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The role of algorithms for producing and curating content as well as potential outcomes of these mechanisms is one of the most debated issues in existing communication research. "Communicating algorithms" affect processes of political, social and interpersonal communication. A broad variety of communication fields is thus currently touched on by algorithms, ranging from news exposure, public opinion forming, information retrieval, and political communication processes among others. However, a scientific sound and objective consideration of algorithms as actors in digital (mass) communication is still scarce.

The special issue "Algorithms and Communication" addresses this research gap. It presents theoretical as well as empirical results in important fields of communication science, such as media literacy, news aggregation or robotics. With this, it aims to shed light on the black-box of algorithms as "hidden actors" in communication processes.

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Abstract: The political, societal or economic impact of algorithms is seen as one of the most debated issues in recent history. In this introduction to the special issue Algorithms and Communication, we elaborate on the importance of algorithms as research objects for communication science. We discuss why algorithms are such an intensively discussed topic. We describe different kinds of "communicating algorithms" that affect processes of political, social and interpersonal communication. In this context, we elaborate on new research questions for communication sciences that arise out of the importance of algorithms. Finally, we conclude with a call for a transformation of traditional models of mass communication. Particularly, we highlight the necessity to systematically describe and define the role of algorithms as "autonomous" senders in communication processes.

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Christina Schumann & Monika Taddicken

Algorithms as Research Objects for Communication Science

1 Introduction

The political, societal or economic impact of algorithms is seen as one of the most debated issues in recent history. In his popular scientific book "Homo Deus," historian Yuval Noah Harari defines an algorithm as "*...a methodical set of steps that can be used to make calculations, resolve problems and reach decisions. An algorithm isn't a particular calculation, but the method followed when making the calculation*" (Harari, 2015, p. 97). As such, elementary school children already learn basic algorithms applied in basic arithmetic operations, such as addition or multiplication – even if they are not aware they are using an algorithm to solve their problem. With this in mind, the meaning of a more computer-scientific-based definition becomes clear. Cormen and colleagues (2009) state that an algorithm is "*...any well-defined computational procedure that takes some value, or set of values, as input and produces some value, or set of values, as output. An algorithm is thus a sequence of computational steps that transform the input into the output*" (Cormen et al., 2009, p. 5). This input-output relation can be straightforward, such as sorting five random numbers in a list from lowest to highest.

Algorithms have accompanied humankind from the early days. In 300 B.C., the Greek mathematician Euclid developed the so-called Euclidean Algorithm to compute the greatest common divisor of two numbers (Honerkamp, 2012). Given that algorithms are not a new phenomenon and can be so simple that elementary school children understand their basic principles, how can so many discussions currently surround this topic? And why – and how far – is this relevant for communication science?

Maybe the key to understanding this lies in combining three aspects: First, algorithms nowadays significantly impact many facets of our daily lives. Second, algorithms still operate to a high share as "black boxes." As such, we do not know much about *how* they intervene in our daily lives. Third, while we do not know much about them, they can "know" much about us, leading to an imbalance in transparency. Turning to the first aspect, progress in computer sciences has made it possible for algorithms to be tasked with solving problems or reaching decisions in almost every single layer of individual, societal, political, and economic life. In other words, algorithms are inevitable (Rainie & Anderson, 2017). Many of these layers are closely entangled with the core research fields of communication science or related research fields, such as media psychology. Algorithms help us find needed information on the internet, remain informed about current affairs, tailor advertising to our interests, make proposals for potential life partners, and even forecast an influenza pandemic. In many cases, algorithms can help to solve problems that are beyond the capabilities of humans. For example, no human can find an excellent solution to an internet search query about maintaining a healthy lifestyle within a second or two, but a search engine algorithm can. As such, algorithms make our lives easier in many ways, having gained a foothold in society. Some might say that our current model of society may even collapse without them.

However, given this huge impact, there is still a lack of transparency in their working principles that regularly calls the attention of politicians, legislators, regulators, or digital activists. This lack of transparency particularly touches communication scientists' expertise when algorithms affect public affairs fields, such as information or news dissemination or privacy violation (Wendelin, 2020). In this context, the argument is that we must know more about *how* algorithms shape these fields. However, since these algorithms are linked to enormous economic interests, it is against the interests of companies to increase transparency. Indeed, the operating principles of their algorithms are considered some of the best kept – and probably lucrative – secrets in the world (Hildebrandt et al., 2015). In addition, progress in deep learning and neural networks enables algorithms to improve and further develop autonomously without the aid of humans. In a deep learning approach, humans only provide learning materials for the algorithm. The analysis of the material and the deduction of related decisions and conclusions are placed in the "hands" of the self-learning algorithm (Christin et al., 2019). Therefore, the question of how the algorithm concludes might even become a black box for coders and developers (Luber & Litzel, 2017).

While there is this lack of transparency in what we know about algorithms, there is also a glut in transparency in what – at least certain types of – algorithms "know" about us, particularly when a big data approach is applied to analyze "human data": It is well-known that the data traces we leave online while visiting websites, online shopping, be- or unfriending and interacting on social media are stored and analyzed to tailor content and advertisements according to our assumed personal interests and profiles. While this might be helpful in some areas, it potentially hinders others. In particular, when it comes to political communication, the discussions on filter bubbles (Pariser, 2012) and echo chambers (Sunstein, 2001), as well as the "famous" scandal surrounding the role of Cambridge Analytica in the U.S. election from 2016 and the Brexit vote being two prominent testimonies of resulting problems.

In this area of conflict between growing societal impact, lack of transparency, and a glut of transparency, various arguments about the benefit and threads of the "age of algorithms" (Abiteboul & Doewk, 2020) are discussed. These range from praise for a more productive, creative, fair, and efficient future to concerns about a loss of human autonomy and humanity in society: problems stemming from potential algorithmic biases deepening divides in society, and even unemployment (Rainie & Anderson, 2017). Considering Melvin Kranzberg's famous first law of technology:

> Technology is neither good nor bad; nor is it neutral... technology`s interaction with the social ecology is such that technical developments frequently have environmental, social, and human consequences that go far beyond the immediate purposes of the technical devices and practices themselves. (Kranzberg, 1986, S. 545)

Thus, we should analyze, understand, and shape the role of this technology in our society. With this special issue, we aim to contribute to the knowledge about the role of algorithms for (public) communication.

For this, we start by describing the different types of algorithms currently the most prevalent in shaping communication processes. Second, we identify and describe several research fields that require refinement and new thinking. Finally, we set our sights on the future and argue that, with the future developments of algorithms, particularly in artificial intelligence and deep learning, we face even more substantial re-orientation of the basic models that define communication science.

2 Communicating algorithms

The algorithmic selection of information is a central function of various online formats, including social media. It is the technical-functional core of a plethora of applications that increasingly affect processes of social information, communication, and transactions (Saurwein et al., 2017) – applications such as search engines, information aggregators, recommendation systems, scoring systems, monitoring, and forecasting applications, automated content production (algorithmic journalism), and allocation applications such as algorithmically set advertising (computational advertising) or algorithm-based trading (algo trading) highly shape communication processes (Latzer et al., 2016). As such, it is of crucial relevance for research and evaluation of their potential benefits or risks for individuals and society to differentiate between different operation modes on various platforms. In the following, we describe four basic functions of "communicating algorithms." In doing so, we do not map the entire range of algorithms that intervene in communication processes but instead focus on the most prevalent ones.

First is the filtering of information which is widespread in the online world. Here, information that does not meet certain formal criteria is removed. These criteria can be different and refer to various aspects. They are either defined by a user or determined automatically (Haim et al., 2018). Search engines are one example of where users rely on algorithmic filtering procedures (Lewandowski, 2015). Second, and also often used in various online services, is the prioritization of information, which includes creating ranking lists. This can be based on chronological order (presenting the newest information first), as well as on specific ranking factors which account for the (assumed) relevance of information for the users (Lewandowski & Spree, 2011). Third, algorithms can be implemented for classification processes to assign information to specific categories, such as different music styles. Fourth, algorithms can apply associate methods and identify relationships between individual elements. Here, the information is compared by aspects they have in common (content-based filtering) or by reactions of users with similar profiles (collaborative filtering), for example, in online shops ('others who have bought this item were interested in') (Senecal & Nantel, 2004).

Different information sources such as news articles, websites or videos, can be the object of these four methods of algorithmic selection. The different methods are based on different requirements regarding the nature of the underlying information and its database. A sufficient amount and variety of data and metadata are needed to ensure it results at a satisfying quality level (Lewandowski & Höchstötter, 2008). Moreover, several ethical concerns about how algorithms make sense out of the underlying data are discussed, such as the possibility for unfair outcomes (for an overview, see Mittelstadt et al., 2016).

In addition to the "hidden" information selectors, algorithms come into play as more "visible" communicators. The so-called "social bots" have garnered much attention lately (Stieglitz et al., 2017a). Bots are defined as "...software designed to act in ways that are similar to how a person would act in the social space" (Abokhodair et al., 2015, p. 840). They can disrupt or influence online discourse in many ways (e.g., spreading spam or astroturfing) (Stieglitz et al., 2017b). Different kinds of social bots can be differentiated. Two distinctions are commonly made in the literature (Stieglitz et al., 2017a) by distinguishing them into benign and malicious bots (Ferrara et al., 2016). Benign bots aggregate content, respond automatically, and perform other useful services. Malicious bots, in contrast, are designed with a purpose to harm. A lot of discussion and concern on manipulation have been triggered due to the existence of algorithmic actors in opinion-shaping environments. There is indeed research that reveals the involvement of social bots in online discussions about current political events, such as the armed conflict between Ukraine and Russia, and the war in Syria, by spamming the discussion with one-sided arguments or unrelated content to distract participants (Abokhodair et al., 2015).

3 Researching algorithms – from new research questions to a reorientation in communication science

Coming from this brief and by no means comprehensive overview of different types of algorithms, we now turn to the question about the extent to which they already shape traditional fields of communication research and what new research questions have been investigated. Again, we cannot mirror the whole spectrum of research fields and questions but instead focus on those we see as particularly important for communication scholars.

3.1 Perceptions of algorithms

Having highlighted the lack of transparency of algorithms, it becomes even more important to focus on the perspective of recipients interacting with them. Are users aware of algorithmic processes, and how do they perceive and evaluate them?

In essence, research has identified effects termed "machine heuristic" (Sundar & Kim, 2019). This describes a general belief that machines are impartial and objective in their information selection compared to humans. This was also found in the context of algorithmic authorship in journalism (Tandoc et al., 2020). Auto-written news stories were rated as less biased than human-written news (Jung et al., 2017; Wu, 2020). In contrast, it was identified that people often exhibit an 'algorithm aversion' (Dietvorst et al., 2015). Whilst it has been shown that the vast majority of forecasting tasks see algorithmic forecasts being more accurate than human forecasts, people often remain resistant to using algorithms and prefer human forecasts to algorithm forecasts (Eastwood et al., 2012). People seem to trust human input more than algorithmic input (Önkal et al., 2009; Promberger & Baron, 2006).

To perceive and evaluate algorithmic content, recipients must be – at least to some extent – aware of algorithmic communicators. However, based on their literature review, Hargittai and colleagues (2020) conclude that a high share of people are still unaware of algorithmic actors, particularly in social media or search engines. This is insofar remarkable because extracting information from these platforms shapes an inherent part of the information diet of many people. From a political point of view, citizens need a minimum amount of knowledge about news production and distribution to evaluate information and make informed decisions. As such, we see that a certain level of so-called code or algorithmic literacy among the populace is crucial for the future of democracies. The expertise of communication scholars can contribute here to defining, analyzing, and discussing concepts of code literacy and making proposals of how to implement these in modern societies. (For more information, see the paper by Dogruel in this special issue).

3.2 *Algorithmic impact on the informed public*

Public communication is at the core of communication science. As algorithms nowadays play a crucial role in information selection or dissemination, communication scholars have begun to scrutinize their role in this context. Closely related to that are the concerns that content curating algorithms could enclose citizens in so-called filter bubbles (Pariser, 2012) or echo chambers (Sunstein, 2001). In addition, concerns have been expressed that they play an active role in circulating fake news and misinformation. For the first, worries about the decreased likelihood of contacting counter-attitudinal political positions and an increase in ideological segregation in modern societies have been raised (for an overview, see Spohr, 2017). In line with that, manifold problems for the functioning of modern democracies have been discussed (Bozdag & van den Hoven, 2015). However, more and more studies – either empirical or literature reviews – conclude that the problem of algorithms causing filter bubbles is not as severe as initially believed (Bruns, 2019; Möller et al., 2018). Indeed, selective exposure mechanisms or tendencies to place oneself in homophilic networks are not recent phenomena of the algorithmic age. Moreover, under certain conditions, algorithmically curated content might even see citizens encounter more information from the opposing political spectrum (Flaxman et al., 2016). Future studies should look in more detail around the interplay between human selective exposure mechanisms and algorithmic content curation. For the latter, a more differentiated consideration of various types of algorithms and how they might foster or "hinder" the emergence of filter bubbles, as proposed by Berman and Katona (2020), will be necessary. In this context, the analysis of the discrete output of algorithmically curated content can also serve as a gateway for a better understanding of how algorithms shape information dissemination in modern societies. The study by Becker in this special issue proposes an approach for realizing a content analysis of news aggregators' output.

Second, communication scholars have started to address the role algorithms play in disseminating fake news or misinformation, particularly as these often circulate through algorithmic-driven social media platforms. Research in this area is still in its infancy, but initial insights on Twitter and Facebook suppose that algorithms might "privilege" fake news over actual news. Fernández and colleagues (2021) provide an overview of the mechanisms behind this, such as an algorithm's preference for emotional "news" (see Borges & Gambarato, 2019) or an algorithm's popularity bias, meaning that recommender algorithms promote trending information on the platform. As fake news often operates with emotions and as they were found to circulate faster and reach more people (Vosoughi et al., 2018) – in other words, become trends – algorithms may accelerate the dissemination of fake news. In addition, algorithms, especially social bots, can be purposively used as autonomous agents to spread false information and/or manipulate citizens to serve the interests of certain actors (Michael, 2017), something that is also called computational propaganda (Woolley & Howard, 2016). However, in contrast to this "harming" role of algorithms for fake news dissemination, they might also be used to mitigate the problem. Algorithms are trained to detect and monitor false news (Fletcher et al., 2020; Hunt et al., 2020; Singh et al., 2021). Therefore, future research will need to scrutinize if and how such attempts can help curb the problem of fake news traveling through wide circles of the population.

3.3 Algorithms and media regulation. Algorithms as media regulators

Communicating algorithms have also called the attention of media regulators, particularly in the context of social media and search engines. Companies often underline that they are "simply" commercial, governmental and public pressure increasingly force them to accept a hybrid role. While initially not intended, they nowadays play a significant role in citizens' information diet about public affairs (Iosifidis & Andrews, 2020).

The list of aspects that principally fall under the responsibility of media regulation or governance is long and ranges from issues of data protection (particularly against the misuse by companies such as in the famous Cambridge Analytica data scandal) and monopolistic concentration tendencies, over hate speech, and the circulation of fake news (Iosifidis & Andrews, 2020). This also includes calls to make the operating principles of the algorithms more transparent (for some pros and cons, see Hosanagar & Jair, 2018). Given that variety of aspects, the question of how a (or several) regulatory framework(s) should look is a challenging one, and detailed consideration of existing models and the related status of academic research would exceed the scope of this paper. Therefore, for a more comprehensive overview about the different principles of regulation, potential actors, or applied instruments, we have to direct the interested reader to recent publications such as the one by Iosifidis and Andrews (2020) or – more centered on the European context – de Blasio and Selva (2021). However, from the various attempts, we see that the algorithms themselves undertaking the role of regulator or governor will need further scientific consideration by communication scholars. Behind this so-called algorithmic governance (Katzenbach & Ulbricht, 2019) stands the idea of applying technical solutions to complex governance questions (Gorwa et al., 2020). Algorithmic content moderation, for example, should regulate the emergence of hate or antidemocratic speech on social media. Also, the aforementioned algorithmic fake news detection falls into this category. In addition to the more technical question of how good these algorithmic systems work, several concerns are currently discussed from a media regulation perspective. Gorwa and colleagues (2020) emphasize an increased non-transparency in poorly understood processes (see Coglianese & Lehr, 2019), doubts about how fair and objective such systems are, and a de-politicization of a political sphere.

3.4 Algorithms in communication research: A look into the future

Given the various research fields of communication science that are affected by algorithmic "intervention," Schäfer and Wessler (2020) even call for a re-orientation of the discipline. They underline the necessity to systematically focus and integrate socio-technological innovations for (public) communication in the research process. Indeed, the impact of technology for communication processes at its best plays a marginal role in the classical and basic models of mass-communication science that lay the foundation of the discipline. Through the lens of communication scholars, it is essential to locate algorithms in the communication process and to apply a finer granulation of functional algorithms that can play within the process.

Looking into the future, we see the necessity for a substantial transformation of traditional models of mass communication. This process had already started when the original sender-, mediator- and receiver-approach was adopted by considering the computer as a mediator (the tradition of computer-mediated-communication research) and, more recently, as a sender (human-computer-interaction research). In the future, we argue that communication science needs an even more comprehensive interpretation of the sender involving algorithms. Notably, we must consider the vast developments in artificial intelligence that will impact communication processes. Guzman and Lewis (2020) introduce a Human–Machine Communication research agenda, Hancock and colleagues (2020) argue for the introduction of AI-mediated communication (AI-MC) research. Here, AI is referred to as "... computational systems that involve algorithms, machine learning methods, natural language processing, and other techniques that operate on behalf of an individual to improve a communication outcome" (Hancock et al., 2020, p. 90). However, 'communicative robots' (Hepp, 2020) enable further algorithmic-based functionalities – often but not always on the basis of artificial intelligence. The paper by Zeller on algorithmic machines, social robots, and Human-Robot-Interaction in this special issue encourages many existing and future perspectives in this research field.

4 The special format of a special issue in the open-access book series "Digital Communication Research"

In addition to the comparably "new" research area of algorithms in communication science, there are several specifics regarding this special issue. First, we decided to make use of the possibilities the online and open access format that the DCR Digital Communication Research series offers. Initially, DCR was conceptualized as a book series and was introduced as "... the official book series of the "Digital Communication" section of the German Communication Association (DGPuK). The book series publishes conference proceedings, edited volumes as well as dissertations and other monographs dealing with digital communication" (see digitalcommunicationresearch.de; translation by authors). In DCR, every chapter (or entire book) undergoes a rigorous peer-review process, and all edited volume chapters or conference proceedings receive a doi of their own. This is a clear testimony that the lines between books and journal publications become blurry when publishing online and that new forms and formats of academic publications are possible. In this respect, we did not feel bound by the format of a book, such as the traditional anthology, when designing this special issue as a somewhat hybrid format: A publication that is published in an open access book series but one that resembles the format of a special issue as known in journal publications.

Second, we noticed – both ourselves and through many discussions in the world of academia – an urgent need for overview articles that bring together different reflections of research and that systematize and elaborate in more detail on research fields than an empirical paper. We assume it is fruitful for the academic world to have such work not only in handbooks and student manuals. As such, we call for a higher entanglement of empirical and theoretical-/meta-analytical research in established academic publication series. Consequently, the present special issue contains both: empirical work and overview articles. However, we are aware of the challenges in publishing such overview articles because they must be well-balanced between an overview and report of the status quo and a novelty value. This is relevant for the authors during the writing process and for the reviewers and editors during the evaluation process.

Third, this special issue was produced during the COVID-19-pandemic. This was (and is) a challenging time for the researchers (and for all other people as well). Many scholars faced serious difficulties in finding the time and cognitive capacity for their research and publication work given the increased demands in teaching as well as caretaking, homeschooling, and other duties during lockdowns. These challenges have affected everyone – editors, authors, and reviewers – as well as those who would have been authors of this special issue but who had to withdraw. Though the entire publication process took considerably longer due to the pandemic, we are proud of ourselves. We have great respect for the authors who managed to bring their contribution to the finish line despite the adverse conditions. We look forward to other opportunities to work with them – and of course, the non-authors. In the sense of this special issue: Scientists are also just human beings, not algorithms.

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Abstract: News search engines are popular tools to navigate the online news landscape. By filtering and ranking articles, they act as secondary gatekeepers and can influence what news is accessible. This study examines to what extent two news search engines deliver different perspectives on political actors in the context of several political events. In a quantitative content analysis of 400 search results and 200 retrieved articles, the portrayal of German politicians in Bing News and Google News search results for 16 different search terms is assessed. The findings show that, although the Google News results are more likely to include opinionated articles, most politicians are portrayed similarly in the articles retrieved by both services.

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Marius Becker

Neutral News Aggregation?

Comparing the Portrayal of German Politicians in Bing News and Google News Search Results

1 Introduction

News media serve several important functions in democratic societies: they highlight relevant issues, provide citizens with information to make informed decisions, monitor the government, and showcase different perspectives (Beck, 2016; Gurevitch & Blumler, 1990; Jarren, 2008). The internet is a significant source of information in Germany, with 80 to 90 percent of the German population using it (Koch & Frees, 2017) and with 68 percent of German internet users consuming online news on a weekly basis (Hölig & Hasebrink, 2019, p. 16).

To cope with the constantly increasing and changing online content, users rely on search engines to find websites relevant to their information needs. These services play a crucial role for online information seeking (e.g., during elections: Arendt & Fawzi, 2018; Trevisan, Hoskins, Oates, & Mahlouly, 2016) and are regularly among the top websites in popularity rankings (Alexa.com, 2017b; Similar Web, 2017). 39 percent of German internet users frequently rely on search engines to find news, with 13 percent ranking them as the most important tool for this purpose (Hölig & Hasebrink, 2019, p. 40).

While these services help users cope with the online information overload, they may introduce information biases. Based on McQuail's gatekeeper definition (2010), search engines can be described as internet gatekeepers, because they decide whether or not information is shown to recipients. While the internet may diminish the roles of individual human gatekeepers (Singer, 2006), these new digital gatekeepers may introduce new biases (Gerhart, 2004).

Differences between services' algorithmic systems used for the selection and ranking of content may result in differing search results when using the same search terms. Drawing from the current literature, this paper first examines the role of search engines as gatekeepers in the modern media landscape and presents approaches and results of previous studies on bias in these services. While the majority of studies focus on the retrieved news sources themselves, this study adds to the existing literature by comparing the search results of two popular news search services, Bing News and Google News, and assessing the content of the retrieved articles in more detail. A quantitative content analysis of the search results was conducted to facilitate this comparison and the resulting findings are discussed with regard to future venues of research and suggestions for practical uses.

2 Theoretical Background

2.1 News Search Engines and Algorithms

Algorithms can be described as sets of instructions to derive a desired output from a given input (Gillespie, 2014). Search engine algorithms can be further characterized as black boxed, embedded, ontogenetic, and contingent (Kitchin, 2017, pp. 20–22). They can be thought of as black boxes because the exact steps that lead to a specific output for a given input are well-kept trade secrets. They are the results of numerous people creating, maintaining, and revising the various parts of the algorithms, and thus become increasingly difficult to understand in their entirety (Kitchin, 2017; Seaver, 2013). Additionally, search algorithms are "never fixed in nature, but are emergent and constantly unfolding" (Kitchin, 2017, p. 21). They are constantly refined to account for new types of inputs, interactions, and contexts, which may generate unexpected results (see Mackenzie, 2005; Steiner, 2012).

Today's most common search engines utilize a web index and a web crawler in combination with various search and ranking algorithms (Risvik & Michelsen, 2002; Seymour, Frantsvog, & Kumar, 2011). A web index is a searchable database of all web content known to the search engine and may be limited to certain types of content (e.g., news; Lewandowski, 2015). Web crawlers are programs that traverse the internet by following links, archive the visited content in said index, and regularly revisited websites to update the index (Lewandowski, 2015; Risvik & Michelsen, 2002). Further, search algorithms search the index based on user queries and ranking algorithms in turn create the search result list by ranking the available content (Lewandowski, 2015).

A considerable volume of web traffic to news sites is generated by search engines (Olmstead, Mitchell, & Rosenstiel, 2011) and this has been demonstrated on numerous occasions. For example, studies on the effects of the shutdown of the Spanish edition of Google News in 2014 report noticeable decreases in daily web traffic, especially for smaller news outlets (Athey, Mobius, & Pál, 2017; Calzada & Gil,2017, 2020). In addition, considerable losses in traffic volume and drops in online marketer rankings were experienced in Germany by publishing house Axel Springer when they temporarily opted out of the German edition of Google News in October 2014 (Axel Springer, 2014; Calzada & Gil, 2020).

Most traffic via these search engines consists of casual users, which leads to increased competition for the audience's attention (Miel & Faris, 2008; Olmstead et al., 2011). In competing for this attention, news media must facilitate easy indexing and may even cooperate with search engine providers directly (Miel & Faris, 2008). For example, publishers may apply for indexing in services like Bing News (Microsoft Bing, n.d.). Until recently, Google News (Google Inc., n.d.c) also provided this option, though it no longer specifies how publishers can ensure their appearance in the service's index (Google Inc., n.d.b).

2.2 Algorithmic Systems as Gatekeepers

As mentioned earlier, by selecting which news content will be shown to users, search engines function as gatekeepers (Wolling, 2002, 2005). Journalistic gatekeeping traditionally refers to the process by which the content of media outlets is determined (McQuail, 2010). More specifically, in the context of news, it refers to how some reports are selected for publishing, while others are not.

Search engines and traditional human gatekeepers do not fill the same roles (Schroeder & Kralemann, 2005; Singer & Quandt, 2009). Journalists, editors, and news organizations not only select information to publish, they also produce and broadcast. In comparison, algorithmic gatekeepers rely on previously published news created by traditional human gatekeepers. Thus, despite the popularity and prevalence of algorithmic gatekeepers, news media organizations still remain crucial to the circulation of news (Nielsen, 2014).

The increasing diversity of actors in modern gatekeeping roles poses challenges to the traditional gatekeeper approach (Wallace, 2017). Some scholars consider the gatekeeping approach obsolete (Williams & Delli Carpini, 2016), while others suggest expanding the process to include secondary gatekeepers (Singer, 2014), or argue for a more flexible understanding of the ways different actors coexist and curate the flow of information (Thorson & Wells, 2016; Wallace, 2017). The concept of online secondary gatekeepers describes an additional step in the flow of online news information in which human users or algorithmic systems take information published by primary gatekeepers such as media organizations and journalists and make it available to a broader audience (Nielsen, 2014; Singer, 2014, Wallace, 2017).

Types of digital gatekeepers can be differentiated via three aspects (Wallace, 2017): the access to information, the selection criteria, and the choice of publication. Human gatekeepers may utilize all available information channels, whereas algorithmic gatekeepers' access to information is controlled by their governing organization. Traditional human gatekeepers select information based on news factors (Galtung & Ruge, 1965), as well as personal criteria, predispositions, and attitudes (Eilders, 2006). Algorithmic gatekeeping similarly requires selection criteria. To circumvent the difficulties of reducing journalistic quality to quantifiable factors, algorithmic gatekeepers commonly redistribute already-published news content as secondary gatekeepers (Singer, 2014; Wallace, 2017) and instead of assessing the journalistic quality of the content itself, they focus on other factors like the popularity of the source or number of times a search term appears in the content (Lewandowski, 2015, p. 92). However, these measures may be manipulated in effort to improve search result rankings (search engine optimization, see Yalçın & Köse, 2010). The output of algorithmic gatekeepers is closely tied and often limited to their proprietary platforms, whereas human online gatekeepers may distribute content across several websites (Wallace, 2017).

The role of algorithmic gatekeepers is an important topic in normative discourses; they influence what is visible online, thereby shaping what is considered public interest (Gillespie, 2014; Wallace, 2017). With technologies filling roles previously occupied solely by humans, there are both hopes and concerns. On the one hand, news search engines can help to curate a personalized mix of news specifically tailored to the individual needs and preferences of every user (Helberger, 2019). On the other hand, there are concerns that these technologies actually impede the democratic exchange of ideas by creating personalized filter bubbles (e.g., Bozdag & van den Hoven, 2015; Kahne, Middaugh, Lee, & Feezell, 2011; Pariser, 2011). However, empirical evidence of this phenomenon is scarce and recent studies have reported only minor evidence of filter bubbles (for an overview, see Bruns, 2019; e.g., Bodó, Helberger, Eskens, & Möller, 2018; Dubois & Blank, 2018; Haim, Graefe, & Brosius, 2018; Krafft, Gamer, & Zweig, 2019). The increased economic pressure on media organizations (Helberger, 2019; Miel & Faris, 2008), and the lack of transparency in algorithmic gatekeeping processes (Diakopoulos & Koliska, 2016) are also viewed critically in the literature. As such, there is currently no clear conclusion on the democratic role of algorithmic news gatekeepers (Helberger, 2019), partly because a lack of coherent standards for human gatekeeping impedes the normative analysis (Nechushtai & Lewis, 2019).

Algorithmic Gatekeeping Bias

Contrary to the popular belief that algorithmic gatekeepers remove human media bias from the gatekeeping process (Bozdag, 2013; Carlson, 2007; Kitchin, 2017; Tavani, 2016), biases may also develop in algorithms (Friedman & Nissenbaum, 1996). These biases, categorized as societal, technical, and emergent, vary in their origins and are connected to different steps in the development and usage cycles. Societal biases influence system designers, which can lead to the implementation of these biases in the software. As algorithms are shaped by the conditions in which they are developed (Geiger, 2014; Kitchin, 2017), (un)intentional biases can originate from the designers themselves, from their working environment or industry, or from their culture in general (Friedman & Nissenbaum, 1996). Technical biases can be caused by technical decisions, imperfections, the quality of training material, and limitations of the deployed systems (Friedman & Nissenbaum, 1996). Lastly, emergent biases may be identified after a system has been in use for longer periods of time. This type of bias is often the result of societal changes or changes to the context of the software that cannot be accounted for in the system itself (Friedman & Nissenbaum, 1996). Emergent biases may also be the result of how users utilize the technology in their everyday life (Kitchin, 2017). Algorithms are therefore not only shaped by the programmers and their environment, but also by how users interact with them (Gillespie, 2014).

Search engines specifically are susceptible to bias at several steps along the selection and ranking processes (Bozdag, 2013, pp. 214–220). First, the indexing itself may introduce bias as the online environment is constantly changing (Baeza-Yates & Ribeiro, 1999) and search indices can never encompass all the available content, which leads to coverage bias (Goldman, 2008; Vaughan & Thelwall, 2004). In addition to technical limitations, which can prevent the web crawlers from accessing certain websites (Barzilai-Nahon, 2008), curated indices further shape which news articles may be retrieved. If publishers must apply for inclusion and need to be vetted, these steps will limit the coverage of the respective index. Publishers who do not apply or do not pass the vetting process may not be considered by the search engine and thus remain invisible to users.

Second, there is potential for bias in the selection and ranking of news content based on the search query. Common criteria to assess a news article's relevance are text-specific factors (e.g., frequency of search terms appearing in the document), popularity (e.g., number of links pointing to the article), and the currency of the content (Lewandowski, 2015, p. 92). Popularity as a selection criterion can lead to authority or popularity bias in which established and popular websites are favored over smaller ones (Introna & Nissenbaum, 2000). Promotion of already popular content may lead to feedback loops, resulting in already influential media groups dominating the rankings (Schroeder & Kralemann, 2005). The factor currency is also contested because it may encourage news websites to hastily republish wire reports or copy articles from others, instead of producing original content (Carlson, 2007; Thurman, 2007), which is an example of third party manipulation via search engine optimization (Yalçın & Köse, 2010). While secrecy about ranking procedures helps combat manipulation, it also means that the validity of rankings cannot be verified (e.g. Hinman, 2005; Machill, Neuberger, & Schindler, 2003).

Third, despite the frequently assumed lack of human involvement, human operators also make editorial judgements on what data to collect, delete, or disregard (Bozdag, 2013). The aforementioned vetting of news sources can include assessment by humans, and therefore may be biased by individual attitudes, beliefs, and experiences. Additionally, the relationship between the search engine provider and the publisher may influence the white or black listing of specific sources (e.g., to punish publishers for lawsuits: Haim et al., 2018, p. 10).

Fourth, measures to personalize the search results based on user preferences and previous interactions may introduce biases similar to the previously mentioned filter bubbles.

Lastly, there is a potential for bias in the presentation of the search results itself as differences in font sizes and font styles between listed search results can further encourage users to visit certain websites instead of others (Jansen & Spink, 2006; Yue, Patel, & Roehrig, 2010).

In summary, algorithmic gatekeepers like search engines play an important role in the online media landscape. However, these non-human gatekeepers are not free of bias, albeit different types of bias compared to human gatekeepers, and should be examined accordingly.

2.3 State of Research

Researchers continuously examine algorithmic gatekeepers. In this context, personalization of search results is a very popular topic, with studies documenting effects of accounts related to search engines (Hannak et al., 2013; Nechushtai & Lewis, 2019; Puschmann, 2019) and the user's location (Kliman-Silver, Hannak, Lazer, Wilson, & Mislove, 2015; Krafft et al., 2019). While there is some evidence of personalized search results in Google Search, Google News appears to limit personalization to clearly labelled areas (Cozza, van Hoang, Petrocchi, & Spognardi, 2016; Haim et al., 2018).

A related avenue of research is the range of online information sources which users of different web services are exposed to. Studies in this area frequently employ click datasets and web-browsing records (e.g., Flaxman, Goel, & Rao, 2016; Nikolov, Oliveira, Flammini, & Menczer, 2015). However, as mentioned earlier, findings of empirical studies on the occurrence of filter bubbles have raised doubts as to the validity of the concept (Bodó et al., 2018; Bruns, 2019; Dubois & Blank, 2018; Haim et al., 2018; Krafft et al., 2019; Möller, Trilling, Helberger, & van Es, 2018). In contrast, Google News results specifically include the highest percentage of ideologically opposing articles when compared to social media and general search engines (Flaxman et al., 2016) and are dominated by general interest news websites (Unkel & Haim, 2019). Although these findings contradict the concept of filter bubbles, they do raise concerns about the adoption of existing media biases in the search results (Unkel & Haim, 2019). For example, there is a potential for country-specific ideological biases as evidenced by an overrepresentation of conservative news sources in the German edition of Google News (Haim et al., 2018) and a left-leaning slant in the US edition's top stories (Trielli & Diakopoulos, 2019). Possible explanations for these contrasting findings include varying efforts in search engine optimization, as well as news sources' relationships with Google itself (e.g., strained relationships due to a lawsuit in Germany, Haim et al., 2018).

While uncertainty about potential ideological bias remains, there are conclusive reports pointing toward overall decreasing numbers of distinct news sources and increasing homogeneity in Google News search results (Haim et al., 2018; Krafft et al., 2019; Nechushtai & Lewis, 2019; Puschmann, 2019; Trielli & Diakopoulos, 2019; Unkel & Haim, 2019). Thus, some scholars argue that the service is not utilizing its algorithmic capabilities and is instead showing signs of source concentration and a mainstream bias (Nechushtai & Lewis, 2019, p. 302) with sets of mainstream news sources making up the core of Google News results (Puschmann, 2019, pp. 828–830).

Studies comparing search results for the same queries between different engines support the reports of media concentration. For example, in a comparison of search results between 2006 and 2008, an overall trend towards declining numbers of distinct news sources in Google News and Yahoo News is reported (Bui, 2010). Considering the important role news websites play in search results (especially for Bing and Google; see Magin et al., 2015), decreasing numbers of distinct news sources may indicate a concentration bias.

Against this backdrop, studies analyzing and comparing the actual content retrieved by search engines are crucial to understand how the previously described trends influence the information that is presented to users. In his paper, Ulken (2005) assesses political biases of Google News and Yahoo News by comparing the results of two search terms before the 2004 US presidential election. However, in the limitations, the author notes two flaws in the coding scheme: the individual coding of each sentence without consideration of context, which prevents the adequate coding of messages stretching across several sentences, and the imprecise definition of favorability. In this comparison, Google News results are more likely to favor or oppose a candidate, while Yahoo News results are generally more impartial. The study found no overarching conservative or liberal tendency in the Google News results. Instead, the search results included both articles with conservative and liberal perspectives. Ulken (2005) suggests that these differences are caused by the wider range of news sources included in Google News‘ index. The inclusion of non-traditional news sources like blogs and a stronger focus on editorials and opinion pieces is in line with Google's stated goal of presenting different perspectives on current news topics (Google Inc., n.d.a).

In their paper, Magin, Steiner, and Stark (2019) analyze the websites retrieved by five search engines for different queries on political topics and focus on the diversity of information in the search results by coding different information elements. Information elements include background information, current events, actors, and potential future developments. Further, they report significant differences in the information diversity based on the topics themselves, and depending on the number of search results considered per search engine. All services performed comparably when the first ten results are considered, though significant differences were observed when only the first three hits were examined (Magin et al., 2019, p. 424): Google and Bing performed similarly, while Ask provided results with the most diverse information.

2.4 Media Portrayal of Politicians

Recent studies have raised concerns about political bias in news search results (see Haim et al., 2018; Trielli & Diakopoulos, 2019). However, these studies focus on the representation of news sources and not the news content itself. So far, only Ulken (2005) has assessed political bias on a content level by analyzing the favorability towards or against the two selected politicians.

There is some empirical evidence that media coverage about politics focuses less on topics or parties, and instead puts individual political actors at the center of attention (Adam & Maier, 2010, p. 231; Karvonen, 2009; van Aelst, Sheafer, & Stanyer, 2012). While current research does not tie citizens' voting decisions directly to individual politicians (see Adam & Maier, 2010), the opinions of politicians likely play an indirect role in the voting process by influencing party perception and identification with the party (Aaldering, van der Meer, & van der Brug, 2018; Brettschneider, 2002; Garzia, 2017).

Politicians can be evaluated in different dimensions which "*...[comprise] 'hard' professional (or performance-related) characteristics, 'soft' personal traits, and the details of their personal lives*" (Holtz-Bacha, Langer, & Merkle, 2014, p. 156). Focusing on professional traits, Aaldering and Vliegenthart (2016) propose a framework consisting of six dimensions that characterize political leadership images: political craftsmanship, vigorousness, integrity, responsiveness, charisma, and consistency. Political craftsmanship refers to the ability to act efficiently in a political environment and encompasses aspects like (issue-specific) knowledge, political experience and the ability to judge and understand political situations and actors. Vigorousness describes the strength of leadership displayed by a politician and includes assertiveness, decisiveness, and negotiation skills. Integrity refers to a politician's trustworthiness and whether they are perceived to be motivated by electorate interests or greed. Responsiveness describes a politician's receptiveness to citizens' concerns and public opinion, and charisma encompasses the ability to inspire followers, to convey a vision to the public, to appear likeable, and to successfully convey all these aspects in media appearances. Lastly, consistency refers to how stable a politician's opinions and views on society are over time, and whether they act in line with these views.

The discussion of the aforementioned personal characteristics in the media is referred to as privatization (Holtz-Bacha et al., 2014, p. 156; Langer, 2010; van Aelst et al., 2012, p. 210) and four broad and easily identifiable categories can be used to assess its prevalence in media coverage (Holtz-Bacha et al., 2014; van Aelst et al., 2012). The first of these categories encompasses all references to families and friends. The second refers to information about politicians' lives before politics, including their upbringing, details about their scholastic career and education, as well as information about unrelated previous jobs. The third focuses on politicians' leisure time, which includes references to private interests, hobbies, and vacations. The fourth and final category is made up of all references to politicians' love lives, including current or past partners, and sexual orientations.

2.5 Research Aim

The discussed literature reveals several research gaps. For example, although some studies compare different services, many focus on examining Google, which is likely influenced by Google's market dominance. Very little empirical data exists on search results retrieved by Microsoft's Bing (e.g., Magin et al., 2015; Magin et al., 2019), the second most popular search engine in Germany (Microsoft Bing Ads, 2016), with even less information on its news search engine. These parts of the services merit closer inspection, because journalistic news sources make up the majority of results in many search engines (see Magin et al., 2015; Magin et al., 2019). The aforementioned content-level study may already be considered outdated (Ulken, 2005) as the constantly changing nature of algorithmic gatekeepers calls for frequent (re-) examination (Kitchin, 2017).

Therefore, the aim of this study is to compare two news search engines on a content level, focusing on the German editions of Google News and Bing News. Google News was selected because Google is the most popular site for German internet users (Alexa.com, 2017b) and its news search engine is the fifth most popular news website globally (Alexa.com, 2017a). Bing News is part of Germany's second most popular search engine, with a market share of ten percent at the time of data collection (Microsoft Bing Ads, 2016).

This study provides a descriptive snapshot of the search results on a content-level. Assuming that the media coverage of politicians can indirectly affect identification with political parties and voting decisions (Aaldering et al., 2018; Brettschneider, 2002; Garzia, 2017), differences in the sources and content retrieved by search engines may influence people's perceptions. In line with Ulken (2005), the portrayal of politicians shall serve as the main point of comparison, leading to the following three research questions.

RQ1: *What news sources are retrieved by Bing News and Google News for search queries related to German politicians and how do they differ?*

This study begins by looking at the actual sources presented by the two services to provide context for the content-level analysis. Previous studies have shown a declining trend in the diversity of sources and have reported greater diversity (Flaxman et al., 2016) and trends of media concentration over time (Bui, 2010). More recent studies have observed selected news sources dominating the search results (Haim et al., 2018; Krafft et al., 2019; Nechushtai & Lewis, 2019; Unkel & Haim, 2019).

RQ2: *To what extent do the two news search engines' results differ in their portrayals of individual politicians?*

This study also compares the services' search results on a content-level by assessing the portrayal of politicians' professional characteristics and private traits. Previously, more evaluative portrayals of politicians have been explained by more diverse sources (Ulken, 2005), though more recent studies have reported trends of source concentration and mainstreaming (Bui, 2010; Haim et al., 2018; Krafft et al., 2019; Nechushtai & Lewis, 2019; Unkel & Haim, 2019). However, as Magin et al. (2019, p. 422) point out, the effect of limited source diversity on the range of perspectives in diversity of the actual content remains unclear and, as a result, the present study examines this development from a content perspective.

RQ3: *To what extent do the two news search engines' results differ in their portrayals of politicians affiliated with different political parties?*

Lastly, this study looks at the overall portrayals of politicians based on their party affiliations. Earlier studies have sought to assess claims of a conservative political bias in search results (Ulken, 2005). Recent findings observe signs of a left-leaning bias in the US edition of Google News (Trielli & Diakopoulos, 2019) and an overrepresentation of conservative sources in the German edition (Haim et al., 2018). Thus, the present study investigates the potential of political bias by examining the portrayals of politicians based on their party affiliations.

3 Method

This study follows a quantitative and cross-sectional design based on a reverse engineering approach (Diakopoulos, 2014, p. 404; Kitchin, 2017, p. 23). The selected search engines are black boxes, where only input and output can be observed, but the internal processing that leads to the output remains unknown (Baumgärtel, 1998; Glanville, 1982; Lewandowski, 2015). The comparison of outputs for identical inputs cannot provide specific information on how the outputs are generated, but it can indicate general differences between the services (Seaver, 2013). Considering the gatekeeping function of search engines, differences in the outputs may influence the composition of users' news diets depending on the selected service.

Data collection was conducted in three steps. In the first of these, several parallel searches using a range of search terms were performed with the German editions of Bing News and Google News. The search terms focus on several events in the German political sphere between December 2017 and January 2018. To replicate realistic and typical search term usage, the chosen search terms were short and not in the format of an actual question (Hochstotter & Koch, 2008; Jansen & Spink, 2006; Silverstein, Marais, Henzinger, & Moricz, 1999; Zahedi, Mansouri, Moradkhani, Farhoodi, & Oroumchian, 2017).

In total, sixteen search terms divided into three categories were selected for analysis (Table 1). These categories are political parties of the German Bundestag, the topic of coalition talks, and the names of two politicians. The topic of coalition talks, specifically talks about the continuation of the grand coalition ("Große Koalition", GroKo) between the Christian Democrats (CDU/CSU) and Social Democrats (SPD), was chosen because it dominated the media coverage at the time the searches were conducted and was of great importance for Germany. The two politicians, Angela Merkel and Martin Schulz, were chosen because of their pivotal roles in these coalition talks.

Four search queries were repeated at different points in time, as there was a significant development in the process of coalition negotiations. The searches for each search term were performed simultaneously for Google News and Bing News, which allows for comparisons between the services. Comparisons between different search terms are not feasible, because not all search terms were used on the same day. In an effort to minimize personalization effects, all searches were conducted in fresh browsers with no connected Google or Microsoft accounts. For each search query, the first results page per search engine was archived, with each page listing 20 search results.

Table 1: Search terms

Search Terms		Date of Search	Context
Political parties			
CDU	(center-right)	16.01.2018	Day after potential coalition partner SPD calls for changes to exploratory coalition talk agreements after slow negotiations
CSU	(center-right)	04.12.2017	Day of CSU leader Horst Seehofer's announcement to resign as Bavaria's chief minister
SPD	(center-left)	21.01.2018	SPD votes on whether to start coalition talks with CDU/CSU
AfD	(right-wing to far-right)	24.01.2018	Day after the AfD assumes head of a committee in the German Bundestag for the first time
FDP	(center to center-right)	23.12.2017	Day after FDP leader Christian Lindner proposes revival of previously aborted "Jamaika" coalition talks (with CDU/CSU and Die Grünen) after new elections
Die Linke	(left-wing to far-left)	30.12.2017	Day of Oscar Lafontaine's (ex-leader of Die Linke) proposal for a new joint left people's party with Die Grünen and SPD
Die Grünen	(centre-left)	08.01.2018	Day of Simone Peters', federal chair of Die Grünen, announcement to not run for this position again
Topic: Coalition talks			
Große Koalition		20.01.2018 22.01.2018	Day before the SPD-vote on coalition talks for a grand coalition (German: Große Koalition, GroKo); Day after the positive SPD-vote to begin coalition talks

GroKo	20.01.2018	Day before the SPD-vote on GroKo coalition talks
	22.01.2018	Day after the positive SPD-vote to begin coalition talks
GroKo Verhandlungen	27.01.2018	After the first day of GroKo coalition talks
Jusos	22.01.2018	The SPD youth organization, Jusos, publicly opposes GroKo after SPD votes to start GroKo talks
Kooperationskoalition	13.12.2017	Day after SPD proposes an alternative, less binding coalition model (cooperation coalition)
Sondierungsgespräche	13.01.2018	Exploratory talks between SPD and CDU/CSU end with agreement to engage in coalition talks
Sondierungen GroKo	13.01.2018	Exploratory talks between SPD and CDU/CSU end with agreement to engage in coalition talks
Politicians		
Angela Merkel	20.01.2018	Day before the SPD-vote on GroKo coalition talks
(CDU leader at the time)	22.01.2018	Day after the positive SPD-vote to begin coalition talks
Martin Schulz	20.01.2018	Day before the SPD-vote on GroKo coalition talks
(SPD leader at the time)	22.01.2018	Day after the positive SPD-vote to begin coalition talks

Order based on number of seats in the German federal parliament (CDU & CSU share seats). Party search terms include common abbreviations: Alternative für Deutschland (AfD), Christlich Demokratische Union (CDU), Christlich-Soziale Union in Bayern (CSU), Freie Demokratische Partei (FDP), Sozialdemokratische Partei Deutschlands (SPD).

In the second step, the first five news articles per results page were archived in their entirety. The links were not clicked during the first step to avoid providing any information about supposed preferences of the simulated user. With no available information on whether Bing News personalizes the main results, these measures of caution were implemented in all searches, even though personalization on Google News does not appear to influence the main results (Cozza et al., 2016). It is also important to note that the two search engines differed in their layouts: Bing News presented one article per search result, whereas Google News grouped several articles together into one. In line with literature on presentation bias, the most prominent article for each of these groups was selected for the content analysis (Jansen & Spink, 2006; Yue et al., 2010). Thus, the topmost link per result was chosen because its larger font size was deemed more likely to catch a user's attention.

The third and final step was a quantitative content analysis of the first ten search results as they appeared on each archived result page and the first five news articles in full length. This sampling strategy is based on user behavior studies that show web search users tend to focus on the first visible results without scrolling down (Granka, Joachims, & Gay, 2004) and concentrate on the first page of search results (Jansen & Spink, 2006). In total, this strategy resulted in a sample size of 400 search results and 200 articles evenly distributed between Bing News and Google News for the content analysis.

3.1 *Source Characteristics and Content Characteristics*

The content analysis was conducted with two different coding units. Search result entries, consisting of headlines, source names and snippets (only in Bing News), were analyzed to collect data on the characteristics of the retrieved news sources. The source categories include the ranking position, the search engine, and the news source. The news sources themselves were differentiated by name and based on their primary background as online-only, broadcast, or print media.

The second coding unit, whole news articles, was used to assess the content characteristics of the search results. Articles were differentiated as copies of wire service reports (Carlson, 2007; Thurman, 2007) and clearly marked opinion pieces. Articles, which were neither wire reports nor opinion pieces, were classified as regular articles. While there are many aspects in which the retrieved content could differ, this study focuses on the portrayal of politicians for three reasons. First, there have been concerns about political bias in search results (see Haim et al., 2018; Trielli & Diakopoulos, 2019; Ulken, 2005). Media portrayals of politicians may influence political decisions and elections (Aaldering et al., 2018; Garzia, 2017; McAllister, 2007), which establishes this aspect as one proxy measure for political bias. Second, analyzing the portrayal of individual politicians has a strong tradition in communication research, which aided the codebook development (Adam & Maier, 2010; Holtz-Bacha, Lessinger, & Hettesheimer, 1998; Karvonen, 2009; van Aelst et al., 2012). Third, the most prominent political topic in the news at the time of data collection was closely tied to the leaders of the different political parties in Germany.

The portrayals of politicians were coded in 20 content categories (Table 2). These categories can be divided into two parts: leadership images, and privatization. The former focuses on politicians' professional characteristics as differentiated by Aaldering and Vliegenthart (2016) and the latter considers their personal lives as defined by Holtz-Bacha et al. (2014). This approach differs from Ulken's (2005) by providing a more detailed assessment of portrayal based on established concepts in political communication research.

Every category was coded up to three times per article, depending on the number of mentioned politicians, and only references to the first three mentioned politicians were considered. For each category, the overall tone of the article in reference to a specific politician's characteristics was assessed. The categories were coded in an ordinal scale differentiating between positive (1) and negative (-1) portrayals. Mentions of characteristics that included both positive and negative evaluations or no evaluation were coded as ambivalent or neutral (0; see Aaldering & Vliegenthart, 2016). The absence of mentions of characteristics was coded outside of this scale.

The six dimensions of leadership images identified by Aaldering and Vliegenthart (2016) were split into twelve individual categories to simplify the coding process. Similarly, broader dimensions of privatization were split into smaller categories. In addition to private relationships, lifestyle (e.g., hobbies), past life and socio-economic background, mentions of age were also considered. For the data analysis, an overall portrayal index was calculated by combining the values of the leadership image categories with those of the privatization categories in a mean index.

Table 2: Content categories

Categories	Sub-Categories	Cohen's Kappa
Privatization[a]		
Age		.91
Religion		–[c]
Private Relationships	Family/Love Life	–[c]
	Friends & Relatives	1.0[c]
Past Life & Upbringing	Childhood	1.0[c]
	Socioeconomic Background	.82
Education		.86
Lifestyle		1.0[c]
Mean reliability		.86
Leadership Images[b]		
Political Craftsmanship	Political Experience	.89
	Knowledge	.84
	Judgement	.74
Vigorousness	Assertiveness	.92
	Guidance	.82
	Decisiveness	.74
Integrity		.89
Charisma	Likability	.90
	Public Support	–[c]
Consistency		.82
Responsiveness	Consideration of Feedback	1.0[c]
	Opportunity for Feedback	1.0[c]
Mean reliability		.84

All categories are coded on a three-point scale: -1 (negative) 0 (neutral / ambivalent) 1 (positive). [a] *Based on Holtz-Bacha et al. (2014) and van Aelst et al. (2012).* [b] *Based on Aaldering and Vliegenthart (2016).* [c] *Lack of variance in pretest sample, these categories are not included in the mean reliability indices.*

The codebook was pretested with a sample of 60 search results and 30 articles coded by two independent coders. The inter-coder reliability for the categories differentiating news sources and article types is sufficient (Cohen's Kappa between .94 and 1.0). The more complex content categories show generally sufficient but varying reliability coefficients (Cohen's Kappa between .74 and 1.0). However, these reliability coefficients need to be interpreted with caution, as the pretest sample lacked variance for most privatization categories (excluding age, socio-economic background and education) as well as for the leadership dimension responsiveness. Although previous studies report low levels of personalization in German news (Emde & Scherer, 2016; Holtz-Bacha et al., 2014; Sörensen, 2016), these categories were included in the final codebook as it remains unclear to what extent the selection of articles in the search results mirror the characteristics of the media landscape (Unkel & Haim, 2019, p. 11).

4 Results

4.1 Retrieved News Sources

For RQ1 *(What news sources are retrieved by Bing News and Google News for search queries related to German politicians and how do they differ?)*, the spectra of retrieved media sources differ between the two services, with 80 distinct sources for Bing News and only 58 distinct sources for Google News. Differences are also prevalent when the types of sources are considered (Table 3). Both services mainly rely on print media sources (Bing News: 67%; Google News: 77%; $\chi^2 = 4.45$; $p = .35$), with Bing News featuring more online-only media ($\chi^2 = 21.50$; $p < .001$) and Google News including more broadcast media ($\chi^2 = 5.23$; $p = .022$).

The top five search results are compared in a similar manner to provide context for the following analysis of the content characteristics (Table 4). Significant differences are observed in the types of articles: more than half of the top five articles retrieved by Bing News (52%) are wire reports, whereas these types of articles only account for 27 percent of the top five articles retrieved by Google News ($\chi^2 = 13.10$, $p < .001$). Neither Bing nor Google feature opinion pieces in the top results frequently, however Google News results seem more likely to include them (Bing News: 6%; Google News: 12%), though this observation is not statistically significant.

Table 3: Overview of the variety of sources retrieved by Bing News and Google News (N = 400 entries).

Search Result Entries	Bing News (N = 200)		Google News (N = 200)			
	n	% (rounded)	*n*	% (rounded)	χ^2	*p*
Online-only media	49	25	15	8	21.50	<.001***
Broadcast media	17	9	32	16	5.23	.022*
Print media	134	67	153	77	4.45	.035*

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 4: Types of sources and articles in Bing News and Google News top 5 results (N = 200).

Top 5 Results	Bing News (N = 100)	Google News (N = 100)		
	n / %[a]	*n* / %[a]	χ^2	*p*
Type of media				
Online-only media	29	5	20.41	<.001***
Broadcast media	6	19	7.73	.005**
Print media	65	76	2.91	.088
Type of article				
Regular	42	61	7.23	.007**
Wire report	52	27	13.10	< .001***
Opinion piece	6	12	2.20	.138

* $p < .05$. ** $p < .01$. *** $p < .001$.

The two services feature similar numbers of distinct sources when looking at the five most frequently featured sources per service (Bing News: 7; Google News: 6; Table 5). These sources account for 21 percent of the Bing News entries and 29 percent of the Google News entries. The Bing News results include the only online-only source in both top five lists. News sources like Spiegel Online, Frankfurter Allgemeine Zeitung, Die Welt, and Tagesspiegel appear in both search engines' results and with similar mean ranking positions.

Portrayal of individual politicians

The following analyses for RQ2 (*To what extent do the two news search engines' results differ in their portrayals of individual politicians?*) are based on the 200 whole articles (100 per search engine). While neutrality has also been addressed in a normative context in previous chapters, it should be understood as journalistic neutrality in the following. Thus, neutral portrayals refer to mentions without clear positive or negative evaluations or with a balanced mix of both.

In total, 96 different politicians are mentioned 464 times in the analyzed articles. More than half of these mentions bring up politicians' leadership images or their personal lives (55%, n = 255). The sample is rather void of privatization as defined in this study, with very low case numbers for Bing News (n = 30) and Google News (n = 23). Leadership images are addressed more frequently but again with no difference in emphasis (Bing News: n = 120; Google News: n = 126). The combined portrayal indices show a general trend towards balanced portrayals with no significant differences between the services (Bing News: m -.09, SD = .56, n = 129; Google News: M = -.07, SD = .70, n = 126; t = -.227, p = .821).

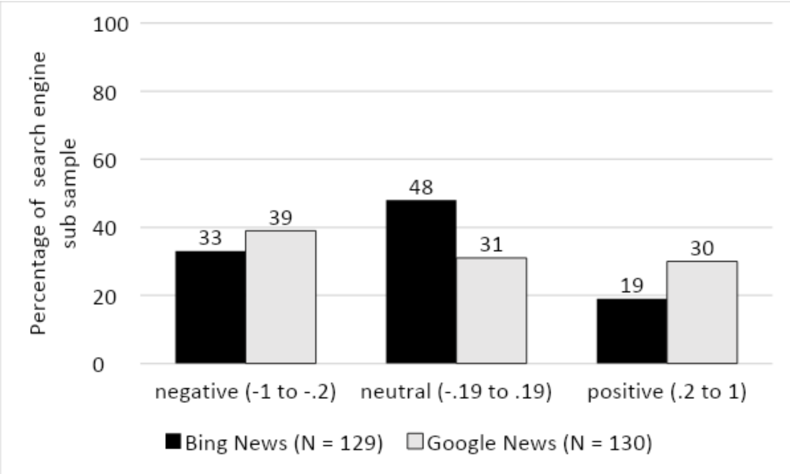
However, significant differences in the distribution of positive or negative portrayals are observed (χ^2 = 8.994, p = .011, Figure 1). Both samples contain similar shares of negative portrayals (Bing News: 33%, N = 129; Google News: 39%, N = 130). Bing News features more neutral portrayals (48%; Google News: 31%) and Google News features more positive portrayals (30%; Bing News: 19%). Overall Google News retrieves a more balanced mix of positive, negative and neutral portrayals, whereas Bing News results emphasize neutral portrayals. The different types of articles show a trend of increasing neutrality from opinion pieces to regular articles to wire reports, though this finding is not statistically significant ($M_{Opinion}$ = -.32, SD = .69, n = 36; $M_{Regular}$ = -.14, SD = :65, n = 194; M_{Wire} = -.03, SD = .53, n = 87; p = .061).

Table 5: Top 5 most frequently featured news sources per search engine.

	Source	Times retrieved	% share of entries by search engine (rounded)	Average Ranking[a]		Type of media source
				M	*SD*	
Bing News (N = 200)						
1	T-Online.de	15	5	4.00	2.67	Online-only
2	Spiegel Online	11	4	4.18	2.96	Print
3	Augsburger Allgemeine	10	3	3.80	2.44	Print
4	Die Welt	8	3	5.75	3.28	Print
5	Frankfurter Allgemeine Zeitung	7	2	3.00	1.53	Print
	Tagesspiegel	7	2	6.71	2.43	Print
	n-tv	7	2	7.43	2.07	Broadcast
Google News (N = 200)						
1	Spiegel Online	22	7	4.68	2.92	Print
2	Focus Online	14	5	5.57	3.00	Print
	Frankfurter Allgemeine Zeitung	14	5	4.64	2.59	Print
3	Tagesspiegel	13	4	5.85	3.53	Print
4	Die Welt	12	4	5.67	2.87	Print
5	Tagesschau.de	11	4	3.91	2.91	Broadcast

[a] *Ranking between 1-10; lower values denote more prominent placement in the search result lists.*

Figure 1: Comparison of the ratios between neutral and evaluative news retrieved by Bing News and Google News (rounded percentages).



Five of the 96 mentioned politicians account for more than half of the coded mentions. The case numbers for the other mentioned politicians are insufficient for further analysis, with mostly one or two mentions for several politicians. The selected politicians are Martin Schulz (SPD, n = 61), Angela Merkel (CDU, n = 37), Horst Seehofer (CSU, n = 19), Christian Lindner (FDP, n = 16), and Kevin Kühnert (SPD, n = 10). As a result of almost half of all mentions (45%, n = 209) occurring without coded references to leadership image or privatization, the case numbers per politician are surprisingly low considering the overall sample size of 464 mentions.

Although there are statistically significant differences in the overall portrayals of two politicians (Lindner: p = .025; Kühnert: p = .039; Table 6), these findings should not be over-interpreted when considering the low case numbers (n between 3 and 10) and high standard deviations. In the case of Christian Lindner, the Bing News results are considerably more negative (M = -.60, SD = .49, n = 6; Google News: M = 10, SD = .57, n = 10). Kevin Kühnert is portrayed somewhat positively in Bing News (M = .17, SD = .29, n = 3), while the news retrieved by Google News are very favorable (M = .63, SD = .26, n = 7).

For the remaining three politicians, the overall trend of positive, negative or neutral portrayals is remarkably similar between the services; however, in the

Table 6: Comparison of the portrayal of the five most frequently mentioned politicians in articles retrieved by the news search engines.

		Overall portrayal[b]					Distribution[c] (%)				
Politician[a]	Engine	*n*	*m*	*SD*	*t*	*p*	-	*a/n*	+	χ^2	*p*
Martin Schulz (SPD)	Bing	30	-.50	.45	.91	.369	80	17	3	.175	.916
	Google	31	-.60	.40			84	12	3		
Angela Merkel (CDU)	Bing	14	-.13	.17	-.35	.726	29	71	0	3.39	.183
	Google	23	-.09	.56			35	48	17		
Horst Seehofer (CSU)	Bing	9	.45	.53	.29	.778	0	44	56	2.71	.258
	Google	10	.37	.72			20	20	60		
Christian Lindner (FDP)	Bing	6	-.60	.49	-2.51	.025*	67	33	0	5.95	.051*
	Google	10	.10	.57			10	70	20		
Kevin Kühnert (SPD)	Bing	3	.17	.29	-2.47	.039*	0	67	33	5.83	.016*
	Google	7	.63	.26			0	0	100		

** p <. 05. ** p < .01. *** p <.001. Portrayals based on very small case numbers deemphasized. [a] Based on number of mentions. [b] Scale from negative (-1) to neutral / ambivalent (0) to positive. [c] Abbreviations:- negative, a/n ambivalent / neutral, + positive.*

cases of Angela Merkel and Horst Seehofer, the standard deviations differ much more between the search engines. While the differences in the distributions are not significant, the p values for the chi-squared tests are noticeably lower than those of the t-tests, which may be related to the significant differences in the overall distribution of evaluations (Figure 1).

The valence of the evaluations themselves likely depends on the political situation at the time of data collection. This means that comparisons between different politicians and party affiliations are not meaningful, though comparisons between the services are not impacted as each search was conducted in parallel in both services.

4.2 Portrayal based on Party Affiliation

For RQ 3 (*To what extent do the two news search engines' results differ in their portrayals of politicians affiliated with different political parties?*), the indices for individual politicians are combined into party averages to compare the portrayal of politicians based on their party affiliation. The following results only describe the overall portrayal of all mentioned politicians, grouped by party affiliation. This does not constitute a portrayal of the political party itself, because the representatives of the different political parties may differ between the two news search engines and political parties encompass more than the individual party members.

Similar to the case of individual politicians, the overall evaluation of politicians based on party affiliation appears largely unanimous, with only slight differences in the degree of positivity or negativity (Table 7). For the mean comparison, only the portrayal of FDP politicians differs significantly between Bing News and Google News ($p = .025$), with Bing News results reporting more negatively ($M = -.66$, $SD = .47$, $n = 7$) than Google News results ($M = .00$, $SD = .63$, $n = 11$). Looking at the distributions, the majority of the Bing News articles featuring portrayals of FDP politicians are negative, whereas Google News retrieved similar shares of positive and negative portrayals. Considering the low case numbers, it is interesting to note that these differences are nearly statistically significant ($p = .066$). However, the FDP case numbers match up almost perfectly with the case numbers for Christian Lindner. Therefore, the result is likely caused by the divided portrayal of this individual politician in the very small sample and does not reflect a bias based on party affiliation.

Table 7: Portrayal of politicians of the eight political parties in the German Bundestag in articles retrieved by the news search engines

		Overall portrayal[b]					Distribution[c] (%)				
Party affiliation	Engine	*n*	*m*	*SD*	*t*	*p*	-	*a/n*	+	χ^2	*p*
Christlich Demokratische Union (CDU)	Bing	20	-.02	.32	.28	.782	20	70	10	1.14	.566
	Google	29	-.05	.49			28	55	17		
Christlich-Soziale Union in Bayern (CSU)	Bing	18	.22	.68	.65	.523	17	39	44	1.27	.530
	Google	16	.06	.77			31	25	44		
Sozialdemokratische Partei Deutschlands (SPD)	Bing	53	.00	.63	.12	.902	49	32	19	5.21	.074
	Google	54	-.19	.69			54	15	32		
Alternative für Deutschland (AfD)	Bing	6	-.25	.42	-.55	.597	33	67	0	4.95	.084
	Google	7	-.05	.87			43	14	43		
Freie Demokratische Partei (FDP)	Bing	7	-.66	.47	-2.35	.025*	71	29	0	5.44	.066
	Google	11	.00	.63			18	64	18		
Die Linke	Bing	7	-.21	.48	.-07	.946	43	43	14	.89	.640
	Google	5	-.19	.26			40	60	0		
Bündnis '90 / Die Grünen	Bing	15	.09	.29	-.88	.408	0	87	13	11.57	.003**
	Google	7	.36	.79			29	14	57		

** p <. 05** p < .01. *** p <.001. Portrayals based on very small case numbers deemphasized. [a] Scale from negative (-1) to neutral / ambivalent (0) to positive. [b] Abbreviations:- negative, a/n ambivalent / neutral, + positive.*

Apart from the FDP cases, there are three more notable differences in the distributions. While not significant, the data for the AfD (p = .084) and SPD (p = .074) show remarkably similar patterns: Google News features higher shares of positive and negative portrayals, whereas Bing News features more neutral portrayals. In the case of Die Grünen, there are significant differences in the distributions (p = .003), with Google News featuring significantly more positive portrayals and noticeably fewer neutral portrayals. While these findings should not be over interpreted considering the small case numbers, they may again indicate different approaches to create an overall balanced mix of news articles.

5 Discussion

The first research question concerns the sources presented in the search results. Both services heavily rely on legacy media sources, thus maintaining rather than decreasing the influence of these organizations (Nechushtai & Lewis, 2019). Whereas Bui (2010) found Google News to retrieve more distinct sources and Ulken (2005) found more online-only sources, the present study observes fewer distinct sources and fewer online-only sources compared to Bing News. Google News' lower number of distinct sources, and resulting stronger reliance on the top five sources, supports the previously reported trends of concentration and increasing homogeneity (Bui, 2010; Haim et al., 2018; Krafft et al., 2019; Nechushtai & Lewis, 2019; Puschmann, 2019; Unkel & Haim, 2019). The findings also suggest a similar trend for Bing News, whose list of top five sources is very similar to the Google News list, despite an overall higher number of distinct sources.

There are some similarities to the findings by Haim et al. (2018) and Unkel and Haim (2019): some conservative sources, like Die Welt and Focus online, appear frequently in Google News results, whereas popular media like Bild.de, T-Online, RTL or Stern do not. Interestingly, one of these underrepresented sources is among the most frequently retrieved in Bing News results (T-Online). However, with individual sources accounting only for a maximum of 7 percent of the Google News search results, compared to previously observed shares of up to 24 percent (Haim et al., 2018, p. 6), these trends are less pronounced in the current study. This may indicate changes in the algorithms, changes in the search engine optimization of other news outlets, or other factors potentially influencing the results (e.g., the used search terms or the sampling procedure which did not consider the respective front pages).

The second and third research questions focus on the content of the retrieved news articles, in which roughly half of all mentions of politicians addressed professional or personal characteristics. The findings generally show no significant differences in the portrayals of politicians between Bing News and Google News. There is a consensus between the two services, with no evidence of systematic favoring of individual politicians or their political party affiliation. Both search engines retrieve more articles with negative than positive evaluations. This is likely a general news media bias and not specific to the algorithmic systems themselves (Unkel & Haim, 2019, p. 11). Negativity itself is a news value (Galtung & Ruge, 1965; Harcup & O'Neill, 2017; Harcup & O'Neill, 2001) and as such is a part of German political media coverage (Kepplinger, 2000). The similarities in the portrayals can partially be explained by the considerable overlap in top search results. Both services seem to rely on very similar cores of mainstream sources (Puschmann, 2019), which may indicate a mainstreaming bias (Nechushtai & Lewis, 2019). The inclusion criteria for these mainstream media cores remain a crucial open question, especially concerning the different media cores reported for the German and the US editions (Haim et al., 2018; Trielli & Diakopoulos, 2019). Closer analysis of the core media themselves seems like a logical next step in this direction. Haim et al. (2018, p. 10) suggest differences in search engine optimization as one potential explanation. These differences could be compared between over- and under-represented media to help understand the search results (e.g., Britvic, Duric, & Buzic, 2014).

While an overall agreement in the portrayals is observed, the degree of positivity or negativity can differ between the services. The mean portrayal measures for individual politicians and party affiliations show high standard deviations and, in some cases, the standard deviations differ considerably between the services, likely caused by different distributions of positive, neutral, and negative evaluations. In total, Google News shows a nearly even distribution, whereas Bing News shows a larger share of impartial portrayals and fewer positive portrayals. The findings for Google News support previous research. Flaxman et al. (2016) report higher percentages of ideologically opposing articles when compared to social media and general search engines. Ulken (2005) also observed higher shares of positive and negative evaluations. While this trend was previously explained by a higher number of distinct sources and the inclusion of online-only sources, the findings for research question one contradict this explanation. Instead, the types of the retrieved articles may explain this result: compared to Bing News, Google News retrieved significantly fewer news agency reports, which are generally less opinionated. The algorithmic systems may differ in the weighting of this type of content. Scholars have previously voiced concerns that wire reports can be copied so as to exploit the ranking factor currency (Carlson, 2007; Thurman, 2007). Bing News may be more susceptible to this strategy, however it is also possible that the two services differ in their approach to create balanced news experiences (Google Inc., n.d.a; Microsoft Bing, n.d.): Bing News strives for balance by emphasizing impartial content, whereas Google News provides equal amounts of positive, negative and impartial content. To assess which of these approaches is preferable exceeds the scope of this paper, as answers to this question vary based on the normative approach used for the evaluation (see Helberger, 2019).

5.1 Limitations

A few limitations must be addressed. First, the presented findings are only a snapshot in a very dynamic field of research. The data was collected at the end of 2017 and in the beginning of 2018, shortly before Google News received a considerable update (Upstill, 2018). Developments of the ranking algorithms and search indices may now yield different results. Nonetheless, this study can provide reference points for further studies.

Second, there are limitations of the content analysis. This study utilizes the portrayal of politicians as a proxy for political slant in the news coverage, which oversimplifies certain situations. Negative evaluations of failed political endeavors or positive evaluations of political successes both may be politically biased or simply impartial reports of the respective events. Considering the mixed empirical evidence of personalization in German media coverage of politics (Adam & Maier, 2010, pp. 225–227), a different proxy for political slant could be beneficial and may result in more evaluations for the analysis. The idea of coding portrayal on an article level is not ideal either, because of the complexity of evaluating each article. Further, the reliability of several categories could not be assessed exhaustively, as some dimensions of leadership images and privatization rarely applied to the collected articles.

Third, the sampling procedure may influence if and how politicians are portrayed in the search results. The search terms themselves were selected to be impartial, however different, more partisan search terms may implicitly influence the ideological slant of the results (Borra & Weber, 2012; Flaxman et al., 2016, p. 311). Therefore, the presented findings are only valid for the selected search terms and in the time frame of data collection. For example, observations like the negative portrayal of Christian Lindner in the Bing News results cannot be interpreted as a general bias against this politician.

Lastly, this study cannot provide insight into real-life situations. Outside of the experimental setting, users frequently do not avoid personalization of search results. Therefore, it is very difficult to simulate identical realistic users to allow for comparisons of these types of services.

5.2 Outlook and Implications

This study adds to the existing body of descriptive studies which examine differences between various news search engines. As a result of the highly dynamic nature of the internet, these types of studies quickly become outdated. However, when taken together, they can document overarching trends and developments over time (e.g., the core of mainstream sources for Google News), albeit without any insight into the intentionality of the observed behavior.

Further research is needed to assess the extent of the observed differences in order to verify these observations for other content aspects (e.g., portrayals of specific issues, portrayals of organizations) and to identify possible explanations for these differences. New data collection methods based on the documentation of search engine use and results by participating regular users may help to fully understand the extent to which differences in search results occur in real life situations (see Puschmann, 2019). Ideally, trends reported in these descriptive comparisons between search engines should be put into context by interviewing developers about their intentions, decisions and limitations leading to the observed behavior (Kitchin 2017, pp. 24–26). However, this approach is naturally complicated by the search engine providers' interest to keep trade secrets confidential. Finally, this study shows that algorithmic gatekeepers may develop a content bias by restricting specific types of articles, which may require new assessment criteria (e.g., based on the observed differences in the distributions of evaluative content). The behavior and characteristics of news media should also be considered in this context as they may directly or indirectly influence the retrieved content. For example, effective search engine optimization may directly affect the ranking position of specific news outlets or indirectly change the ranking algorithm as certain counter measures are implemented by search engine providers to prevent the exploitation of the algorithms (e.g., putting less emphasis on wire reports). This ties into the moral and ethical responsibilities of news search engine providers; while they must continue to combat attempts to exploit their algorithms, their roles as gatekeepers call for cautious and farseeing actions. In this sample, it seems that Google News' avoidance of wire articles leads to more evaluative articles compared to Bing News. While this may very well be a conscious decision, it could also be an example of an unwanted effect.

From a user perspective, the findings emphasize the importance of information literacy (*see Dogruel in this volume*) as internet users need to be educated about the processes behind the services they use every day. Insight into ranking differences between search engines may even improve user's online information seeking: users looking to compare different opinions may benefit from consciously selecting Google News to retrieve more opinionated reports.

All things considered, perhaps the commonly cited advice to cross-reference information between different sources needs to be expanded to also include the cross-referencing between different services to find said information.

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Abstract: While communication research has been particularly focused on examining the effects of algorithms on (public) communication processes, less attention has been dedicated to studying media users' understanding and perceptions of algorithms in online contexts. This contribution provides a first step into studying Internet users' competences in navigating algorithmically curated environments by proposing a theoretical concept on (lay) Internet users' algorithm literacy. Based on existing concepts in media literacy research, we present theory-driven dimensions to address algorithm literacy among Internet users. This is complemented by suggestions for an operationalization of these dimensions informed by findings from qualitative interviews with Internet users. As a result, the proposed concept of algorithm literacy comprises two cognitive dimensions, namely awareness & knowledge and the (critical) evaluation of algorithms, and two behavior-related dimensions, addressing individuals' coping behaviors and abilities for creation and design in terms of the use of algorithms.

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What is Algorithm Literacy?

A Conceptualization and Challenges Regarding its Empirical Measurement

1 Introduction

The automated processing of data based on certain rules shapes almost all information and communication situations and particularly those, in which we navigate digital, networked environments. Algorithms play a crucial role in the selection, prioritization, categorization, and presentation of information and communication and, thus, have a critical impact on our perception of the world as well as on our decision-making (Gillespie, 2014; Kitchin, 2017; Pasquale, 2015). While communication research has been particularly focused on examining the effects of algorithms on (public) communication processes, for example, opinion formation and the (possible) effects of audience fragmentation (e.g., Bakshy et al., 2015; Bodó et al., 2019), less attention has been dedicated to studying media users' understanding and perceptions of algorithms in online contexts (e.g., Rader & Gray, 2015). Public surveys inquiring into Germans' or Europeans' general awareness of and attitudes towards algorithms in society (Fischer & Petersen, 2018) point to a lack of awareness and understanding of algorithms in general. A more in-depth analysis of the public's level of understanding of and competence to cope with algorithmic-curated online environments is however scarce (Hargittai et al., 2020). This is contrasted by a call for algorithmic, or more broadly speaking, code competent citizens – as demanded in public and policy discourses (e.g., Dreyer et al., 2014).

Given this background, this contribution sets out to develop a concept to study (lay) Internet users' algorithm literacy. We hereby focus on algorithms employed in online environments to encompass those that Internet users generally encounter. This includes algorithms used in online activities, such as in the provision of (personalized) news, in information searches, during online shopping, on music or movie platforms, and for targeted advertising, where users are in contact with algorithmic selection and filtering (Latzer et al., 2016). In order to derive a framework for algorithm literacy we first provide an overview of how and when users encounter algorithms in their Internet use and what risks, as well as benefits, are associated with algorithmic curation to outline why developing algorithm-related skills matters. Second, existing concepts in media literacy research and neighboring areas, such as digital/code literacy, new media literacy, and privacy literacy, are introduced to deduce theory-driven dimensions to address algorithm literacy among Internet users. In order to examine the current understanding and awareness of algorithms among Internet users, we further present findings from qualitative interviews to develop sub-dimensions and suggestions for an operationalization of these dimensions. Finally, we critically discuss the opportunities and limits of examining algorithm literacy based on the proposed framework.

2 Navigating algorithmic-curated environments online and why algorithm literacy matters

Algorithms largely govern the way we use the Internet. In their systematization, Latzer and colleagues (2016) outlined that algorithmic applications online encompass aggregation, filtering, recommendation, or scoring. According to this "algorithmic turn" (Napoli, 2014), algorithms have a crucial impact in terms of how we navigate the Internet: Algorithms filter the news we see, influence decisions about what we buy at what price, determine the type of music we listen to, or govern whom we interact with in social media; in particular, algorithms are implemented to calculate personalized services such as advertising, news, or product recommendations online (e.g., Bozdag, 2013; Newell & Marabellli, 2015; Soffer, 2019; Thurman et al., 2019). Because of algorithms' impact on our world perception and behaviors, they are increasingly considered as "autonomous actors with power to further political and economic interests" (Just & Latzer, 2017, p. 245) or as "emerging tools of public knowledge and discourse" (Gillespie, 2014, p. 185) with the power "to shape realities and societies" (Latzer et al., 2016, p. 402).

Arguing from a technological point of view however, algorithms can simply be defined as "encoded procedures for transforming input data into a desired output based on specified calculations" (Gillespie, 2014, p. 167) or "computational procedures" that provide some kind of output "through a software program" (Christin, 2017, p. 2). Such a purely technological understanding of algorithms however, does not allow the uncovering of the social implications and socio-technological underpinnings of algorithms, as suggested by numerous scholars (e.g., Bucher, 2017; Gillespie, 2014; Kitchin, 2017; Willson, 2017), and instead, algorithms have to be considered as embedded in a complex ecosystem with shared agency between humans and software components that permanently shape each other (Latzer & Festic, 2019).

Following this socio-technical perspective, Internet users are not mere receivers of algorithmic decisions, but they are interwoven with the process itself. Acknowledging that algorithms employed in Internet services largely rely on user-generated input (e.g., personal and behavioral data, interactions), "every click, every query, changes the tool incrementally" (Gillespie, 2014, p. 173). Considering algorithmic curation online as a socio-technological process does not imply an even power distribution between users and algorithmic systems. Instead, a growing body of research has outlined that algorithmic decision-making is associated with a wide range of potential risks – ranging from privacy infringement, forms of political and economic manipulation, censorship, and discrimination to biases in computing outputs (for an overview, see Latzer et al., 2016). Further, the algorithmic procedures of selection and filtering, as well as their underlying criteria, are invisible and largely unavailable to end users and thus remain 'black boxed' (Burrell, 2016; Pasquale, 2015). According to Burrell (2016), this opaqueness stems from different reasons, with algorithmic service providers' strategies for keeping their codes a secret as well as the complex structures of algorithmic systems coupled with lay users' lack of understanding of algorithmic operations being key aspects among them. Even for experts, it is almost impossible to understand algorithmic systems completely, particularly because algorithms are linked to the data that they process and, thus, "perform in context" (Kitchin, 2017, p. 25).

The significance of addressing Internet users' knowledge and competences in navigating algorithmic-curated online environments can be based on three key arguments: The first and most obvious reason refers to the widespread use of algorithmic systems – shaping almost all areas of Internet use – as, for instance, Latzer and Festic (2019) vividly illustrate by explaining how algorithmic applications impact users' social and political orientation online as well as their recreational, commercial, and social Internet use. As users are therefore constantly challenged to cope with algorithms impacting their decision-making, it seems obvious to systematically investigate their understanding of these systems. Second, research found that users' skills in coping with algorithms greatly differs, with the existence of some "power users" who have developed their own, specific ways of how to engage with algorithms and even manipulate them (Bishop, 2019; Cotter, 2019; Bucher, 2012). Users' (lack of) abilities to identify, understand, and potentially counter the impact of algorithmic decisions may further reinforce a digital divide that potentially leads to an increase in the benefits (and risks) that people can draw from using digital services (Gran, Booth, & Bucher, 2020). While there have been initial attempts to survey populations' algorithm-related knowledge (Fischer & Petersen, 2018; Grzymek & Puntschuh, 2019; Gran et al., 2020), a valid instrument for systematically addressing citizens' knowledge and competences is still lacking. Finally, and arguing from a policy-making perspective, providing evidence on users' algorithm literacy is critical for developing regulations, such as transparency measures, regarding the operation of algorithms and potential intervention measures (for an overview, see Potter & Thai, 2019).

In order to develop an eligible measure for studying Internet users' algorithm knowledge, skills, and competences, a conceptualization together with a critical assessment of potential challenges in terms of operationalization represents an essential basis that will be pursued in this contribution.

3 Literature review and development of dimensions of algorithm literacy

So far, attempts at developing conceptual approaches and applicable measurements of algorithm literacy remain scarce. While some conceptualizations rely on a computer scientist background (e.g., Csernoch & Biró, 2015; D'Ignazio & Bhargava, 2015; Hamilton et al., 2014; Siebert, 2018), they are of limited use in more profoundly addressing Internet users' understanding of algorithms. In addition, some studies have inquired into specific forms of algorithm skills, such as the curation of social media feeds (e.g., Eslami et al., 2015; Rader & Gray, 2015) or news literacy, which algorithmically curated information is a part of (Vraga & Tully, 2019). Few attempts have been made with regard to developing a general understanding and measure for algorithm literacy. One notable exception is the recent study by Hargittai and colleagues (2020) in which they outline the challenges of studying algorithm literacy and give insights into a qualitative interview study design to assess adults' algorithm skills. However, a conceptualization of "algorithm literacy" or "algorithm skills" is still missing.

In order to fill this research gap, we rely on neighboring approaches developed in the broader field of digital and new media literacy to derive relevant dimensions for users' understanding and competences with regard to algorithms.

Acknowledging that media literacy has been covered using different approaches and labels (e.g., digital, information, new media literacy, for an overview, see Hobbs, 2010; Koltay, 2011), the following literature review focuses on four areas of research considered as being related to the area of algorithm literacy: (1) media literacy, which can be labeled as the umbrella term encompassing approaches to examining skills related to a wide range of different media (for an overview, see Potter, 2010); (2) digital literacy focusing on knowledge and skills necessary for using digital media applications (e.g., Eshet-Alkalai, 2004; Livingstone et al., 2005); (3) new media literacy (e.g., Jenkins et al., 2006) centering around the use of Internet and computer-based communication applications; and (4) privacy literacy (e.g., Masur, 2018; Park, 2013), which can be considered as relevant with regard to algorithms, acknowledging that algorithms rely on large amounts of (personal) data.

Starting with *media literacy*, as the umbrella concept for addressing individuals' media-related knowledge, competences, and skills, Aufderheide (1993), for instance, defined it as "the ability to analyze, augment and influence active reading (i.e., viewing) of media in order to be a more effective citizen" (p. 26). In the German-speaking discourse, Baacke's (1996) differentiation of four dimensions of *Medienkompetenz* is often cited in outlining that media literacy encompasses (1) a critical evaluation of media (content) (*Medienkritik*), (2) knowledge about the functioning of the media in general (*Medienkunde*), (3) media use skills (*Mediennutzung*), and (4) media creation skills (*Mediengestaltung*). According to these principles, media literacy is not only about consuming media in predefined ways but also about generating content and using the media in a wide range of forms and in whatever way is effective and useful according to the user.

In addition, Livingstone (2004) proposes a broader definition of media literacy, without limiting it to a political area of informed citizenship, by stressing that „Media literacy [...] is the ability to access, analyze, evaluate and create messages in a variety of forms" (p. 5). Potter (2010) and Hobbs (2011), in contrast, introduce two different approaches for defining media literacy, namely protectionism and empowerment. The protectionism approach characterizes media literacy as the ability to protect oneself from negative effects related to media (use) and thus encompasses strategies that prevent individuals from experiencing such potential negative effects (p. 684). Pointing in the opposite direction, Hobbs (2011) refers to the opportunities connected to media (use) and defines media literacy as the ability to make your own decisions, as a consumer as well as as a creative designer.

Pfaff-Rüdiger, Riesmeyer, and Kümpel (2012) consider both perspectives – protectionism and empowerment – in their definition of media literacy. Their approach further relies on the media literacy approaches of Livingstone (2004) and the self-determination theory of La Guardia and Patrick (2008). According to self-determination theory, media literacy is connected to a conscious and well-reflected use of media, which leads to a satisfaction of personal needs. Pfaff-Rüdiger et al. (2012) divide media literacy into three dimensions, namely expertise, self-competence, and social competence. The first component, expertise, includes media knowledge and an awareness of mediality. Media knowledge encompasses "technological, legal or social discourses, [and] is a precondition for being able to benefit from the Internet while avoiding risks" (Pfaff-Rüdiger et al., 2012, p. 46). The second component, self-competence, contains evaluative, motivational, emotional, and creative skills related to media use. In particular, these dimensions refer to reflection on the benefits and risks of individuals' own media use (evaluative skills), the fulfillment of their needs (motivational skills), mood management (emotional skills), and the ability to create media, such as a homepage, themselves (creative skills). The third component, social competence, covers participatory, communicative, educational, and moral skills related to media, which subsumes not only online interactions (participatory skills) but also the processing of one's online experiences by reflecting and talking about them in real life (communicative skills). Finally, educational skills encompass the ability to teach media knowledge and multimedia skills, whereas moral skills include the ability to relate one's actions to media-related values and norms (ibid.). Taken together, individuals are considered media literate "if they are able to fulfil their developmental tasks successfully using the media and to reflect upon the consequences and risks of their media use" (ibid., p. 54).

With the spread of digital media, a growing body of literature is investigating how users are incorporating the Internet into their daily lives and assessing how online behaviors differ between population segments (for an overview, see Hargittai, 2010, 2005; Koltay, 2011; van Laar et al., 2017). Following Gilster (1997), *digital literacy* broadly refers to how users understand and evaluate information from different digital sources. He distinguishes four main skills: (1) information search abilities in conjunction with critical thinking, (2) publication and communication competences, (3) an awareness of values and norms in the digital sector, and (4) knowledge acquisition competences. Further approaches focus on specific areas of digital skills (e.g., an evaluation of online information). Pointing in a similar direction, Livingstone and colleagues (2005) argue that abilities in terms of evaluation skills should include the ability to compare and assess online sources of information in order to identify correct information and eliminate irrelevant aspects. Hobbs (2010) specifies her approach to media literacy, stating that digital media literacy can be defined as a "constellation of life skills that are necessary for full participation in our media-saturated, information-rich society" (p. vii). According to her, these necessary skills encompass users' abilities to evaluate the quality and credibility of content and to create digital media and content for own and communal or participatory purposes using digital tools, as well as to ethically reflect on one's own communication behavior in digital media. She again stresses that literacy has both to serve practical purposes (e.g., how to find and evaluate relevant information) but also has an empowerment dimension to enable users to engage in civic activities and communities or collective problem-solving.

Coming from a more practical perspective, Eshet-Alkalai (2004) describes digital literacy as a "survival skill in the digital era" (p. 102) and divides it into five different sub-categories: photo-visual literacy, reproduction literacy, branching literacy, socio-emotional literacy, and information literacy. These dimensions cover users' ability to read and understand visual representations, the creative recycling of already existing material, the competences needed for orientation in the digital world, an awareness of danger when it comes to online interactions, and knowledge about evaluating sources (ibid.). Focusing on ICT skills from a more general perspective (also including work-related tasks), van Laar and colleagues (2017) conducted a systematic literature review of studies focusing on the areas of digital competences, digital literacy, and digital skills, resulting in seven core digital skills, namely technical, information management, communication, collaboration, creativity, critical-thinking, and problem-solving skills. This (short) overview on scholarship addressing digital literacy already points to the diverse fields of research, which differ greatly based on the particular type of "digital media" considered in the study. We can conclude that digital literacy encompasses both concrete knowledge about digital media (and their technical underpinnings) as well as skills related to the creation, evaluation, and use of digital content and applications.

Closely related to digital literacy, some scholars have addressed competence-related demands of new media environments, such as the early Web 2.0, and the rise of social media applications under the umbrella term of *new media literacy* (e.g., Chen et al., 2011; Jenkins et al., 2006; Lin et al., 2013). Jenkins et al. (2006), for instance, reflect on the competences needed to use social web applications and consider these as a "set of cultural competencies and social skills that [...] people need in the new media landscape" (p. 4). In a follow-up paper, Jenkins (2007) proposes a concept of new media literacy comprised of twelve competences: play, performance, simulation, appropriation, multitasking, collective intelligence, judgement, transmedia navigation, networking, negotiation, distributed cognition, and visualization. According to him, this list encompasses all the necessary competences linked to new media consumption, ranging from understanding the complexity of the environment and being able to criticize the values of media content to performing social interaction and creating media content (ibid.). Chen et al. (2011) adopt a similar approach, noticing that new media introduces new genres, rules, codes, conventions, and symbol systems of communication, which justifies the need for new competences. According to them, new media literacy can be understood as "two continuums from consuming to prosuming literacy and from functional to critical literacy" (Chen et al., 2011, p. 85), while functional literacy is related to online behaviors, such as the use of media tools and content. As a result, their media literacy concept encompasses four dimensions: (1) functional consuming, (2) critical consuming, (3) functional prosuming, and (4) critical prosuming.

Based on the framework of Lin et al. (2013), as well as Chen et al. (2011), Koc and Barut (2016) developed a comprehensive scale for measuring new media literacy and presented an operationalization of its dimensions. Judging it today, however, some of the items already appear outdated, which is one of the key challenges for scale development in this area given the rapid change of new media environments.

Acknowledging that the functioning of algorithms primarily relies on exploiting (personal) user data (Tucker, 2018) and that privacy violations are considered a risk in the implementation of algorithms, conceptualizations of privacy literacy are also relevant for mapping algorithm literacy. Without stepping into the debate on privacy definitions, we refer to Burgoon's (1982) definition of privacy as the ability to "control and limit physical, interactional, psychological and informational access to the self or one's group" (p. 207). Concerning this understanding, individuals need to develop competences to uphold their control in these domains to avoid violations. Such violations may stem from both horizontal (e.g., other Internet users, such as social media contacts) as well as vertical (e.g., online service providers, governments) actors (Schwartz, 1968). Masur (2018) develops a comprehensive concept of privacy literacy, defined as the knowledge that can be acquired and the cognitive ability and skills to solve privacy-related problems on the Internet, and the willingness to implement these solutions in various communication and usage situations (p. 451). According to him, privacy literacy consists of four dimensions: (1) factual privacy knowledge, (2) the ability to reflect on privacy, (3) skills related to privacy and data protection, and (4) the ability to critically reflect on privacy (e.g., its societal relevance). Empirically however, this concept has not been operationalized yet; instead, Trepte et al. (2015) have focused on the first and, to a limited extent, the second dimension by developing an online privacy literacy scale designed to measure Internet users' privacy-related knowledge (the OPLIS scale). Park (2013) adopts a similar approach for examining digital literacy related to privacy. According to him, privacy literacy encompasses a critical understanding of data flow and its implicit rules for users to be able to act. Literacy, in this sense, should empower users to undertake informed control of their digital identities. He operationalizes privacy in three dimensions: technical familiarity, an awareness of institutional practices, and policy understanding – following a similar approach to Trepte et al.'s OPLIS scale.

3.1 Developing dimensions of algorithm literacy

Based on the literature review, four dimensions of media competence can be derived, which can be identified as being relevant across different approaches and which, at the same time, seem to be relevant for capturing algorithm literacy as well. First, two cognitive dimensions can be distinguished, namely *awareness and knowledge* and the *(critical) evaluation* of algorithms, and these are complemented by two behavior-related dimensions, addressing individuals' *coping behaviors* and abilities for *creation and design* in terms of the use of algorithms.

Cognitive Dimensions of Algorithm Literacy

- Awareness and Knowledge

Knowledge is considered a relevant (cognitive) dimension in almost all approaches to media literacy, yet it varies with regard to the sub-dimensions covered. For studying algorithms, we propose a differentiation between awareness and knowledge. While awareness captures to what extent users can tell that algorithms are implemented in a given service and how they function (e.g., sorting, ranking, filtering content), knowledge, in contrast, aims at capturing users' general understanding of the types, functions and scope of algorithms on the Internet.

- (Critical) Evaluation

The second dimension (evaluation) is also a key category in existing literacy approaches relying on the assumption that being able to evaluate and reflect on media-related techniques and content is a precondition for being capable of autonomously using (media) services and developing creative forms of use (prosuming media dimension, e.g., Chen et al., 2011; Livingstone et al., 2005; Masur, 2018; Pfaff-Rüdiger et al., 2012).

Behavior-Related Dimensions of Algorithm Literacy

In addition to the cognitive dimensions addressing algorithm literacy, two sub-dimensions are included to account for users' actual behaviors in terms of algorithmic curation, namely coping behaviors and creation and design. While some literacy concepts focus on one behavior-related dimension, we believe that developing two distinct, yet related categories is more eligible for gathering users' behavior-related skills in interacting with algorithms. While the first dimension refers to users' abilities to use existing algorithms competently, the second dimension focuses on users' skills in developing or changing algorithms themselves (e.g., based on programing competences but not limited to them) as research into users' strategies of how to cope with algorithmic curation and "play the algorithm strategies" outline (Bishop, 2019; Cotter, 2019).

- Coping Behaviors

Existing approaches consistently argue that competences regarding the use of (new) media applications as well as the ability to employ privacy protection measures are crucial components of media literacy. When adapting this dimension to the area of algorithms, two aspects need to be taken into account: First, we have to again consider that coping strategies are connected to users' knowledge and evaluation competences. Users have to be *aware* of algorithm decision-making in internet applications and are then able to, at least to a certain extent, *evaluate* the effects of such actions and, consequently, implement adequate coping behaviors. Second, and this differs in some ways from previous media literacy constructs, this dimension is not about the competence of being able to use algorithms but about the ability to use algorithms *competently*. Acknowledging that algorithms are ubiquitously employed across the Internet and that their use often happens unconsciously, literacy is not so much focused on developing skills or reflecting on how to use algorithms but instead on learning to deal with their requirements and consequences. This means that individuals are able to apply strategies that allow them to modify predefined settings in algorithmically curated environments such as in their social media newsfeeds or search engines, to change algorithms' outputs, compare the results of different algorithmic decisions and protect their privacy.

- Creation and Design

The fourth derived dimension of algorithm literacy encompasses the activities of creation and design (or functional prosuming according to Chen et al., 2011). The creation and design dimension targets user activities that go beyond the mere use of particular services and aims at capturing more elaborate forms of usage, such as users' abilities to modify existing algorithms or create algorithmic applications themselves. Even though we do not expect that the majority of today's Internet users are equipped with programming skills, this might be of growing relevance for the next generation of individuals (e.g., Klawitter & Hargittai, 2018; Popat & Starkey, 2019).

4 Development of sub-dimensions to examine Internet users' Algorithm Literacy

In order to develop sub-dimensions and to, in a follow up study, operationalize the above-described dimensions of algorithm literacy, we relied on two sources: First, we recur on existing literature, e.g., to derive areas of application of algorithms, functions as well as risks and benefits associated with these systems; second, we use data collected in a qualitative interview study among 30 German Internet users which was part of a larger project on media users' understanding and perceptions about algorithms in online contexts. The semi-structured interviews were conducted by two trained interviewers and one member of the research team. German participants were recruited following a quota on age and gender and focused on adults who were regular Internet users. Participants' mean age was around 36 years (ranging between 17 and 70 years) and the quote of gender was almost met (16 women). Interviews lasted around one hour and started with some open questions on participants' Internet use and then moved to their understanding of algorithms in general and their awareness of algorithmic operations concerning eight different domains (news selection, information searches, job searches, dating services, navigation, online shopping, music and movie selection, and advertising). The interview then moved on to a standardized task and asked users for their perceptions of risks associated with algorithms, but this will not be covered in this paper. The interviews were recorded, transcribed, and coded using the software MAXQDA.

We hereby relied on an emerging coding scheme starting with the categories of the interview guideline. This process involves repeated readings to develop and refine thematic inductive categories (Mayring, 2000).

While this study was not deliberately designed to inform an operationalization of algorithm literacy, findings of these interviews were considered as helpful insight to deduce potential items for a follow up quantitative study. We thus recur on findings of the interviews where it seems appropriate and helpful to carve out insights in how to address Internet users' algorithm literacy.

Awareness and knowledge on algorithms

Acknowledging that algorithms are considered opaque and their working often remains invisible to end-users, it makes sense to first examine users' awareness of these systems in their Internet use. A measure on algorithm literacy therefore needs to address in how far Internet users are aware of the different areas and applications where algorithms are implemented in and what functions they perform. According to Latzer et al. (2016) for instance, algorithms on the Internet serve a wide range of functions such as aggregation, filtering, recommendation, rating or even forms of content production. Among them, personalization can be considered a specific kind of information filtering which is widely employed across the web (Bozdag, 2013). While it is obvious that these areas of Internet use would be virtually unusable without the use of algorithms, lay Internet users are not necessarily aware of this kinds of algorithmic curation as research on the newsfeed (e.g., Eslami et al, 2015) or search engines such as Google (Powers, 2017) demonstrate. This was as well mirrored in the interview study. Here, we found that the awareness of algorithms differed greatly with regard to different areas of Internet use. Most of the users were aware that advertisings are personalized based on their previous surfing and shopping behaviors as one of our oldest participants explicated with regard to advertising "When I'm online [...] I come across this all the time when I am interested in something specific, for example a Spanish red wine, and then it often appears a day later [...]" (I3, male, 70). They were less familiar with the curation of their newsfeed or news in general (e.g., in news aggregators) or how algorithms were employed in services such as navigation. Items targeting users' awareness of application areas of algorithms may for instance ask users in how far they are aware that algorithms were employed in search engines, social network sites or dating apps – or more particularly, in how far they are aware that search results as well as their newsfeed is subject to algorithmic curation.

In addition to previous concepts that address media literacy, we further suggest inquiring individuals' understanding of algorithms; i.e. how they would define algorithms in their own words. This is again a result of the user interviews. Here, we found that users differed greatly when being asked to explain algorithms in their own words. While some participants expressed at least a vague idea about the implementation of algorithms in Internet services and were likely to identify it as a 'technical' or "mathematical program that runs in the background at large companies like Google & Co" (I1, male, 37), others simply stated that they have come across the word algorithms but do not really know what it means. From a methodological standpoint, capturing users' general understanding of the term "algorithm" will be difficult to operationalize in a standardized measure but is more likely to be applicable in in-depth qualitative studies (see further Hargittai et al., 2020).

Knowledge on algorithms does not only relate to the areas of application and functions of algorithms but as well relates to the mechanisms underlying these systems. In particular, the collection and processing of personal and use related information can be cited as well as potential effects of algorithms such as filter bubbles or threats to privacy (e.g., the type of data being collected). A measure of algorithm literacy therefore needs to assess in how far users are aware of the extent and type of data algorithms recur on and understand that algorithms may carry biases and do not necessarily provide more "objective" results compared to human decisions. Further, also knowledge about potential regulatory and coping measures related to algorithm decision making in Internet applications – such as knowledge about legal regulations and user rights, e.g., regarding the automated data processing and privacy protection, need to be included into the cognitive dimension of measuring factual knowledge on algorithms. These in turn can be considered necessary requirements for users being able to apply coping behaviors. From a methodological point of view, the knowledge-dimension can primarily be assessed through factual knowledge questions, e.g., true false queries or having users select the right answer among a set of statements. One has to keep in mind that such measures of factual information are just a (poor) proxy for addressing individuals' structural knowledge which is "structured, organized, and of enduring significance" (Potter, 2019, p. 20). Following Potter, in particular media literacy requires strong knowledge structures to competently understand and evaluate the media offer – which is primarily addressed in the second dimension of algorithm literacy.

Critical evaluation

While the awareness and knowledge dimension is targeting Internet user's factual knowledge, the second dimension is targeting users' evaluation skills, e.g., individuals' abilities to reflect on the opportunities and risks associated with algorithms and potential effects of algorithmic curation on the individual and societal level. While in academic risks associated with algorithms, e.g., potential biases in information or news presentation, discrimination, censorship, or the emergence of echo chambers and potential privacy violations received considerable attention (e.g., Flaxman et al., 2016; Latzer et al., 2016; Lepri et al., 2017; Zuiderveen Borgesius et al., 2016) it remains largely unknown how users evaluate potential implications of algorithmic curation.

In our interviews, users were most likely to associate risks related to algorithmic curation in three areas: Potential manipulation and limits to information diversity, threats to privacy and data sovereignty as well as economic interests of third parties. Many interviewees identified the area of news as critical for algorithmic systems and mentioned manipulation, censorship, filter bubble effects and more generally, limits to information freedom as potential threats of algorithms employed in the curation of news. As one participant explained: "Manipulation of users and limited diversity of opinion, and filter bubbles is actually a danger. If you look, for example, at how many people are simply radicalized somehow via Facebook, because a radical, a Nazi or a Muslim, writes something and then [the algorithm] don't show them anything else..." (I23, male, 20, similar I11, male, 19). Secondly, participants were likely to connect algorithms to privacy threats acknowledging that "[algorithms] collect data from everywhere and you don't really have any control who knows what about you and where it is stored and what happens with it (I5, female, 23).

Related to the area of targeted advertising, some participants were concerned about the manipulation of user's decision making as one of our older participants explicates "the Internet companies are not so keen on just wanting to do good to me or do good to humanity, but I assume that they all want to make a profit. I think they push people in a particular direction to spend more. So I'm already heavily manipulated as a user which I find negative (I15, female, 54). The proposed sub-dimensions thus aim at measuring in how far users reflect on the advantages and disadvantages of algorithm-based decisions. Empirically, this dimension may recur on users' self-reports using Likert scales in how far they agree with certain statements. Such statements can either be broad in scope to assess in general 'in how far users feel capable of assessing the implications of algorithms on themselves or the society at large' as well as address concrete areas of applications of algorithms, e.g., by asking participants 'in how far they think they can well explain why users see different postings in their newsfeed' or 'in how far they have been thinking a lot about how good or bad search results in Google's hit lists really are'.

We further suggest to examine users' algorithm-evaluation competences regarding both internal reasoning (in how far they think about certain issues) as well as their abilities to articulate their ideas in social interactions which is also an indicator of users' perceived self-efficacy with regard to algorithms (Bandura, 1993; for the relationship between literacy skills and self-efficacy see Livingstone & Helsper, 2010).

Coping

While research examining users' interactions with algorithmic systems is scarce, some initial studies (even though addressing a very particular group of end users) have indicated that users have adopted different strategies to cope with algorithmic decisions, ranging from ignoring, manipulation, or criticizing these systems (e.g., Christin, 2017; Bucher, 2017). Related, Brunton and Nissenbaum (2011) indicated for data collection online that users developed ways to hide their information or engage in 'playing the system' strategies such as producing misleading, false or ambiguous data. Similarly, research on privacy has outlined that users employ a range of privacy protection measures including both technical solutions as well as information management strategies (for an overview: Masur et al., 2018; Matzner, Masur, Ochs, & von Pape, 2016). Based on our interviews, we found that users apply different coping strategies regarding the use of algorithms, e.g., by consulting different services (e.g., different search engines, shopping platforms or news media) to compare recommendations made by algorithms and to mitigate the effects of personalization. Findings also reveal that some, in particular elderly users were less competent in coping with unwanted or inaccurate algorithmic curation e.g., in the case of targeted advertising or product recommendation resulting in a feeling of helplessness and the decision to refrain from using particular websites and services. Measuring individuals' coping strategies, thus has to take into account very different levels of expertise.

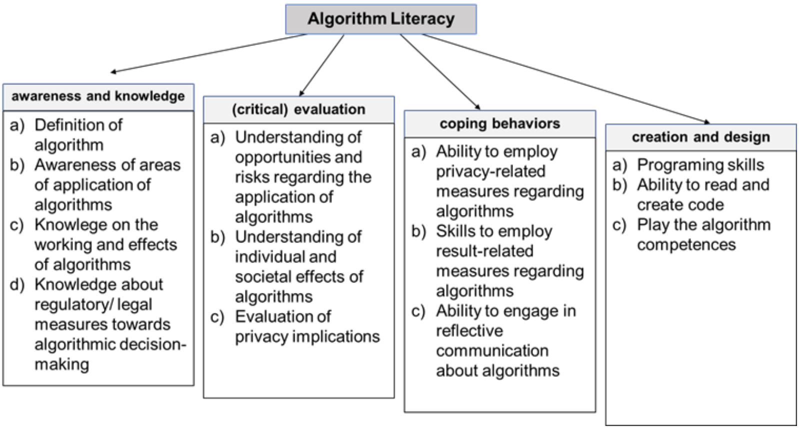
Conceptually, we may differentiate three types of coping strategies towards algorithm, namely privacy-related measures (e.g., private browsing, deleting of cookies) as highlighted by Masur (2018), result-related measures (e.g., consulting different search engines, deliberately manipulating interactions with algorithms) and third, critical communication and activism around algorithms. The latter category aims at capturing if users engage in actively questioning the application and design of algorithms on the Internet, e.g., by using online forums to discuss potential (mal)functions or changes in their design, which happen on a more or less regular basis, e.g., on social network sites such as Facebook or Twitter. In the future, we might even expand this third category to account for potential activism related behaviors, e.g., hacking, engaging in online petitions or other ways of demanding regulatory measures towards the application of algorithms.

Creation design

The last dimension is the least developed area to examine users' skills regarding the use of algorithms as it is targeted towards users' abilities for modifying and creating algorithmic application (prosuming function). Acknowledging that creating algorithms requires at least some basic understanding and competences of programming we propose to capture users' programming skills and their ability to read and write code, which we see as a necessary precondition for such an endeavor. This dimension aims at capturing practices of Internet users where they transform or convert existing algorithmic applications in ways not intended by providers of designers of algorithms (as described by 'play the algorithm strategies' in the literature, c.f., Bishop, 2019). We thus suggest to further include items that comparable to the "play the algorithm" coping strategies measure if users engage in deliberately manipulating algorithms to transform their functionality.

Figure 1 summarizes the dimensions and sub-categories for algorithm literacy based on the following elaborations. While it is helpful for analytical reasons to present each of the dimensions separately, we have to bear in mind that the domains are not entirely independent from each other but are interrelated and, to some extent, mirror a process character (indicated through the layers in Figure 1): If users lack awareness about the implementation of algorithms in a certain context and do not know anything about their operation, it is unlikely that they are able to evaluate the consequences of algorithmic decisions and even more unlikely that they are able to implement adequate coping behaviors or create and program algorithms. This mutual dependency of literacy dimensions has been outlined by previous research as well (e.g., Livingstone, 2004).

Figure 1: The dimensions and sub-categories of algorithm literacy



5 Discussion

When navigating the Internet, we are almost constantly in touch with algorithmic systems that filter, rank, or recommend the information and content that is presented to us or that decide what news or music we consume or even with whom we interact; algorithmic decisions impact most of our interactions online, and this has provoked a large number of studies inquiring into the risks, biases, and effects of algorithmic curation. At the same time, research investigating how users perceive these changes to their decision-making and how they cope with algorithms remains scarce. This article set out to propose a concept for studying Internet users' algorithm literacy. We considered literacy an appropriate framework to address relevant knowledge, competences, and skills that Internet users may need to be able to understand, evaluate, and employ algorithms in a self-determined way. The four proposed dimensions, including different sub-categories, provide a framework for understanding algorithm literacy beyond simply measuring users' awareness of algorithmic curation (e.g., to identify supposedly ignorant users) and are based on the competences that have been outlined in previous approaches to (new) media literacy.

While the present article did not aim at developing a comprehensive scale to empirically measure algorithm literacy, we see this concept as a framework to develop such operationalization. Still, we have to bear in mind that transforming this framework into testable items is a challenge due to several reasons: The first challenge (1) concerns the *time sensitivity* of the instrument. While the first dimension, the knowledge and awareness of algorithms, can be operationalized by testing users' factual knowledge, we have to bear in mind that this knowledge, in particular in the area of algorithms, is time-sensitive – both regarding the areas of application of algorithms (e.g., what services individuals use and how algorithms are implemented into these systems) and the performance of algorithms themselves. While, for instance, today, the performance of algorithms in the area of content production is still limited (e.g., to more standardized texts), this is likely to change in the future. Addressing users' knowledge about the performance (and limits) of algorithms therefore needs to be adjusted to the actual evolvement of the capabilities of algorithms. Still, we can see some stable patterns in the ways algorithms are implemented (e.g., regarding the filtering, ranking, and sorting of information), which is unlikely to be subject to radical changes in the near future.

A second challenge (2) addresses the use *of self-reports* in measuring users' skills in terms of reflection and coping strategies (dimensions two to four). The operationalization of users' literacy through self-reports has already been critically discussed in previous research (e.g., Hargittai, 2010; Hobbs, 2017; Masur, 2018). Hargittai (2005), for instance, pointed out that measuring users' digital or computer-related abilities and skills through self-reports poses the risk of misreporting. While for the first dimension, awareness and knowledge, questions addressing users' actual knowledge are considered better predictors compared to measuring users' self-perceived abilities, examining users' coping skills would benefit from a different approach. As stressed by Masur (2018), with regard to privacy literacy, measuring users' skills would require actually observing how users perform in terms of these behaviors in order to draw conclusions about their competencies or abilities. For practicability reasons, it thus seems reasonable to see users' actual coping strategies as a proxy for their skills.

A third challenge (3) (and at the same time a limitation of this proposed framework) is the focus on 'algorithms on the Internet'. The idea of this concept was to target algorithms that Internet users are in contact with when online, which, of course, covers a broad range of activities and situations. While this paper set out to develop a framework that can be used to assess users' algorithm literacy on a general level, this necessarily comes with limitations regarding the depth of knowledge and skills when thinking about particular services or applications (i.e., the use and evaluation of search results, online shopping, or the curation of social media environments requires specific skills and knowledge). It thus remains a challenge to create measures that are both specific enough and broad enough at the same time to measure users' actual knowledge and skills without disadvantaging users who engage with different services or applications (e.g., users who do not use social media).

Related to this aspect, the fourth challenge (4) concerns how it remains to be decided how constructs or items from existing, related literacy measures (e.g., web skills, privacy literacy, online news literacy) should be included in the measure of algorithm literacy. While these are arguably intertwined with knowledge and skills related to algorithm literacy, stretching the framework towards related constructs makes it more difficult to differentiate between both concepts and to examine their relationship.

The proposed framework thus presents a first, yet necessary, step towards deducing an empirical measure to capture Internet users' algorithm literacy. While more research is needed on operationalizing the dimensions and on the sub-categories identified, this framework provides an extension of existing (new) media literacy concepts, encompassing more recent developments in media users' media and communication environments.

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Abstract: This article discusses aspects of future research in communication sciences related to a popular and omnipresent artefact of algorithmic machines, social robots. Social robots are defined in this article as physical entities or machines, which may resemble a human being or animal and are able to replicate certain human or life-like movements and functions. Experts predict that robots, just like AI, will replace a significant number of jobs in the near future, including non-industrial jobs such as robots working in offices or the service industry alongside human 'co-workers' (Brookfield Institute, 2016; Ford, 2015; Gunkel, 2018). Likewise, we may find more robots in our private lives, for example, replacing human care workers (Ishiguro, 2018; McGinn et al., 2020). Overall, the field of robotics, and particularly social robots, offers a broad range of research opportunities and exigencies for communication scientists. The aim of this conceptual paper is to provide a framework for the discussion of algorithms, social robots and communication sciences.

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Frauke Zeller

Algorithmic Machines

From Binary Communication Designs to Human-Robot Interactions

1 Introduction

It is today rarely contested that algorithms influence our lives in all dimensions – social, economic, political, legal, and cultural. Communication scholars have thus started to critically look into the role of algorithms, their functions, and how they influence our communication processes (see, for example, Andersen, 2018; Bucher, 2017; Gillespie, 2014, 2016; Kitchin, 2017; Klinger & Svensson, 2018). Similarly, there is an increasing number of publications from researchers in the STEM (Sciences, Technology, Engineering & Mathematics) fields who offer cross-disciplinary introductions and discussions of algorithms (see, for example, Christian & Griffith, 2016; Fry, 2018).

This paper discusses an applied aspect and artefact of algorithmic culture (Striphas, 2015) - that is algorithms and machines such as in Human-Robot Interaction (HRI). While there has been growing attention in media (BBC News, 2018; Fowler, 2020) as well as academia (Clerwall, 2014; Dörr, 2016; Ferrara, 2020) to so-called online robots, or bots, and how their algorithmic design can cause havoc on social media, this article focuses on 'traditional' robots: physical entities or machines which may resemble a human being and are able to replicate certain human movements and functions (Oxford English Dictionary). Or, using a more technical definition, a robot can also be defined as "a physically embodied artificially intelligent agent that can take actions that have effects on the physical world" (Simon, 2017).

Experts predict that robots, just like AI, will replace a significant number of jobs in the near future (Brookfield Institute, 2016; Ford, 2015; Gunkel, 2018; IFR, 2019; Spence, Westerman, & Lin, 2018). Likewise, we may find more robots in our private lives in the near future, for example, replacing human care workers (Ishiguro, 2018; McGinn, 2020). Particularly robots in our social and private lives, so called social robots, often do not come with an obvious impression of being made of inorganic hardware and algorithms. Instead, social robots tend to resemble humans or animals – at least in some basic characteristics such as having eyes, a mouth, and limbs. This means they "are designed to promote anthropomorphism and zoomorphism (the attribution of human or animal characteristics to a non-human/animal entity)" (Fraser et al., 2019, p. 62). They also aim to imitate human beings or animals in their behaviour and communication patterns (Breazeal, 2002; Zeller, 2005). Thus, based on those design decisions, one can assume that they are intended to make us forget that they are autonomous machines, operating, as any intelligent machine does, on algorithms. Arguably, the past decades' development of social robots has focused in many areas on designing and producing social robots that are "increasingly humanlike, not only in physical appearance but also in the display of human psychological, affective, and behavioral features" (Giger et al., 2019, p. 111). Among developers, one main rationale for this development is the assumption that the more humanlike a social robot is, the more it will be accepted by the human user given that the similarity of human features and behaviours facilitate the interaction (Giger et al., 2019). User acceptance is also mentioned as one of the main goals in the design of HRI (Blow et al., 2006; Breazeal, 2002).

The overall aim of this conceptual paper is to provide a framework for the discussion around algorithms, social robots and communication sciences. The aim, however, is not to argue that communication researchers should become trained in programming algorithms for social robots themselves, nor to understand or reproduce the computer science details related to algorithms. Rather, in order to understand and research the relevance and role of algorithms in social robotics, algorithms or the computational processes in general need to be seen as part of the holistic, overall 'interaction' design approach. Similarly, Dudek and Jenkin (2010) describe the relationship between algorithms and robots in a certain subset of robots, that is mobile robots: "Mobile robots are not only a collection of algorithms for sensing, reasoning, and moving about space, they are also physical embodiments of these algorithms and ideas that must cope with all the vagaries of the real world" (Dudek & Jenkin, 2010, p. 2). This paper will discuss the interconnectedness and interdependency by discussing the front-end and back-end[1] of social robotics, and future research avenues for communication researchers. The first part of this paper will briefly introduce social robots and algorithms. It will then explain what kind of algorithms guide robots by using the binary front-end and back-end distinction as a guiding framework, and finally provide discussions of future trends and research avenues in this field for communication researchers. Given the extent and interdisciplinary nature of the field of robotics and social robotics, and the limitations of any paper published in a special issue, this paper uses a funnel-approach: it starts by providing a wide and general introduction to the overall topic, to then gradually narrowing down when it comes to discussing future trends and research avenues.

2 Social Robots and Algorithms

2.1 Social Robots

Overall, social robots can be described as being designed to interact with humans – be it to help or support them, or as friends, lovers, etc. – and thus are required to have some form of personality and usually an anthropomorphic or zoological embodiment. This means most social robots either look like humans (or at least imitate basic human features such mouth, eyes) or animals (Breazeal, Dautenhahn, & Kanda, 2016; Fraser et al., 2019). In general, one can say that a social robot fulfils all abilities and functions of a robot according to

1 Front-end and back-end describes the classic binary distinction in machines, where the front-end depicts what the user sees and interacts with, and the back-end the technological and algorithmic design (hardware and software). See, for more detail, section 2.3 of this paper.

the ISO (International Organization for Standardization) definition[2], but does that in the context of interacting with humans in a human-centric way (see also Breazeal, Dautenhan, & Kanda, 2016).

An interesting question is whether a social robot must be able to perform a certain function as industrial robots do, for example. Breazeal, Dautenhahn and Kanda (2016) state as the main unifying function or characteristic that "social robots engage people in an interpersonal manner, communicating and coordinating their behavior with humans through verbal, nonverbal, or affective modalities" (p. 1936). One of the earlier definitions of social robots takes a more socio-centric point of view:

> Social robots are embodied agents that are part of a heterogeneous group: a society of robots or humans. They are able to recognize each other and engage in social interactions, they possess histories (perceive and interpret the world in terms of their own experience), and they explicitly communicate with and learn from each other. (Dautenhahn & Billard, 1999)

Breazeal (2003) focuses on how people perceive robots and extracts her definition from there. Her point of departure is inspired by different works, such as the media equation (Reeves & Nass, 1996), which posits that humans tend to apply social models when interacting with machines, including robots.

> Autonomous robots perceive their world, make decisions on their own, and perform coordinated actions to carry out their tasks. As with living things, their behavior is a product of its internal state as well as physical laws. Augmenting such self-directed, creature-like behavior with the ability to communicate with, cooperate with, and learn from people makes it almost impossible for one to not anthropomorphize them (i.e., attribute human or animal-like qualities). We refer to this class of autonomous robots as social robots, i.e., those that people apply a social model to in order to interact with and to understand. (Breazeal, 2003, p. 168)

Zeller (2005, pp. 99-100), based on Breazeal (2002) and Dautenhahn et al. (2002), provides an overview of the different sub-classes or degrees of 'social' in social robots, ranging from:

2 According to the ISO 8373:2012, a robot is an "actuated mechanism programmable in two or more axes (4.3) with a degree of autonomy (2.2), moving within its environment, to perform intended tasks" (https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en).

- socially evocative (robots aiming to create anthropomorphization processes in humans),
- socially communicative (robots that are capable to communicate, usually in natural language),
- socially receptive (robots that can learn from humans, from motoric functions to language/communication),
- socially cooperative/sociable (robots that have their own/personal motivations which usually include the social interaction with humans),
- socially situated (robots that can perceive their environment), and
- socially intelligent (robots with empathic ability, based on human-like cognitive structures and social competencies).

One social robot can certainly cover a range of those notions of sociability, although each single objective or social trait requires often different, complex algorithmic and technological abilities. Thus, the more social traits included, the more sophisticated and usually expensive the robot is.

Generally speaking, terminologies and even definitions around social robots can be considered as changing or 'moving' targets: For example, the term social robot used to be "applied to multi-robot systems where the dominant inspiration came from the collective behavior of insects, birds, fish such as flocking, foraging etc." (Breazeal, 2003, p. 168). In her paper, Breazeal elaborates that the term 'social' had changed "to become more strongly associated with anthropomorphic social behavior" (2003, p. 168).

The notion of embodiment, one of the core concepts in the beginnings of HRI, is also changing. Deng, Mutlu and Mataric (2019) state that "most socially interactive robots do not need to physically interact with their environments in order to perform their tasks" (p. 251), and provide a research overview of the role of physical embodiment in social robotics[3]. Similarly, we have to understand the context of the term 'autonomous' used in Breazeal's quotation above. The term then is not necessarily comparable to current connotations of 'autonomous', when, for example, referring to self-driving cars. Rather, 'autonomous' refers to the ability of a robot to process sensor-based data input and then produce or show corresponding reactions, so that it appears to be autonomous or freely choosing its behaviours. Braitenberg (1984) famously discussed in his thought experiment how easily machines (or mechanical agents) can appear to be autonomous or show emotions by simply using a sensor coupled to a motor. For example, a simple moving agent (such as, a small robot on four wheels) with a light sensor can appear to be drawn towards the sun, and thus imitate emotional, autonomous behaviour (Damiano, Dumouchel, & Lehmann, 2015; Dautenhan, 2007)[4].

The broader field within which social robots are discussed is called Human-Robot Interaction (HRI). Bartneck et al. (2020) describe HRI as a discipline, which "is related to human–computer interaction (HCI), robotics, artificial intelligence, the philosophy of technology, and design" (p. 7). They state that social robots, or rather the interaction of humans with social robots, usually represent the main perspective or objective of the field, and that those "interactions usually include physically embodied robots, and their embodiment makes them inherently different from other computing technologies" (p. 7). The authors claim that social robots can be perceived as "social actors bearing cultural meaning and having a strong impact on contemporary and future societies" (p. 7). This statement can also be connected to the close coupling of social robots and fiction or popular culture in general, where robot-like automata have been displayed and narrated even a long time before Karel Čapek coined the term 'robot' in his play R.U.R. – Rossum's Universal Robots (Onnasch & Roesler, 2020; Cohen, 1966). Overall, HRI is being described as inherently multidisciplinary, connecting scholars from a broad range of disciplines and research fields such as mechatronics, engineering,

3 The literature on embodiment in HRI is vast, and discussions highly diverse. This paper will focus on embodied social robotics. For further research in this field, see Beckerle, Castellini and Lenggenhager (2018); Breazeal and Scasselati (2002); Brooks (1999); DiSalvo and Gemperle (2003); Fischer, Lohan and Foth (2012); Foster (2019); Giger et al. (2019); Gunkel (2020); Kaplan (2008); Miller and Feil-Seifer (2017); Wainer et al. (2006).

4 Braitenberg's thought experiments have since been numerously applied in basic programming or introductory AI lectures (see, for example, Ertl, 2009).

linguistics, philosophy, psychology, design, anthropology, and communication research (Bartneck et al., 2020; see also Kanda & Ishiguro, 2013). Arguably, the communication perspective has been emphasized in the field of HRI and social robotics from the start, with early studies already posing questions such as: "What are the common social mechanisms of communication and understanding that can produce efficient, enjoyable, natural and meaningful interactions between humans and robots?" (Breazeal, Dautenhahn, & Kanda, 2016, p. 1935).

2.2 Algorithms

According to Fry, "[a]n algorithm is simply a series of logical instructions that show, from start to finish, how to accomplish a task" (Fry, 2018, page 8). While the author admits that such a broad definition would also mean that, for example, baking recipes are algorithms (see also Gunkel, 2020; Bryson, 2020), too, it also needs to be stressed that this definition represents the basic form of algorithms and does not necessarily suffice to explain algorithms used in machine learning and in neural networks. Fry (2018) distinguishes between rule-based and machine-learning algorithms. Whereas the rule-based algorithms are fully programmed by humans and can be described as "direct and unambiguous" (Fry, 2018, p. 10), the second type of algorithms is "inspired by how living creatures learn" (p. 10). In fact, machine-learning algorithms are designed to be capable of basically writing themselves, based on a given framework and with the use of large data sets that allow for trial and error-based training and learning approaches to a given problem until an optimal path is found. Thus, the human programmer is not needed to provide the whole path, nor different options (so-called IF-THEN routines, for example). These algorithms have proven to be rather useful for problems that are more vague, such as in image recognition (Fry, 2018; Gunkel, 2020). However, they are also representing a technical as well as societal challenge insofar that "if you let a machine figure out the solution for itself, the route it takes to get there often won't make a lot of sense to a human observer. The insides can be a mystery, even to the smartest of living programmers" (Fry, 2018, page 11).

Staying with the algorithmic basics, according to Fry (2018, pp. 8-9) typical tasks for digital algorithms (i.e. those implemented in computing and/or digital environments) are:

- Prioritization, i.e. making ordered lists, such as in search outputs.
- Classification, i.e. picking certain categories such as in classifying and removing inappropriate content in multimedia platforms (for example, YouTube).
- Association, i.e. finding links and relationships in data sets such as on matchmaking platforms (for example, partner search).
- Filtering, i.e. sorting and isolating what is important such as in speech recognition where algorithms need to be able to filter the noise from what is actually said.

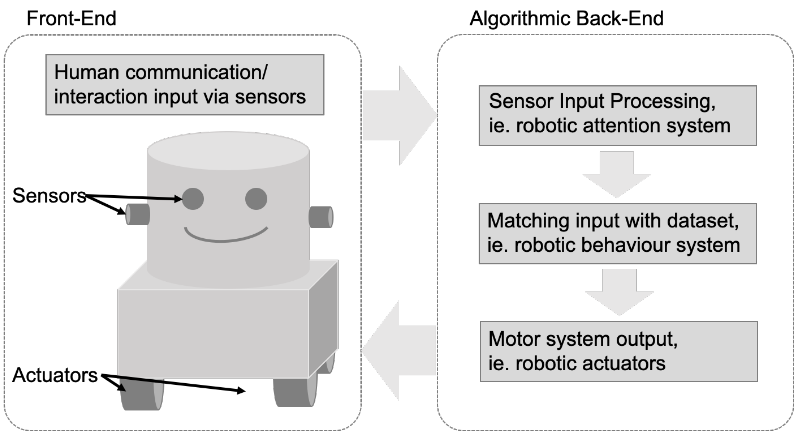
When looking at these main tasks, what comes to mind is that they are also carried out on a daily and continuous basis by humans: We need to be able to prioritize what needs to be done first when, for example, the aim is to simply have a bath (i.e. first, put the plug in the bathtub, then, run the water, etc.). We classify when we consume news or media in general, picking what is most relevant to us. Sometimes we also use association to help us here, or we associate certain experiences with new situations in order to know how to proceed. Finally, filtering needs to be performed non-stop in our communicative interactions, be it simply to filter out background noise when talking to someone in the street.

Bryson (2020, p. 6) provides a connection to the physical context or embeddedness of algorithms by stating that algorithms are first and foremost "abstractions" and, taken at face value, merely "inert" lists of instructions. Thus, other than the comparison of algorithms to baking instructions, an algorithm can be depicted as a computational procedure (Gunkel, 2020; Cormen et al., 2009). This means, physical computation is an essential part of an algorithm, no matter whether the algorithm is "intelligent" or not (see below, section 4.2): "Just as a strand of DNA in itself is not life – it has no capacity to reproduce itself – so instruction sets [algorithms] require not only input (data) but also physical computation to be run. Without significant, complex physical infrastructure to execute their instructions, both DNA and (...) algorithms are inert" (Bryson, 2020, pp. 6-7). The author's statement connects to this paper's objective, which is discussing algorithms and social robots, by emphasizing that algorithms cannot stand on their own. Rather, they are always dependent on the wider physical, computational context of a robot, and define not only the inner mechanisms and processes of a robot but also its outer reactions, interaction patterns, and abilities.

2.3 The Social Robotic Front-End and the Algorithmic Back-End

Braitenberg's (1984) thought experiment can function as an example for the classic binary distinction in machines: front-end and back-end, where the front-end depicts what the user sees and interacts with (i.e. the interface), and the back-end represents the technological and algorithmic design (hardware and software). When it comes to robots, and social or autonomous robots, the robotic system must be able to perceive its environment (or features of it) and respond to sensory input (see also Bartneck et al., 2020). The example of Braitenberg's vehicle, where a simple machine or robot moves toward the light and thus appears to the layperson to be showing a natural direct reaction, can actually be broken down into several steps or subsystems.

Figure 1. Simplified robotic front-end and back-end relational system (author's own drawing)



To demonstrate this, Figure 1 illustrates the robot interface as the front-end, including in this example two kinds of sensor input: cameras for vision (here, shown as imitated eyes on the anthropomorphized robot head) and microphones for auditory input (here, shown as imitated ears). This input is then processed in the back-end, which can also be called the robotic attention system (the term was adapted from Breazeal, 2002; and Gunkel, 2020). The processing usually contains interpreting the input (sensory input), and matching it with the internal dataset of the robot. For example, if the input is light, the dataset could contain the rule to either move towards a light source or to avoid it, and with this producing the impression that a robot either likes the light or tries to avoid it. Once the matching is successful, the machine will choose the corresponding output and activate the robot's actuators; in this case, the wheels of the robot, which produce movement. These processes are based on algorithms, which are, as depicted above, simple instructions as to what to do under certain conditions.

This simplified example shows that when it comes to planning HRI or the design of social robots, one cannot think of direct relations where a stimulus causes a straightforward reaction. Rather, a stimulus (i.e. input from a sensor) needs to be detected by the back-end, processed, and then embedded in the robotic behaviour system to finally come up with a corresponding output or reaction. Likewise, a social robot cannot function if the chosen sensor does not receive any input. Using the example of the light again, the robot will not show any reaction (ie. move towards the light) if the light source is not working, such as when the electric light fails or the sun is not visible. The fact that robotic systems are prone to malfunction given even small irregularities in their environment, deters the establishment of close relationships between humans and social robots. Following up on the light example, human users can still function when the sun is not visible or a light bulb ceases to function. Thus, in an HRI context, where a social robot's design successfully makes the user feel comfortable believing that they can interact with the robot in a similar way to the way they would interact with other human beings, those small malfunctions can trigger an uncanny valley and thus lead to a strong negative reaction on the human user side (see also Breazeal, Dautenhahn, & Kanda, 2016). Uncanny valley (Mori, 2012; Pollick, 2009) describes in robotics the effect when, for example, a robot displays some familiar humanoid features yet the arrangement or quality of these appear strange or unnatural to the user. This could be when a computer-generated voice does not match a fully anthropomorphic robot (see, for example, Hanson et al., 2005).

While Figure 1 aims to visualize the high-level functioning of a robotic system, it does not include the different extended interfaces of a robot, particularly a social robot. Zeller (2005) distinguishes four main categories of interfaces, whereas for social robots only the first three interface categories are relevant: The category *technological interfaces of a robot* mainly distinguishes between hardware- and software interfaces (as also depicted in Figure 1 as back-end). These range from interfaces between the processor and main circuit board, to algorithms that allow for the robotic hardware to work with the software. The second category is called *human-robot interface* and encompasses all components that are available for humans and robots to interact with each other. They basically range from the on/off button of a robot to computer program interfaces that allow for humans to remote control robots (these days, this is often complemented by apps that can be downloaded and installed on the user's phone). The third category, the *robot-environment interface*, can be compared to the front-end in Figure 1. Social robots need to be able to perceive their environment, at least to a certain degree, when they are intended to move around and interact (Zeller, 2005). The notion of a moving entity also expands the end-user's perception and kindles a whole set of additional interaction possibilities and expectancies (see also Breazeal, Dautenhahn, & Kanda, 2016). For example, a lot of social robots are able to follow (to a certain degree) a human user, which instils the impression of belonging together, friendship, and intelligence.

2.4 Algorithms to Imitate Human Action

Social robotics in general follows the idea of embodiment, meaning that physical robots are, on the one hand, built resembling humans so that we can learn more about humans by way of robotic experiments. On the other hand, resembling humans helps to build robots that can function in our (social) environments, that is, robots should learn from humans given that we carry out cognitive, manual, etc. tasks that are often highly complex (see, for example, Bartneck et al., 2020). Therefore, robotics and particularly social robotics apply algorithms that are based on human action analysis. This means that humans, their behaviours but also physical movements, actions, etc. represent the model social robots aim to imitate: "When a robot is doing service work or assisting humans in our daily life, it also needs to collaborate with humans and is expected to simulate human behaviors during the collaboration. For the purpose, robots are designed to understand human actions and to predict human intentions (...)" (Ji et al., 2019, p. 1). The authors differentiate between different human action categories for which algorithms are programmed so that they can study human actions and then create an algorithm-based model in order to imitate those actions. One main category is 'gestures', where particularly human hand gestures are studied via video and 3D analyses, translated into algorithms and then implemented into robots. The kind of algorithms used in these approaches utilize machine-learning, so-called deep learning algorithms. This implies that big data sets are used to arrive at possible algorithmic – and finally robotic – translations and applications. A simplified example would be the analysis of slow motion videos of manually picking up an apple and holding it. The slow motion video shows the different individual steps, including what fingers and even muscles are used, basically breaking down a gesture that might only take a few seconds into multiple screen-shots. Modern algorithms are capable to first capture those human movements, differentiate them into millions of single instances, and then translate them into technological counterparts for the robot, i.e. what sensors are used, what electronic parts are needed when and how, etc. Ji et al. (2019) thus differentiate for the analysis of human body motion multiple sub-categories, such as simple motion analysis or skeleton mapping. These are then via algorithms translated into a so-called "semantic representation", which means formal representations as in programmes and models that a machine can process, and finally result in algorithms that apply the actual interaction or action imitation (Ji et al., 2019). Overall, a multitude of research and publications on different algorithms for different aspects of robotic interactions, movements, actions, etc. exists. Many studies use humans as a model, however with varying degrees of analytic detail.[5]

5 Thomaz, Hoffman and Cakmak (2016) provide an exhaustive overview of computational, algorithmic approaches to HRI. Their meta-study complements earlier overview studies by Fong, Nourbakhsh and Dautenhahn (2003) and Breazeal, Takanishi and Kobayashi (2008) and systematically documents the different studies and approaches in computer sciences in HRI.

3 Algorithms and Communication in Social Robotics

As mentioned above (see section 2.1), communication between human users and social robots has been a pivotal topic from the start. Thus, studies looking into the different aspects of communication design including the corresponding back-end algorithmic design can be found in great numbers. Breazeal, Dautenhahn and Kanda (2016) provide an overview for social robotics research and communication, while Onnasch and Roesler (2020) include numerous exemplary studies relating to communication in HRI (see also Baron, 2015; Kanda, Shiomi, & Hagita, 2011; Sandry, 2015; Taipale & Fortunati, 2018). Thomaz, Hofmann and Cakmak's (2016) overview of computational/algorithmic approaches to HRI presents the following main areas of computational research in HRI:

- Foundational Competencies: Perceiving humans (for example, face and person recognition, gesture and pointing recognition); verbal communication (for example, generating and perceiving speech, modeling task and domain knowledge); nonverbal behaviour (for example, deictic gestures, eye gaze); affect and emotion (for example, facial expressions, recognizing human emotion);

- High-Level Competencies: Intentional action (for example, theory of mind, communicating intent); collaboration (cognitive and planning frameworks, collaborative manipulation); navigation (social models for navigation, navigation and verbal instructions); learning (characterizing human learning input, social imitation learning). (Thomaz, Hoffman, & Cakmak, 2016, p. 111)

The overview shows that most categories include communication aspects or directly point to communicative interaction features. Even features such as *navigation* include computational/algorithmic approaches to combine, for example, the navigation of a robot with verbal instructions. Zeller (2005) summarises the broad communication perspective in HRI by translating engineering and computer sciences' approaches to communication aspects in HRI into a taxonomy based on linguistics and communication research. Her taxonomy encompasses the following four main categories:

Text-based communication: A social robot's instructions, such as manuals, are one form of text-based communication. Manuals etc. are not the best communication form from a design perspective given that social robots should be designed in a way that a more natural, instinctive form of interaction is possible (Zeller, 2005). Given the analog nature of most manuals (i.e. printed) there is no algorithmic back-end either, which also underscores the break in the design logic given the algorithmic nature of a robot. Another text-based communication form is touch screens or panels for interaction. Examples are often found in service robots that, for example, are designed to help users to find their way in a hotel or to find a certain product in a warehouse (for example, Baxter, Wood, & Balpaeme, 2012; Döring et al., 2015). Touch screens using text-input often represent an additional choice of communication in order to meet different communication preferences of users.

Sound-based communication: This form of communication can range from very rudimentary sounds to signal-based functions of a robot, such as on/off, low battery level, etc. to designs that are based entirely on sound (according to Zeller, 2005). The toy robot BB8 by Sphero[6] is an example of a robot that exclusively uses different sounds (and colour signals) to communicate. Pet robots, such as the well-known SONY AIBO[7] robot dog, also use sounds like barking, yelping etc. Regarding the design of social robots, an exclusive usage of sounds does not necessarily mean that a robot is less communicative. Because we can make links to the intended living object (i.e. a dog, a baby), we are able to make up for the lack of linguistic/verbal utterances by referencing interaction with the living examples.

Visual and non-verbal communication: A commonly used communication form for social robots are color-based signals. For example, red is uniformly used for signalling a problem, such as lack of power or input/output problems. Gestures are also a form of non-verbal communication and can be found in many examples of social robots. Particularly pet robots, such as the aforementioned AIBO dog, use different movements to communicate certain feelings or behaviours. An example is here tail wagging, which signifies excitement. Another well-known robot is Kismet, developed by Breazeal (2002) at the MIT (Massachusetts Institute of Technology), which used extensive facial movements such as eye movement, eyebrows, ears and mouth to signal different moods and expressions (Zeller, 2005).

Speech-based communication: Natural language input and output represents one of the most natural communication forms between humans and social robots (Zeller, 2005; Bartnetck et al., 2020). In robotics, two different forms or sets

6 https://www.sphero.com (last retrieved 17 November 2020)
7 https://us.aibo.com (last retrieved 17 November 2020)

of abilities can be found – speech recognition and speech synthesis. A robot equipped with speech recognition is capable to perceive and 'understand' natural language input (from the human user), process it and provide adequate feedback. This feedback could be certain actions, for example when it is being told to move around, or gestures, or any other form of communication (colour/optical signals, etc.). A robot, which is also equipped with speech synthesis, can respond in natural language. In any case, one feature does not automatically trigger the other feature, or understanding language does not mean that a robot can also speak. This is because both features are very complex and require different yet collaborating algorithms and processes in the back-end.

4 Future Trends

The first sections in this paper provided general introductions to the main objects or fields of this research paper: social robots, algorithms, and communication. The following sections discuss in more detail future trends and research avenues for communication researchers in the field of social robotics and algorithms.

4.1 Socio-Economic Impact and Future Trends of Robotics

Robots have fascinated humankind for thousands of years, traceable to Greek mythology or old Egypt (see Cohen, 1966; Ichbiah, 2005; Reichardt, 1978). They have also played an almost permanent role in popular fiction, art, and the media (see, for example, Bartneck, 2004; Bartneck et al., 2020; Dautenhahn, 1998; Murphy, 2018; Pfadenhauer, 2015; Sarrica, Brondi, & Fortunati, 2019; Weiss, 2020), and there is no reason to expect that this will end soon. However, robots also elicit diverse feelings: on the one hand, robots tend to kindle curiosity and enthusiasm, or even caring instincts. On the other hand, robots have always come with a dystopian tone, challenging a strict division between 'master' and 'servant', and kindling unease that they might take over one day[8].

As a matter of fact, it is robots used in industry that, for example, 'threaten' the loss of labour carried out by humans (see, for example, Ford, 2015; West, 2018).

8 See the Golem myth, for example, in Cohen (1966).

And whereas this paper focuses on so-called social robots, recent developments in industrial production systems also call for intelligent, agile robots that can work as smart assistants together with humans: “The interaction between human and robots improves the efficiency of individual complex assembly processes, particularly when a robot serves as an intelligent assistant” (Krüger, Lien, & Verl, 2009, p. 628). This means that industrial robots also develop in the direction of intelligent collaborative robots, so-called cobots (see, for example, Akella et al., 1999; Brending et al., 2017; Bitonneau et al., 2017; Peshkin et al., 1999), a domain of research in advanced robotics (Küpper et al., 2019). As a result, Hentout et al. (2019) register that, with the development of cobots, HRI research in the context of industrial robots has significantly increased. This trend also represents a future research avenue for communication scholars, since humans and robots co-working in industrial settings and workplaces also require successful interaction and communication. From an economic point of view, industrial robots represent the biggest robotics market penetration and financial impact. According to a report by the International Federation of Robotics (IFR), the leading association for industrial robotics, robot installations in the world in 2018 amounted to 16.5 billion US Dollars, which translates into more than 420,000 installed robotic units globally. And industrial robots have been on the rise throughout the past decade: from 2013 to 2018, installations of industrial robots increased by 19% annually; with China, Japan, the United States, the Republic of Korea and Germany being cited as the main markets for industrial robots, amassing 74% of robot installations worldwide (IFR, 2019).

Boston Consulting Group (BCG) also forecasts a high growth rate for the advanced robotics market, estimating an increase of 46% of the global market value for robots in manufacturing to 18.6 billion US Dollars by 2021, and a market value for robots in logistics of three billion US Dollars (Küpper et al., 2019). Focusing again on the relationship between humans and robots, the same report predicts that advanced robotics adoption will impact the workforce in Germany, for example, to up to 43% (i.e. workers being replaced by robots), and China leading with an anticipated 67% of its current workforce replaced by robots, followed by Poland (60%), Japan (57%), and Canada (52%) (it should be noted that these statistics however fail to capture the creation of new jobs).

The IFR provides a category for non-industrial robots working alongside with and for humans – Service Robots – which encompasses different kinds of robots. Its subcategory ‘Professional Service Robots’ is defined as robots, “which are used outside of the home and conventional manufacturing scenarios" (Anandan, 2018, para. 5). Professional service robots encompass a range of different service segments, such as robots used for logistics-related tasks in factories and warehouses, medical robots deployed for surgeries and diagnostic tasks, or public relations robots, "which are used to provide information in shops and public spaces" (Müller, 2019). Given the overall aging populations in developed countries, medical robots' sales growth is estimated at an average around 47% annually between 2019 and 2022 (Müller, 2019). Overall, the market for professional service robots saw an increase "by 32% to US$ 9.2 billion in 2018 (over 2017)", "reaching a total of about US$ 38 billion in 2022" (Müller, 2019, para. 1, 12). Another subcategory is called 'Personal/Domestic Service Robots' and relates to robots that are designed for personal, individual interactions. Compared to the first subcategory, this one is often referred to as niche, albeit showing a great variety, too. The niche expression derives from the comparatively small market penetration, however particularly cleaning robots showed an increase of 24% in 2018 (over 2017), totaling in sales of 2.4 billion US Dollars (Müller, 2019). Market growth is estimated to strongly increase in the next three years "by an annual average of 35% [...] to just over US$ 11.5 billion in 2022" (Müller, 2019, para. 12). Given that we find personal and domestic robots often closest and most personal to us, they are also commonly referred to as social robots.

It can be expected that recent developments relating to the worldwide COVID-19 pandemic will have an impact on the socio-economic impact as well as socio-cultural role of service robots. Yang et al. (2020) are predicting more potential roles for robots in the public health sector. This is a development that already started with the 2015 Ebola outbreak, where service robots were identified for three main areas: "clinical care (e.g., telemedicine and decontamination), logistics (e.g., delivery and handling of contaminated waste), and reconnaissance (e.g., monitoring compliance with voluntary quarantines)", and the "COVID-19 outbreak has introduced a fourth area: continuity of work and maintenance of socioeconomic functions" (Yang et al., 2020). In fact, a number of academic publications have been published on the potential increase of impact and roles of service robots in sectors like travel and tourism (Kwok & Koh, 2020), geography and urban planning (Chen, Marvin, & While, 2020) or service management (Karpen & Conduit, 2020). Despite the sudden rise in interest and publications caused by the COVID-19 pandemic, the deployment of social robots – or different versions of professional service robots – cannot be expected to be a clear and linear development. Recent discussions around the physical embodiment of social robots, and whether digital versions might be just as useful (see, for example, Deng, Mutlu, & Mataric, 2019), provide an example of the changing nature of the field and the need for nimbleness and openness to emerging conditions among HRI researchers. These dynamics introduce changes in to the communication design of social robots and to the formats and contexts in which they are introduced to our daily lives.

4.2 Intelligent Social Robots

Discussions of artificial intelligence and social robotics ultimately should start with the question whether social robots can be as (or even more) intelligent as their human partners, and also include the ethical question whether they should be as intelligent.[9] It can be assumed that human users expect a social robot to be more intelligent than other robots, simply because a social robot's objective is to interact socially with humans in different contexts (Bartneck et al., 2020; Gunkel, 2020; Zeller, 2005). This does demand, in a perfect condition, a certain range of agile reaction and flexibility, which in return means a robot needs to be able to process in real time its context and respond correctly to it. Breazeal, Dautenhahn and Kanda (2016) state the long-term objectives for social robots as being "competent and capable partners for people" (p. 1935), and provide concrete demands for future social robots:

> They will need to be able to communicate naturally with people using both verbal and nonverbal signals. They will need to engage us not only on a cognitive level, but on an emotional level as well in order to provide effective social and task-related support to people. They will need a wide range of social-cognitive skills and a theory of other minds to understand human behavior, and to be intuitively understood by people. (Breazeal, Dautenhahn, & Kanda, 2016, p. 1935)

The field of HRI comprises a multitude of studies and experiments that address intelligence in social robots, such as Coronado et al. (2018) who introduce modular

9 Providing a holistic introduction to the topic AI and robotics would go beyond this paper's objective as well as any page limitations. Further reading in the field can be found here: Brooks (1999); Bryson (2018); Murphy (2019); Dubber, Pasquale and Das (2020); Wachter, Mittelstadt and Floridi (2017); Torresen (2018).

programming tools for the development of intelligent behaviour in social robots. The more engineering-related articles in this field often address discrete problems, such as related to robot vision, movement, etc., and present algorithmic solutions accompanied by context-dependent experiments with often very small sample sizes (see, for example, Phillips et al., 2018; Rosen et al., 2020)[10]. Other studies look into how people perceive intelligent social robots (see, Onnasch & Roesler, 2020, for an overview) or provide solutions for specific use cases, such as Edwards et al.'s (2018) study on AI and robots for instructional environments or studies into security and privacy issues around intelligent robots (see, for example, Ramesh, 2017).

When discussing future perspectives, the question relies on whether we are aiming to develop intelligent social robots or socially intelligent robots. The latter relates to the objective for robots to "perceive the user's needs, feelings, and intentions, and adapt to users over a broad range of cognitive abilities" (Wiese, Metta, & Wykowska, 2017, p. 1663). This led to new research coming from neurosciences and psychology, where "behavioural and physiological neuroscience methods such as motion/eye tracking, electroencephalography (EEG), […]" (p. 1663) are used in HRI studies (see also Cangelosi, 2010; Chaminade & Cheng, 2009; Cross, Hortensius, & Wykowska, 2019; Jamone et al., 2016; Mergner & Tahboub, 2009; Reuten, van Dam, & Naber, 2018; Schindler, et al., 2017; Urgen et al., 2013; Wykowska, Chaminade, & Cheng, 2016). These studies tend to show differing results given that they are often bound to small sample sizes. However, they also represent a promising new direction, where additional methods and new interaction data could enrich our understanding of HRI, including different perspectives of communication (i.e. neurological and neurocognitive-psychological insights).

Regarding the question of a social intelligent robot, Gunkel summarizes:

> [O]ne of the persistent and seemingly irresolvable issues is trying to decide whether these social artifacts do in fact possess actual social intelligence, or whether the social robot is just cleverly designed device that simulates various interpersonal effects that we […] interpret as being social, even if the device is not. (Gunkel, 2020, p. 222)

10 The broad range of academic dissemination venues in the field of robotics and intelligence provide a huge amount of potential research paths and projects. See, for example, IEEE International Conference on Autonomous and Intelligent Systems (AIS), AIAA Intelligent Systems Technical Conference, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) or AAAI conference on artificial intelligence.

Similarly, in AI, simulated intelligence versus real intelligence (weak vs. strong AI) is also discussed. As already mentioned above, algorithms can either be rule-based or use machine learning. While the scientific field of AI started with both options, the first one, also called symbol-processing approach, dominated the field of AI and the development of robots for a long time (and is therefore now called GOFAI – Good Old -Fashioned AI, see Gunkel, 2020, Dautenhahn, 2007). Gunkel (2020) describes the two inherently different approaches by citing Dreyfus and Dreyfus:

> One faction saw computers as a system for manipulating mental symbols; the other, as a medium for modeling the brain. One sought to use computers to instantiate a formal representation of the world; the other, to simulate the interactions of neurons. One took problem solving as its paradigm of intelligence; the other, learning. One utilized logic; the other, statistics. One school was the heir to the rationalist, reductionist tradition in philosophy; the other, viewed itself as idealized, holistic neuroscience. (Dreyfus & Dreyfus, 1988, pp. 15-16; cited in Gunkel, 2020, p. 69).

Regarding social robots, either approach exists. However, relating back to the future needs of social robots' abilities depicted above, and also taking into account that there will be increased interaction with social robots in our daily lives (Bartneck et al., 2020; Müller, 2019), advances in machine learning approaches, and also artificial neural networks (ANN) appear to be promising. This particularly relates to the demand for social robots to communicate naturally with human users and to interact and move freely in our homes, etc. These features appear to call for a machine learning approach, given that "[i]n general, symbolic reasoning is more appropriate for problems that require abstract reasoning, while machine learning is better for situations that require sensory perception or extracting patterns from noisy data" (Kaplan, 2016: 36). Similar to human beings, the ANN approach is based on emergent intelligent behaviour rather than preprogrammed sets of intelligently appearing behaviours. In the ANN approach, artificial neurons are represented by the individual processors in a network, which do not possess any intelligence *per se*. Rather, the synaptic connections are represented by the messages the processors exchange ("real numbers"), and "[d]ata propagated through the network produce a pattern of activations in the interconnected artificial neurons that eventually result in some output" (Gunkel, 2020, pp. 72-73). Through 'learning', the network then is "progressively adjusting the weighted connections" in the network and the "system can be adjusted or 'tuned' to exhibit different kinds of output behavior" (Gunkel, 2020, p.

73). ANN approaches are also called deep learning and are currently widely discussed in both academia and news media, often lacking expertise and precision, at least in the latter domain. This calls, too, for more research in the field, also coming from communication researchers, critically addressing these approaches as well as their public perceptions (Zeller, Wolling, & Porten-Chee, 2010; Zeller, 2020).

Whereas machine learning approaches in general are said to be promising for future improvements in HRI, one has to note that with the beginnings of the scientific field of AI in the 1950s, it was predicted that within a decade we would have strong AI, that is intelligent artificial systems. However, as Bartneck et al. (2020) state, "half a century later, AI still struggles with understanding human sentences" (p. 206). And although the impression might be supported by means of news media reporting that deep learning and ANN are new developments, their origins also go back to the 1950s. Furthermore, when comparing studies in HRI regarding human acceptance and interaction preferences with social robots, there is a "lack of comparability and generalizability", which can be attributed to the "plethora of robotic appearances and interaction concepts" (Onnasch & Roesler, 2020). This, consequently, results in the need for even more data that must to be collected, annotated and processed to become training data for ML approaches. And referring back to the socio-economic impact discussion above, even though social robots are said to develop increased market share in the future (Müller, 2019), their market penetration is still relatively small compared to industrial robots. Thus, the question remains whether it would be profitable and whether funding agencies and industry have sufficient interest to invest the funds needed to support vast data projects in AI social robotics.

4.3 Disciplinary Trends

We have seen a recent increase in the number of publications in HRI coming from scholars in media and communication studies (see, for example, Fortunati, 2018; Fortunati, Esposito, & Lugano, 2015; Guzman, 2018a; Hasse & Søndergaard, 2020; Smith & Zeller, 2017, 2018; van der Woerdt & Haselager, 2019; Zeller, 2005; Zeller et al., 2019; Zhao, 2016). Whereas technology as a medium has been studied from the start in our field, robots *per se* have been more absent in the past. Moreover, the study of communication has traditionally been defined around human interaction. As Guzman (2018b) points out, "In textbooks, communication is presented within a primarily, if not exclusively, human context, with models, theories, and examples focused on people's interactions" (p. 2). The technologies discussed in this article, however, cannot be 'reduced' anymore to a medium only. Looking into the different kinds of AI-based algorithms that bring robots 'to life' shows that we are dealing with a technology in its own right, or rather an autonomous communication entity and partner to humans. Arguably, notwithstanding the actual 'intelligence' and autonomy level of any technology, in our popular media narratives (for example, Ichbiah, 2005; Murphy, 2018), and thus to a certain degree also in our preconceptions around social robots, we already tend to believe that they fulfill the roles of independent entities and (synthetic) beings. Consequently, the study of communication (messages) and effects in HRI needs to take this preconception into account, given that it influences our communication patterns and social interactions. This has been done to a certain degree and underscored by the aforementioned new studies and their reception in the communication research community. A common skeptical remark, however, is around the question whether HRI, or a field related to it, merits the disciplinary recognition as a sub-field in communication research.

One advantage of having a focused sub-field in, as Guzman (2018b) suggests, Human-Machine Communication, is that it would enable a more focused approach for the many different communication researchers and their diverse disciplinary and methodological approaches.

Second, it is important to note the paradigm shift regarding social robots and their back-end algorithms. They evolved from the role of a communication medium or facilitator to autonomous systems, and Guzman (2018b) states: "These technologies enable a qualitatively different type of interactivity than their predecessors. To use the machine is to communicate *with* it, and the "it" is more than a tool to use" (p. 12, italics in the original). Furthermore, "communication with these technologies is often personalized. These technologies do not just talk, they talk *with us*. They know *our* name, can distinguish *our* voice, and learn *our* preferences. They enter into *our* social world as active participants through their design and use" (Zhao, 2016, as cited in Guzman, 2018b, p. 12, italics in the original).

5 Main Areas for Communication Research and Research Questions

This paper discussed the connection between algorithms, social robots and communication, by emphasizing the important and persisting role communication plays in HRI and its application to the front-end and the back-end dimensions of social robots and algorithmic machines. This article also discussed multiple potential research areas for communication researchers who are interested in social robotics and algorithms. The following section lists some concrete areas for researchers in communication sciences, focusing on algorithms and social robots as well as social robots in general.

5.1 Algorithms, Social Robots and Communication

Communication researchers can enrich the HRI field by providing the necessary connection between the front-end interaction design and the back-end algorithms for successful human-robot communication. They can provide communication models and theories that will show the different contexts of communicative interaction, and translate the main parameters into an HRI design. With a high-level understanding of the back-end algorithmic and technological design, communication researchers will be able to actively consult with the wider HRI community to make pragmatic decisions as to what features are necessary in each context for communicative interaction. Additionally, communication researchers coming from the social sciences, thus having social interactions as one of their main research objectives, bring a broad set of theories, models and methods that can be adopted in HRI given the advanced nature of AI-based social robots, for example (see, for example, Gunkel, 2012; 2020; Pentzold & Bischof, 2019; Sandry, 2015; Suchman, 2007; Taipale & Fortunati, 2018; Zhao, 2016; Zeller, 2020).

5.2 Public Perceptions and Discourses of Social Robots

Content, framing, and discourse analyses are core instruments in communication research. Thus, a relevant research question is how media innovations such as social robots, AI, autonomous systems etc. are framed in public discourse (see, for example, Fritz, 2018; Šabanović, 2014; Wolbring, 2016; Wolling, Will, & Schumann, 2011; Zeller et al., 2019). These studies can provide important input for the design of robots and HRI insofar as they can point out the main topics or concerns that need to be addressed. The fact that social robots are now often mixed with autonomous systems and AI can lead to increased or heightened levels of concern when it comes to forming trust in social robots. The public discourses mentioned in the beginning of this article show that, when it comes to robots, a whole range of concerns has gained attention in recent years, including data privacy risks and surveillance through robots, the danger of being replaced by robots in the workplace, or ethical considerations (see Spence, Westerman, & Lin, 2018; Wolbring, 2016). Arguably, these points also underscore the need for communication researchers with expertise in knowledge translation and mobilization, and an important research question in these domains is 'How can institutions, companies, etc. best communicate about social robots, AI, algorithms, etc.?' For the future design of humans and robots working collaboratively, for example, and social robots entering our homes, it is important to understand the factors that promote both respect and acceptance among users. Moreover, it is also crucial to collect feedback from the public regarding needs, research interaction patterns, emotions, and preferences, and to also look into potential dysfunctional aspects in HRI (Taddicken & Reif, 2020). Knowledge translation and mobilization aims to engage the public and to enter a fair discourse between researchers, developers, politicians and end-users (Haidegger et al., 2013; Horowitz, 2016; Smith & Zeller, 2018; Wilkinson, Bultitude, & Dawson, 2011; Zeller & Smith, 2015). Communication researchers have the instruments and knowledge to mobilize these discourses and to analyze them.

Communication researchers are also equipped to provide a taxonomy or classification of concerns, helping to disentangle the multiple discourses around social robots, intelligent algorithms, autonomous systems and the threats coming from each of these topics. Not all social robots (probably only a small proportion) use machine-learning based algorithms and employ high-end AI techniques. Nevertheless, it is difficult to differentiate the different levels of algorithms and their potential 'harms' in public discourse and popular scientific communications. Communication researchers can use their wide repertoire of quantitative and qualitative instruments to provide an overview of the different voices, opinions and topics. Furthermore, they could also follow-up with the important question as to how the public or different groups receive such messages, and what impact they have.

5.3 Communication between Humans and Social Robots

Another important area of research is to analyze the conversations between humans and social robots. One of the most prominent approaches is the application of personality traits in HRI.[11] These studies attempt to discover (a) whether personality traits in humans have an influence on engagement with robots, and (b) which personality traits in robots have a positive impact on HRI. Santamaria and Nathan-Roberts (2017) provide an exhaustive overview of this specific approach and their finding is that studies rarely look at personality traits and their influence on the communication and interaction on both sides – humans and robots. Instead, they mostly focus on robots. Also, whereas most studies use the Big-Five Personality approach, the majority of these focus exclusively on extraversion and introversion (Santamaria & Nathan-Roberts, 2017).

It is an open question whether humans address and interact with robots the same way they would communicate and interact with humans. Overall, the problem is that there is a lack of consistency of study designs and thus results. This problem has been pointed out by several researchers. According to Dautenhahn (2007), social robots tend to come in a broad variety of designs and are used in a multitude of different contexts. Thus, it is difficult to achieve replicable approaches that will also allow researchers to arrive at more consistent and representative study results. However, there is an increasing number of publications and studies that look at the communication perspective in HRI. Brandstetter and Bartneck (2017) look at the question whether robots have the potential to influence our language use, since we are often willing to adapt to a robot's communication repertoire for the sake of a successful interaction. They found that "robots owned by highly connected people [people with more social attachment] have less effect on the dynamics of language than robots owned by less connected people [people with less social attachment]" (p. 275). The results are interesting given that most studies focusing on lexical entrainment[12] in HRI (see, for example, Beckner et al., 2015; Brandstetter et al., 2017; Iio et al., 2014, see also Tangiuchi et al., 2019) are restricted to small sample sizes

11 Whereas personality traits and the Big-Five are often criticised elsewhere, in HRI they appear to dominate, as found out in a meta-study by Santamaria and Nathan-Roberts (2017). See, for example, McColl et al., 2016, for studies that use different approaches, such as affect and emotions.

12 Lexical entrainment describes the tendency of a person to change their language usage to adapt the language usage of the robot.

and also often to bilateral interaction setups, i.e. one human and one robot. Brandstetter and Bartneck (2017), on the other hand, used simulations in order to expand the standard setup and include more humans and robots, adding the variable of group behavior influence. Thus, with the rise of studies that use and/or combine communication research, linguistic, and behavioral studies[13], we can enhance significantly the number of studies that answer to important standards in terms of reliability and validity. This will enable us to arrive at more holistic, potentially representative conclusions and insights in the field of HRI.

6 Conclusion

Communication research – and neighboring disciplines such as linguistics or behavioral studies – can be seen as carrying an essential role in the research and development of social robots and/or algorithmic machines. Using the two terms – social robots and algorithmic machines – in fact also reflects the dichotomy in HRI, which has long influenced its research aims, outlooks and approaches. 'Social robots' basically stands for the 'front-end', which the user sees and (thinks) they are interacting with. 'Algorithmic machine' stands for the 'back-end', which is the hardware and software and something the user usually does not get to see. However, with the increasing critical discussions about robotics, AI, and algorithms, which are also the concern of communication researchers, the need and desire to understand more about the 'back-end' has been kindled in the user. Arguably, it has been mostly humanities and social sciences researchers that have started to critically discuss ethical and moral, but also legal, economical, and societal aspects of robotics, AI, and deep learning algorithms in the recent years (see, for example, Dubber, Pasquale, & Das, 2020; Gunkel, 2012, 2018; Lin, Abney, & Bekey, 2011). It is probably also because of those discussions that research funding agencies are

13 I am mentioning linguistics and behavioral studies here, too, since communication research in HRI and HCI often tends to be multi-disciplinary (see also Guzman, 2018) and some of the examples mentioned also use approaches and concepts from linguistics and behavioral studies.

starting to demand more interdisciplinary research and create new programs, which feature terms like 'responsible AI' in their mandate[14].

Given the rapid increase of social robots in our daily lives – from service robots in stores or hotels to toy robots in our homes – communication research needs to expand the notion of 'social interaction' to algorithmic machines that act and are accepted as independent social actors in their own right. This does not negate the fact, of course, that there will always be robots, which will be perceived more like computers or other digital devices. Nevertheless, our communication and interaction sphere has changed and will be even more challenged in the near future, such as our notion of a unified public sphere that now appears fragmented in the context of social media, for example. Similar to the development of new sub-fields in communication research, such as computational communication sciences and computational social sciences to answer the new demands of social media research, it is also time for the institutional and educational introduction of human-machine communication or Human-Autonomous Systems-Interaction (HASI[15]). Institutional in the sense that important research venues such as international conferences and associations should include sections that recognize social robots and intelligent systems in their own right. Educational means that we need the introduction of theories and applied methods for/into algorithmic machines into the communication research syllabus.

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15 Terminology suggested by the author.

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