen as standing in a cultural tradition of robots such as R2-D2 and others that have made prominent appearances in movies” [31, p. 258].

Embodiment was also ranked among the frequently mentioned attributes with a total of 26 mentions, in reference to android robots such as Ava, Baymax and Maria [2, p.7]:

“Fritz Lang’s Metropolis (1926) was revolutionary in its comparisons of the human to the machine. The robot Maria has a curved, metallic shape that emanates sexual desire, yet demonstrates domination and control. Although in the film the robot Maria is finally overcome by man, her likeness to the human form demonstrates the fascination that man has with fusing the human body to the machine.”

We also classified each mention into its perceived purpose as indicated through our process of qualitative coding [Research Aim 1—part d]. We deduced that 40 mentions were intended to as a means of communication to readers primarily as a means of comparing today’s advent of technology to that depicted in sci-fi. We only found 25 mentions that we could clearly determine linking the sci-fi robot to a means of inspiration for the authors.

The most popular venue from which we found papers for our sample was the Human-Robot Interaction (HRI) conference, having 19 records (see Figure 2) [Research Aim 2—part a]. The

Fig. 2. A short list of the popular venues.

SIGGRAPH series had nine records in total as did the technical magazine *Communications of the ACM*, which had nine papers in the sample.

Almost two-thirds of the mentions originated from Philosophical or Empirical papers (33.1% and 32%, respectively) [*Research Aim 2—part b*]. Philosophical referrals related to mostly author inscribed consequences of the deployment of autonomous agents or robots, such as the following quote regarding Skynet:

“AI is a field that addresses a big, fundamental problem with core societal and philosophical implications. A natural consequence is that the field fragments over time, giving rise to dozens of subfields and their conferences, which in turn further fragment the field, sometimes in oddly semi-religious ways. This fragmentation is bad for the community, because we become too siloed to work on the larger problem that inspired us in the first place. It is bad for policy and outreach, because it becomes difficult for us to speak to policymakers and the public about the issues of the field; hence, when Hollywood stirs up public sentiment about Skynet destroying us all, there’s no scientific voice offering a clear riposte” [16, p. 8].

Twenty-four percent of the mentions were found in papers that were presenting technological advances as the main theme of the paper. Both empirical and philosophical papers were peaking in the recent years, which probably indicated that (a) sci-fi is progressively contributing toward the evaluation and bench-marking of technology, and (b) authors are contemplating and discussing the various implications of sci-fi-based technology.

4.2 Significance Testing on Associations between Codes

We ran a series of Chi-Square Tests to evaluate the associations between our codes to primarily answer *Research Aim 3*. Here, we report on the significant results.

Fig. 3. Cross section of purpose of mention against nature of referral.

We first conducted chi square tests on the nature of the referrals and the specific purpose of the mention, the type of paper and the robots themselves [Research Aim 3—part a].

There was a significant association between utopian references and inspiration to authors ($\chi^2(N = 121,8) = 76.08, p < 0.0001$, adjusted residual $z = 4.3$), utopian references and communication to readers ($\chi^2(N = 121,8) = 76.08, p < 0.0001$, adjusted residual $z = 3.2$). As expected factual mentions had a significant association with neutral referrals ($\chi^2(N = 121,8) = 76.08, p < 0.0001$, adjusted residual $z = 5.8$). The cross-sectional trends of nature of referral and purpose of mention is provided; see Figure 3. There was a significant association between dystopian references and philosophical or opinionated papers ($\chi^2(N = 121,6) = 24.8, p < 0.0001$, adjusted residual $z = 4.5$); see Figure 4. Last, in relation to [Research Aim 3—part a], we tested for which robots were more likely to generate particular types of references and found this to be significant ($\chi^2(N = 121,34) = 80.6, p < 0.0001$). Wall-E had a significant association with positive or utopian references (adjusted residual— $z = 3.5$). 85% of all Wall-E referrals were utopian, an example being [65, p. 209]:

“This paper explores aspects of a potential alternative to facilitate acoustic interaction, Non-Linguistic Utterances (NLUs). NLUs are sounds comprised of beeps, squeaks and whirrs, rather than spoken language, and have been used almost exclusively by the world of animation to great effect (R2D2 and WALL-E provide vivid examples).”

Fig. 4. Cross section of paper types against nature of referral.

Skynet, Gort, and Maria all had significant associations with dystopian or negative references (adjusted residual— $z = 3.1, 3.8, 2.6$, respectively). A graph plotting the nature of references to the robots is also provided (see Figure 6). At times, the public perception of such rogue AI's was referred to [59, p. 2]:

“Science fiction has for too long portrayed robots as villains; ‘GORT’ (Genetically Organized Robotic Technology) from the film the Day the Earth Stood Still, Maximilian—The Black Hole, the gunslinger in West World, and ultimately the Terminator. All designed to make us be afraid of what we don’t understand.”

We also checked for significant associations between the various social attributes and the type of paper, purpose of mention, and the robots themselves [Research Aim 3—part b]. Theoretical papers had a significant association with intelligence ($\chi^2(N = 121,3) = 9.961$, $p = 0.02$, adjusted residual— $z = 2.9$). Papers that presented empirical studies as their main theme had a significant association with voice ($\chi^2(N = 121,3) = 8.89$, $p = 0.03$, adjusted residual— $z = 2.8$). Voice as an attribute emerged as a popular inspirational element as exemplified by its significant association with the purpose of mention categorized by inspiration to authors ($\chi^2(N = 121,4) = 18.9$, $p = 0.001$, adjusted residual— $z = 4.0$). In research papers, where the qualitative remarks of participants were recorded showed that the personality of the robots was the attribute that was most often mentioned as compared to the other attributes ($\chi^2(N = 121,4) = 17.5$, $p = 0.002$, adjusted residual— $z = 4.0$).

Fig. 5. Frequency chart of robots and their associated attributes mentioned.

There were also significant associations between the attributes being referred and a number of robots (see Figure 5). These included intelligence ($\chi^2(N = 121,17) = 41.3$, $p = 0.001$, adjusted residual for Skynet— $z = 3.8$) and embodiment ($\chi^2(N = 121,17) = 47.92$, $p < 0.0001$, adjusted residual for Maria— $z = 2.1$, Baymax— $z = 3.8$ and Ava $z = 2.6$). There was a nearly significant association between voice and HAL 9000 ($\chi^2(N = 121,17) = 25.03$, $p = 0.09$, adjusted residual— $z = 2.4$). As early as 1973, Nelson recognized the voice capabilities of HAL [55, p. 26]:

“From Weizenbaum’s ELIZA program to HAL-9000 of Kubrick and Clarke’s 2001, there is a constant sense that ‘of course’ we want talking computers.”

As mentioned prior, our list of IMDB robots was sourced from Reference [71]. This paper also showed up in our search on the ACM computing library for the set of seven robots. This resulted in seven possibly biased data points in our sample (one for each of the robots considered from this list). We therefore decided to repeat our association analysis by excluding these seven data points. We now report on some significant trends in addition to those mentioned prior. HAL 9000 was seen to have a significant association with intelligence as an attribute—($\chi^2(N = 114,15) = 39.2$, $p = 0.001$, adjusted residual for HAL 9000— $z = 2.1$). Both Wall-E and HAL 9000 had a significant association with voice as a referred attribute ($\chi^2(N = 114,15) = 26.08$, $p = 0.04$, adjusted residual for HAL 9000— $z = 3.2$ and for Wall-E— $z = 2.3$). We also observed a significant association between intelligence as a referred attribute and dystopian references ($\chi^2(N = 114,2) = 8.5$, $p = 0.01$, adjusted residual— $z = 2.5$) and between voice as a referred attribute and utopian references ($\chi^2(N = 114,2) = 14.39$, $p = 0.001$, adjusted residual— $z = 3.7$).

5 DISCUSSION

Our results and analysis has revealed interesting trends on the occurrence, utilization, and potential linkage of sci-fi robots on computing literature. At face value, our study indicates that sci-fi robots seem to play a role in computing research. However, instead of merely reporting

Fig. 6. Graph of nature of reference against every robot.

quantitative measures, such as term-frequencies, we endeavored to understand in detail the nature of these robot referrals. To do so, we qualitatively reviewed each mention with regards to the type of paper it appeared in, the overall purpose of the mention, and the specific robot attribute(s) that co-occurred in the context of the mention. In the following, we discuss aspects of this investigation.

Wall-E emerged as the most popular and idealistic robot with 17 of its 20 references positive or utopian in nature. The cuteness or sympathetic nature of Wall-E was occasionally referred to. Both Wall-E and R2-D2 were also specifically relevant in articles that mentioned non-linguistic interaction. In contrast, Skynet, Gort, and Maria were among the robots that had the most negative references. This is expected and seems understandable as these robots/AIs are portrayed as primarily villainous in nature in their respective movies. HAL 9000 was the most interesting case study; having both positive and negative references, it probably provides the community still—50 years after the release of *2001: A Space Odyssey* by Stanley Kubrick in 1968—with a number of ethical guidelines and lessons on the societal implications of autonomous technology (such as singularity). In some papers, the evil personality of HAL 9000 was mentioned and in other papers its highly autonomous behaviour, such as its ability to think, talk, and converse was referred to—a spectrum of referrals that do reflect the transformation of AI as depicted in *2001: A Space Odyssey*. Similar to HAL 9000, the potential harm caused by a rogue AI such as Skynet can also be used in potentially positive applications, for instance, cyber warfare or to enable researchers to reflect on increasing security of their systems.

In summary, utopian references were more frequent than dystopian references and appeared predominantly for the purpose of inspiration for authors and as a means of communication for readers (such as in the case of “heroic robots,” namely, C-3PO). While the positive and inspirational reach of sci-fi is widely understood by researchers, the robotics community seems more reluctant to utilise sci-fi as a venue for technological debate and reflection—as exemplified by the nonsignificant association between dystopian references and sci-fi referrals with the purpose of author inspiration or reader communication. Dystopian references were mostly meant as factual referrals or providing information to readers. In addition, in cases where participants in a research study mentioned sci-fi robots, they did so in an utopian or neutral context only. Therefore, on the basis of our results, it appears that both researchers and participants in HRI research are reluctant to relate to sci-fi robots in a dystopian context. In extension, dystopian mentions were only found in philosophical papers and not in empirical studies.

In similar fashion, there was an insignificant association between dystopian robot referrals and empirical and technological papers. This is despite there being a number of dystopian and reflective case studies from sci-fi to look at Reference [30]. Such examples could prove to be highly influential for both authors and readers alike as lessons on the implications of technology deployment in society. Utopian references were found to be a source of inspiration to the authors; however, we did not observe a significant association between papers that described advances in technology and utopian references. Therefore the true and tangible relationship of sci-fi with advances in robotic and computing technology is relatively unclear in the context of our research methodology and study approach, which is to investigate these manifestations in the context of the communication of science. However, one must acknowledge that sci-fi’s role extends beyond the implementation and practical aspects of robotic technology of the future. Sci-fi has the ability to contribute through the initiation of discipline areas such as design fiction, motivating students and young children to take up technical sciences as a career or education pathway and, as we have stressed, permeate an understanding and awareness in society of the pros and cons of adoption of various novel forms of technology.

As showed in our method, we were unable to locate a single relevant article that mentioned David from the movie *A.I.* Due to the vague and general name of the robot and the movie, which resulted in a number of false positives, we can only speculate if David—as a robot—is used in the ACM DL or not. Due to the nature and limitations of the research, a quantitative seek and retrieval and qualitative review of the contextual mentions, we could not code the entire set of papers we retrieved when the search term “David” was used exclusively (as this query resulted in more than 50,000 records). We did reduce this set to 51 records through additional search terms (David + *A.I.*, see Table 2) but found none of these mentions as relevant. Furthermore, as mentioned prior, we were unable to resolve the extensive set of false positives for the two *Matrix* robots (Oracle and Smith), yet again due to the ambiguity associated with the robot names.

The most common venue in our data of 121 records was the HRI conference. The HRI conference is considered to be one of the premier conferences in social robotics [3]. From the 19 papers of the HRI conference, 14 were utopian references, in contrast to the Communications of the ACM magazine, which had 5 negative or dystopian mentions across the total of 9 papers. A possible explanation could be the distinctive focus of either venue; with the HRI conference being more technical and system-oriented in contrast to the Communications of the ACM magazine, which is more philosophical in nature. This can also give reason for the significant association between philosophical papers and dystopian references as authors are provided with the opportunity to reflect and discuss about certain negative implications of portrayed sci-fi technology.

We also noticed there to be a clear peak of robots being mentioned in the years 2015 and 2016 (17 and 25 mentions, respectively). This led to an increase in other categories as well, such as

dystopian mentions and empirical studies. Across both years there was no dominating venue of publication; instead the year 2015 composed of 12, and 2016 of 14 unique venues, respectively. Likewise, there was diversity in the robots being referred in both 2015 and 2016 (8 and 14 robots, respectively). Having excluded a specific venue or individual robot as cause of the increase in retrieved papers in these years, we next investigated if the peak then could be attributed to an overall growth in papers on the topic of HRI or Robotics in recent times? To do so, we carried out some background checks to establish if a topical peak was emerging or not: A search in the ACM Guide to Computing Literature Repository for papers whose full text matched the term “Human-Robot Interaction” did not vary significantly between years 2010 and 2016 (ranged between 456 and 740 records). We repeated this search with keywords “Robotics” and “Robot” and yet again noticed that the number of papers retrieved did not vary significantly across the years 2010 and 2016 (ranged between 7,200 and 8,500). Prior to carrying out these background searches, we also considered normalizing the frequency results by research output of each venue. However, the research team came to the opinion that such a normalization was not necessary for the following reasons. First, our background searches were showing that the overall volume of papers in the broader area of Robotics and HRI was not fluctuating, and second, we believed that normalization was inconsequential due to the small number of records that were being retrieved in our search of sci-fi robots. After further debate, we reason that the peak in 2015 and 2016 is perhaps the manifestation of an alignment of the advancements of technology and visions depicted in sci-fi in research, among those for example Google Now, Apple Siri, Amazon Alexa, and similar smart assistants. This claim is backed up by both, the popularity of “voice” as an inspiration element for authors in 2016 (11 records from a total of 27) and the recent proliferation and promotion of these systems in the consumer mainstream.

As we stated prior, the timing and progression of the referrals was not dictated by a specific movie release or driven by the popularity of a robot. In fact, HAL 9000 and Maria are fairly old robots (in consideration of the release date of the movie they appeared in), but they continue to be referred even in more recent articles. Clearly, portrayals of sci-fi provide a long lasting vision for many years to come and certain aspects of these visions are approaching fast. Just to provide one example, Ali reasoned in the year 2001 that [1, p. 55]:

“First, the AI field is insufficiently mature—we are still trying to solve difficult problems; and more work is needed. The Matrix is a long way off. Second, technologies like HAL are not cost-effective; I wouldn’t mind a wired house, for example, but I don’t feel the need to pay extra to have a conversation with it. Similarly, a robot waiter is unlikely to cost less than paying a real human waiter.”

A simulated reality as seen in The Matrix is probably still “a long way off,” but many people speak to their electronic devices now on a regular basis. Not only are a variety of different digital, smart assistants available at the present time, they are routinely benchmarked against each other as sort of pop-cultural entertainment (e.g., Reference [62]). Most recently, the Google 2018 developers conference [28] demonstrated their latest innovation called Google Duplex, an AI that mimics human voice through natural-sounding speech, filler words and slang terminology. The company demoed Google Duplex (on the phone) [27] booking a hairdresser appointment or attempting a restaurant reservation effectively deceiving the human respondents on the other end of the phone line; an event that according to technology journalists approximates the passing of the Turing test [17]. Likewise, Ali’s [1] robot waiters have arrived. Cheong [10] developed an autonomous robotic waiter system while restaurants in China introduced robot waiters in 2016 [73], whose acquisition costs average around 1,200 dollars per device [56], an amount equal to roughly two-months worth of salary of that of a human waiter.

Fig. 7. The Puffy robot; images adopted from Reference [23].

In our analysis, the robot attribute of Embodiment also emerged as popular and interesting referral, particularly in the case of the Baymax robot, as exemplified by the assistive robot “Puffy” [23]—see examples of the Puffy robot in Figure 7. Intelligence was by far the most commonly referred attribute in theoretical papers and voice was the most frequently referred attribute in empirical papers. We speculate this to be a clear form versus function debate. In the real world, robotics developers and researchers are most likely dedicating their efforts toward first creating robots that can accomplish tasks regardless of their form factor. In this analysis, we have restricted ourselves to robots in the CMU Hall of Fame and a set of popular robots from a user-generated list as found on the IMDB. Astro Boy was the only robot having its origins from Asia. We only found 2 relevant mentions of the Astro Boy. In most papers, the robots brought their cinematic image to academic literature. “Good or heroic” robots had a majority of utopian references (such as Wall-E). Others such as Gort, Maria, and HAL 9000 carried forward their image from the movie and received negative indications.

5.1 Implications to Human-Robot Interaction

Although our sample size was a restrictive set of quotes that referred to a fixed set of sci-fi robots, we believe that we can generalize some of our findings into implications for Human-Robot Interaction. Herein below, we present some of the implications that we have extracted on the basis of our results:

- (1) Our results illustrate that the occurrence of sci-fi robots in robotics and computing literature is not negligible and considering the fact that our search was not exhaustive there may be many more papers that refer to our selection of sci-fi robots. Furthermore, case studies such as Puffy confirm that sci-fi can truly drive and originate scientific research. Last, as alluded to prior, the relationship between sci-fi and computing research is complex and its study needs to go beyond simple textual search within publications.
- (2) Our results also show that, the scientific community in general does not refer to sci-fi robots in a dystopian context; this is maybe a reluctance driven by trepidation or simply a lack of awareness. The research community should always allow channels for reflection to promote the discussion of all viewpoints of particular forms of technology.
- (3) Our results also indicate that voice and intelligence appear to be the two modalities of robots that do seem to inherit context and ideas from sci-fi. The rise of digital assistants and speech being the most natural form of interaction could in itself be plausible reasons.
- (4) We believe that our search and analysis strategy of finding keywords in academic publications is a methodological contribution to Human-Robot Interaction and Computing

research; albeit limited, we have shown that we can inherit textual analysis methods in combination with qualitative content analysis to successfully unearth the relationship of paradigms and concepts on academic literature.

- (5) Our results also highlight that sci-fi could have an even more deeper and profound relationship with robotics research. Since the usual expectation within the research community is to only disseminate complete pieces of research output, most works in the field are incremental in nature. This tendency may discourage authors and researchers to incorporate sci-fi visions in their projects. The robotics community should hence push for technological advancements and new ideas—demo tracks in conferences is one way to achieve that. Sci-fi presentation tracks in conferences or keynotes from sci-fi producers and directors could also facilitate the intermingling of the two disciplines. Ultimately, such avenues will provide robotics researchers a platform to implement visions from sci-fi.

6 CONCLUSION

Our study has shown that some robots from sci-fi have been referred in computing research more frequently than others and attributes such as voice or speech interaction have grown in ascendancy. Contrary to expectations, embodiment or how a robot is meant to look like does not draw as many inspirations from sci-fi as intelligence or dialogue abilities. Rise and falls in frequencies were witnessed for not only general mentions of sci-fi robots but also specific aspects of the same sci-fi robots. Wall-E emerged as one of the more popular robots, whereas HAL 9000 was observed to not only offer positive inspiration but also lessons and reflections originating from a dystopian line of thought. Our results also showed that sci-fi does not only have a relation with the development of technology but even more elaborate is its role as a medium of discourse, discussion, and communication. Researchers are most likely easily attracted to the utopian visions of sci-fi and the dystopian views are at times neglected, particularly when it comes to state-of-the-art research. In summary, science fiction has an important and significant relationship with the development of technology and one that we would expect to continue to evolve [29].

6.1 Limitations

We would like to identify certain limitations of our analysis. First, we were extensively constrained by the nature of author-based nomenclature. Robots were syntactically referred to in different ways, such as HAL/HAL 9000/HAL9000/HAL-9000 or R2D2/R2-D2 or Robby, the Robot/Robbie, the Robot, and so on. We only adopted the terms as given in our data sources and hence may have missed papers in which authors referred to the same robots in syntactically different terms, such as with or without spaces. Case in point “Astro Boy”; when we carried out a search for “Astroboy” (without a space), we found the following quote [76, p. 1]:

“For example, Honda’s Asimo humanoid robot is said to have been directly inspired by the Astroboy manga series.”

This was a clear example of a sci-fi robot being mentioned in the context of an inspirational element. We are of the opinion that due to these lexical inconsistencies, our sample size is as small as 121 records. As future work, a more robust and brute search or a snowballing technique could unearth many more papers that mention robots from our list of short-listed sci-fi robots. For example, a number of papers mentioned more than one sci-fi robot both from within and outside of our sample of considered robots (e.g., The Iron Giant robot from the similar named movie; Maximilian from the Disney movie *The Black Hole*). In addition, researchers from robotics or HRI may be implicitly or conceptually be “inspired” by sci-fi content and hence may not explicitly mention such sci-fi agents in their research articles. Moreover, the extent of the inspiration is difficult to be determined

by the number of occurrences of a sci-fi agent or robot in each individual paper. The example of “Puffy” [23] being inspired from the Baymax robot from *Big Hero 6* provides a compelling case of the usage of a fictional robot for real-world purposes, in that case, as a mobile companion for children with neurodevelopmental disorder. Although one could argue that Baymax had a profound impact on the design of Puffy, Baymax was only mentioned once in the actual research paper. While the quantitative text retrieval of specific robot terms is a disadvantage in this study, the qualitative, contextual inspection of every mention does provide the detail necessary to visualize its clear benefits to the research, a double-edged sword that both enhances and limits the research presented. Eventually, we believe that to fully understand and comprehend the relationship between sci-fi and computing science, we would need to interview and communicate with the researchers themselves.

Second, we realize that we have only focused on the ACM Digital Library, future work may well consider other repositories such as Springer, Scopus, or IEEE Xplore. Third, we have restricted our search terms to the CMU Robot Hall of Fame and the Top 10 robots as per IMDB, which mostly comprise newer and recent sci-fi robots from the North American region and, therefore, Western culture. The cultural bias [45] of inferring from pre-dominantly Western sci-fi only seems to prevail here too. Prior research [41] illustrates that the cultural perception of technology and sci-fi robots is a key factor and this would in most likelihood extend to not only the general public but also the researchers in that region. As we mentioned earlier on in our article, hundreds of robots from sci-fi exist and are popular, such as the mecabots from Japanese anime or manga culture [5, 46]. Future work should consider such robots too and those that may not immediately seem to be popular.

In addition, the two listings (CMU Hall of Fame and IMDB sorted list) that we have employed are not only biased toward region or time but also in their medium in the form of cinematic sci-fi given that there are many more robots in sci-fi literature. The advantages and disadvantages between the mediums and formats of sci-fi literature, movies, and videogames on the topic at hand have been recently outlined by Reference [61] and are assessed as another trade-off of affordances and constraints for HCI/HRI design, inspiration, and innovation.

Fourth, we have carried out a manual search with a search strategy to reduce false positives; however, we acknowledge that we may have missed some relevant papers due to our restricted choice of keywords in the process, and as such as our results must be interpreted in light of the final set of 121 mentions across the 102 papers.

APPENDIX A ROBOT IMAGES

Table 3. Links to Images of Our Final Set of 18 Robots (as Sourced from the IMDB Picture Gallery)

Robot	Image Link
Astro Boy	https://www.imdb.com/title/tt0056739/mediaviewer/rm2639234048
Ava	https://www.imdb.com/title/tt0470752/mediaviewer/rm1158938368
Baymax	https://www.imdb.com/title/tt2245084/mediaviewer/rm1051184896
C-3PO	https://www.imdb.com/title/tt0076759/mediaviewer/rm503646208
Data	https://www.imdb.com/title/tt0092455/mediaviewer/rm659341568
Gerty	https://www.imdb.com/title/tt1182345/mediaviewer/rm3130146560
Gort	https://www.imdb.com/title/tt0043456/mediaviewer/rm4044602112
HAL 9000	https://www.imdb.com/title/tt0062622/mediaviewer/rm1106455040
Huey Dewie Louie	https://www.imdb.com/title/tt0067756/mediaviewer/rm2701669632
Jarvis	Virtual AI (No Image Link)

(Continued)

Table 3. Continued

Robot	Image Link
Maria	https://www.imdb.com/title/tt0017136/mediaviewer/rm3367303680
R2-D2	https://www.imdb.com/name/nm0048652/mediaviewer/rm2787544832
Robbie The Robot	https://www.imdb.com/title/tt0049223/mediaviewer/rm2088081408
Sentinel	https://www.imdb.com/title/tt1877832/mediaviewer/rm3317829376
Skynet	Virtual AI (No Image Link)
T-800 Terminator	https://www.imdb.com/title/tt0088247/mediaviewer/rm3657772544
Tars	https://www.imdb.com/title/tt0816692/mediaviewer/rm2841711616
Wall-E	https://www.imdb.com/title/tt0910970/mediaviewer/rm702909696

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