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How many facets does a "social robot" have? A review of scientific and popular definitions online

Mauro Sarrica
Department of Communication and Social Research,
Università degli Studi di Roma La Sapienza, Roma, Italy
Sonia Brondi
Department of Education Studies,
Università degli Studi di Bologna, Bologna, Italy, and
Leopoldina Fortunati
Department of Mathematics, Computer Science and Physics,
Università degli Studi di Udine, Udine, Italy

Abstract
Purpose – On the verge of what has been hailed as the next technological revolution, the purpose of this paper is to examine scientific and popular definitions of the social robot, reflecting on how expert and lay spheres of knowledge interact. Drawing on social representation's theory, this paper aims to elucidate how social robots are named and classified, and to examine the dynamics contributing to their definition.
Design/methodology/approach – Scientific and popular definitions of the social robot were investigated by conducting: a systematic review of relevant articles published from 2009 to 2015 in the International Journal of Social Robotics; an analysis of the definitions retrievable from the scientific literature using Google Scholar; and an assessment of the interest in the public sphere, and of the popular definitions retrievable online (by inputting "social robot" in Google Trends, and in Google).
Findings – Scientific definitions of the social robot adopt two strategies, one drawing on and merging previous definitions, the other proposing new, visionary, forward-looking definitions. Popular online definitions of social robot's attribute new emotional, linguistic and social capabilities to their physical body.
Research limitations/implications – The findings need to be confirmed by further research, given the limited size of the data sets considered, and the distortions in the data due to filters and the opacity of the online tools employed.
Originality/value – Both scientific and non-scientific definitions see social robots as being capable of interacting with and working for humans but attribute them a different degree of (functional or full) autonomy. In future, any controversy over the connotation of social robots is likely to concern their sociality and autonomy rather than their functionality.
Keywords Knowledge integration, Shared knowledge, Literature review, Text analysis
Paper type Literature review

Introduction
This paper aims to address how the social robot, a technological artefact at the intersection between technology and society, is defined.

Although robotics has been paying attention to the social qualities of robots ever since the end of the Second World War (Grey, 1950), social robotics is a fairly new field of study. School and university courses dedicated to social robotics have been activated and, in the last decade, research institutions focusing on social robotics have

transcended disciplinary boundaries, attracting the attention of broader sectors of academia, the media and society [1]. Research topics in this emerging field have included, among many others: attitudes to social robots, and public perceptions of them; human-robot (e.g. Thompson and Gillan, 2010), human-human interactions in the presence of robots (e.g. Höflich, 2013), and robot-robot (e.g. Bicchi, 2015) interactions; practices and behaviors in various contexts and domains (e.g. domestic, educational and healthcare services) (Taipale et al., 2015; Fortunati, 2018); usability of robots and assessment of their use (De Graaf and Allouch, 2013). Less attention has been paid to users' expectations when they come to interact with social robots (e.g., Smarr et al., 2014), or to activities promoted by stakeholders to connect people with this emerging techno-scientific innovation (e.g., Wilkinson et al., 2011; Fortunati, Cavallo and Sarrica, 2018). Even less has been done to shed light on the shared representations that form the cultural background, shaping expert knowledge as well as lay thinking and imagination regarding social robots.

This paper argues that we can gain a better idea of how they are perceived by taking a look at the scientific and popular definitions of "social robot" retrievable online and in the scientific literature. Lay definitions form part of the cultural milieu in which experts work, and consequently influence what those experts do. According to social scientists (e.g., Amaturo, 2012), scientific and popularized definitions of social robots, or of any other technological artefact, evolve alongside new scientific and technical developments. The more the concepts behind them are clear and shared by the scientific community, the easier it is to operationalize them and explain them to potential users. But such definitions are rarely, if ever, consensual and unequivocal. They are neither autonomous (being the object of continuous negotiations among social actors), nor linear (as they change with time to include and accommodate multiple meanings and perspectives).

The micro-genesis of definitions demands implicit knowledge and social representations that enable fluent communications between members of groups with a common theoretical and professional background (Flick et al., 2002). As Bourdieu (1977) stresses, definitions are intrinsically interwoven with historicity and praxis.

In the present contribution, we first reflect on the encounter between scientific and popular understanding of social robots, looking specifically at the definitions circulating online, and comparing them with those proposed in a major scientific publication specializing in the field. Then, taking the social representations perspective, we argue that – especially in the case of new artefacts like social robots – the relationship between scientific and popular definitions is mutually interdependent, since these definitions express ongoing semiotic processes (Veltri, 2015), and their historical and cultural "situatedness."

In the following sections, we briefly introduce the theoretical background for the present study and previous research on the scientist's and the layperson's understanding of what a robot is. Then we outline the specific goals of this study and conduct a systematic review of the explicit definitions retrievable: in the International Journal of Social Robotics, from its first issue in 2009 to the last issue of 2015; and online, using the Google Scholar, Google Trends and Google search engines. On the strength of this review, the discussion focuses on the characteristics of social robots – as described in the literature and translated in online media – and we point out the potential implications of the processes of social construction in the field of social robotics.

Social representation processes

From a psycho-social perspective, social robots have been largely studied in terms of the variables influencing people's perception and acceptance of them, and behavior toward them (e.g., Meister, 2014). At individual level, they have been treated as stimuli, and researchers have investigated the effects of individual and situational factors such as the perceived human likeness of a robot (e.g., Halpern and Katz, 2014), or the physical distance between robots and humans (e.g., Kim and Mutlu, 2014). At societal level, the attitudes of aggregates of respondents have been explored (e.g., Eurobarometer 382, 2012;
Eurobarometer 427, 2015). While these studies are important, sociological and cultural studies have amply shown that the process of innovation is neither techno-deterministic nor socio-deterministic. Faced with new technological artefacts, individuals, groups and societies actively engage in processes aimed at understanding, domesticating and constructing technology (e.g., Geels, 2010; MacKenzie, 1998; Silverstone, 2006).

In this study, we refer to social representations theory (SRT) (Moscovici, 1981) as an overarching framework in examining the specific role of definitions in the social construction of social robots. According to Moscovici, social representations are "systems of values, ideas and practices, which have a twofold function. First, they aim to define an order to shape the material and social world and control it; second, they aim to make it possible to communicate among the members of a social group or community by supplying them with a code for naming and classifying the various aspects of their world and their narrativity" (Moscovici, 1973, p. XIII, our italics).

SRT has been widely used to go beyond the "impact" or "acceptance" frameworks in the study of relationships between society and technology (e.g., Brondi and Neresini, 2018). According to Moscovici's theory, in order to understand how novelties are accepted, ignored or refused, we need to understand the communication systems in which individuals and groups position themselves. In other words, individual encounters with social robots do not occur in a cultural vacuum but should be conceived as a part of communication games that are neither neutral nor disconnected from power dynamics. When something new and unfamiliar – like the social robot – enters the life of a social group, its members engage in communication and a collective elaboration in an effort to attribute meanings to the novelty; this is known as symbolic coping (Wagner et al., 1999). Objectification lends shape to the new element by decontextualizing and selecting information, transforming it into schemas and images (i.e. the figurative nucleus) and naturalizing it. Once anchored by means of naming and classifying processes, the new object is integrated in pre-existing cognitive systems, linked with already-established content, and converted into something that can be communicated. Naming and classifying are crucial to the positioning of an object in the semantic field, and its concomitant inclusion in a hierarchy of references and values (De Rosa, 2013).

Veltri (2015) recently suggested that this socio-constructivist dynamic, which establishes denotative and connotative meanings of a social object, can be conceived as "the outcome of the processes of recursive social semiosis within and between social groups in the public sphere" (p. 243). This approach stresses the group dynamics at the base of meaning-making processes and gives a special role to scientific definitions, and to experts who act as initiators in the communication game. As Veltri (2015) emphasized: "The role of naming, although in theory available to everyone, is in fact restricted to certain groups within society. Scientists represent a powerful group that is

able to introduce new descriptions of reality; they forge denotations from their perceived epistemic position as knowledge-seekers" (p. 244). These definitions are then associated with connotative meanings, in "the act of interpretation of new social objects that includes contextual knowledge, values and attitudes" (p. 246). The denotative and connotative meanings of an object of representation are established through recursive processes that entail intragroup (between experts) and inter-group (between experts and the public) conflict. The resulting representation is only temporarily stable and not necessarily accurate or scientifically correct. "That is, whether an image is accepted or not by a group is neither a problem of truth nor an arbitrary choice but determined by the group's experiential world and the negotiated consensus of the group members" (Wagner et al., 1999, p. 100).

Social robots across multiple layers of meaning

Multiple layers are currently involved when we decide what a social robot is (its denotative meaning), and how it should be considered (its connotative meaning).

In the scientific world, describing robots as "social" triggered a shift from a unitary idea of purpose-built machines to more articulated conceptions (Fortunati, Esposito, Sarrica and Ferrin, 2015). Experts joining in the debate tend to deconstruct them, describing them as: "intelligent agents, automated personal assistants, future smart environments, ambient assistive living technologies, computational intelligent games/storytelling devices, embodied conversational avatars, and automatic health-care and education services" (Fortunati, Esposito and Lugano, 2015, p. 626). In this vein, for example, Vincent (2013) saw the social robot as a personalized device comprising a given individual and his/her mobile phone, while Sugiyama (2013) launched the definition of the mobile phone as a "quasi-robot."

The tension between the scientific worlds and the layperson's understanding of social robots emerges clearly in university students, especially those enrolling for technological courses: as they become more familiar with an implicit knowledge shared by professionals (Flick et al., 2002), their assumptions about what is impossible, possible, and probable (Bourdieu, 1977) change. A study by Fortunati, Sarrica, Ferrin, Brondi and Honsell (2018) showed that young people are fascinated by the new opportunity's robotics can generate, but also increasingly aware of its limitations, especially when it comes to the creativity, emotions, talent and capacity to take part in social rituals, which are considered inherently human.

Among lay users, this tendency for deconstruction seen in the scientific literature is translated into a multiplicity of robotic agents recognized as such (e.g., drones, humanoids, swarms, robots used in cleaning, manufacturing, emergencies and space exploration). These agents seem to combine the classical idea of the industrial robot used to perform unpleasant, tedious or dangerous tasks with a concept of automata inherited from the past, and from the literature. As visual media and transmedia studies have shown, transmedia products currently play a prevalent part in shaping lay users' knowledge and imaginings about social robots (Vincent et al., 2015; Fortunati, Cavallo and Sarrica, 2018). Here again, however, research reveals a tension between the imagery in the media and the pragmatic experience of actual interactions with robots today, which is perceived as poor and disappointing (Enz et al., 2011; Stafford et al., 2014).

The tension between scientific denotations, transmedia connotations and current practices is also evident for the younger generations being socialized into the world of this new technology. Far from being passive recipients, children reinterpret transmedia

products and provide an already nuanced understanding of what a robot is. Recent studies show that children consistently recognize robots as mechanical devices capable of moving more than toys but lacking in fully human bodily and cognitive characteristics (Fortunati et al., 2015). Children conceptualize social robots as advanced technical devices characterized by anthropomorphic shapes and bodies, like Transformers and the Terminator, but only partly equipped with human-like cognitions, feelings and behaviors, like Futurama and Wall-e (Fortunati, Esposito, Sarrica and Ferrin, 2015). It is therefore hardly surprising that children are convinced, for instance, that robots cannot really keep you company.

Aims

In this study our aims were:

- to review and compare scientific and popular definitions of social robots in order to take stock of how scholars and lay people name and classify social robots, identify intra-group and intergroup dynamics and conflicts, and clarify the recursive social semiosis that may lead to some representations prevailing over others; and

- to investigate whether the translation from expert to lay knowledge layers reveals processes of decontextualization and selection of the information that twist the original definitions, and whether popular definitions introduce elements that deserve to be retained in the scientific domain too.

Method

Scientific and popular definitions of the social robot were identified from a systematic review of articles published in the International Journal of Social Robotics, by searching the scientific literature with the Google Scholar search engine, and by seeking popular definitions of this construct retrievable online.

The definitions adopted in articles published in the specialist journal were systematically reviewed to shed light on the social semiosis within the specific scientific field. The journal in question aims to attract contributions to the scientific debate on this specific topic, and to provide readers with a comprehensive overview of the current state of the art of the emerging industry of social robotics. Our search for the string "social robot" in the full text of the whole corpus of 312 articles published by the journal from 2009 to 2015 led us to identify 143 articles. After reading all the retrieved papers, the articles were further classified by the authors as: "highly pertinent" ¼ articles that explicitly defined social robots (no. 33); "moderately pertinent" ¼ articles that referred to social robots, but only provided a few explanations or little information (no. 32); or "scarcely pertinent" ¼ articles that employed the term "social robot," without adding any definitions, explanations, or information (no. 78). The definitions provided in the highly pertinent articles were then submitted to a thorough content analysis to identify the main denotative and connotative characteristics attributed to the social robots by the authors. Sources mentioned by the authors of the other less pertinent articles (i.e., classified as moderately and scarcely pertinent) were explored to identify the prevailing scientific origins, and any intersection with popular online definitions.

The string "social robot" was keyed into Google Scholar and produced about 7,500 results (data retrieved on April 10, 2018). Google Scholar is a free search engine for scientific works that indexes full-text scholarly literature across many disciplines and databases. It retrieves "journal and conference papers, theses and dissertations,

academic books, pre-prints, abstracts, technical reports, and other scholarly literature from all broad areas of research" (Google Scholar, 2018). Its search results are ranked by relevance and number of citations, and can be rearranged by year of publication, albeit with some limits. The use of Google Scholar as a standalone source for conducting scientific literature reviews is a matter of debate. On the one hand, researchers criticize its use for systematic reviews due to: variability in the retrieval of content as a result of Google algorithms being updated; search filters, which are linked to an individual's search history and location; and the current limitation to the first 1,000 records, which also limits the percentages of the search results. On the other hand, Google Scholar shows good coverage of the literature, including proceedings, reports and books not included in other databases, making it a good resource when searching for gray literature (Atkinson and Cipriani, 2018; Bramer et al., 2016; Haddaway et al., 2015). It was these latter advantages, in particular, that prompted us to use Google Scholar to explore the attention paid to social robots, and the emergence and dynamics of definitions in vogue across different scientific domains. To identify potentially influential definitions (in terms of their acknowledgment and retrievability), an "influence" indicator was created for the first 100 results (i.e. the first ten Google Scholar pages) by weighting the total number of citations obtained by each result by a coefficient of visibility related to the page on which it appeared (e.g. number of citations obtained by the result "×" multiplied by 1 if it appeared on the first page, by 0.9 if it appeared on the second, by 0.8 if it appeared on the third, and so on). Then the analysis focused on the 23 results with an influence indicator higher than 50.

To extract data concerning the consumption and production of denotative and connotative meanings associated with social robots in the broader social arena, our review looked at the definitions of "social robot" retrievable on the web. Internet can be considered nowadays as the most vital place for investigating popular understanding of scientific issues, especially Scientific and popular definitions online Downloaded by 37.117.175.78 At 05:39 12 April 2019 (PT) when it is used to obtain further information about a subject that is already familiar (Eurobarometer, 2008), or of particular interest to a given audience (Bucchi, 2016). Despite differences in access and digital literacy, internet content is produced and used by billions of people all over the world. It makes multiple fields of signification and practice more open and fosters the dynamics of transformation envisaged by social representation theory (De Rosa, 2013; Jovchelovitch and Priego-Hernandez, 2015).

Our review sought the definitions of interest using Google tools. The string "social robot" was entered in Google Trends to get an idea of how much "social robots" attract attention in the online public sphere. The search interest index provided by Google Trends is a standardized value obtained from the (no. of queries concerning a keyword)/(total Google search queries). Given the variability of the database searched by Google, language issues, and the filters imposed by its ever-changing algorithms, caution is needed in considering the resulting trend if our interest lies in the absolute volume of searches. On the other hand, this index can be seen as a proxy of collective attention toward a given topic (e.g., Curme et al., 2014).

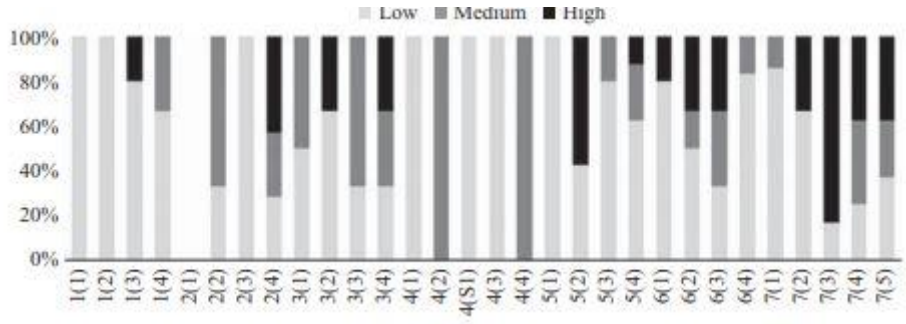
A general Google web search was also run to examine definitions accessible online. This analysis was limited to the first 50 results (i.e., the first five Google pages) because, from the fifth Google page onwards, most of the webpages listed were either irrelevant (e.g., blogs or shops named "social robot," but not devoted to this technology), or concerned scholarly works (and thus the object of our previous analysis). This approach is also consistent with the findings of several seminal studies

in the sphere of computer science addressing users' habits during web searches (e.g., Höchstötter and Lewandowski, 2009; Pan et al., 2007; Rose and Levinson, 2004): overall, they indicate that the vast majority of internet users do not go beyond the first page of results, while a few go past the third page. Finally, the anonymous browsing mode was used to avoid obtaining profiled results.

6. Results

6.1 Definitions of the social robot in the International Journal of Social Robotics Judging from our analysis of the 143 papers containing the string "social robot," the articles that used this label and actually defined what the authors meant by it are unevenly distributed and have increased proportionally among the highly pertinent contributions in recent issues (Figure 1).

Figure 1. Trend of the papers that mention the notion of "social robot"
Notes: The x axis indicates volumes and number of the issues between parentheses; the y axis indicates the percentage of papers we classified as high centrality (which provide explicit definitions), medium centrality (which provide details and or information) and low centrality (which just mention the notion)



6.1.1 References cited from scarcely and moderately pertinent articles.
The reference cited from the 110 articles in question come from scientific journals (60), and conference proceedings (50), while book chapters (15), books (3) and PhD theses (2) are less often cited. The International Journal of Social Robotics is by far the most widely cited scientific source (20). Other journals cited more than once are Robotics and Autonomous Systems (4); IEEE Transactions on Systems, Man, and Cybernetics (3); Interaction Studies (3); Autonomous Robots (2); the International Journal of Advanced Robotic Systems (2); and the International Journal of Humanoid Robotics (2).

Overall, there is a wide variety of references (130), and the theoretical background seems to be rather patchy. Some works are cited more than others, as listed below by their frequency of citation:

- Duffy (2003);
- Broekens et al. (2009);
- Saldien et al. (2010);
- Fong et al. (2003);
- Leite et al. (2013);
- Li and Chignell (2011);
- Pacchierotti et al. (2006);
- Breazeal (2002);

- Breazeal et al. (2008);
- Satake et al. (2009); and
- Shaw-Garlock (2009).

We will see that these sources point to influential definitions that can be retrieved from the web, but no clearly preferred epistemic source seems to emerge.

6.1.2 Definitions provided in highly pertinent articles. These articles were submitted to a more in-depth analysis to classify the contents of authors' definitions of the social robot (Table I).

Only a few of the authors of these papers merely adopt a definition, while the majority acknowledge and discuss the lack of a generally accepted and accurate definition, and the difficulty of defining a social robot.

Some authors combine two or more definitions to stress specific details of the construct. For example, Welch et al. (2010) merge the widely acknowledged definitions given by Duffy (2003) and Fong et al. (2003):

> In general, a social robot is an autonomous agent that can act in a socially appropriate manner based on its role in an interaction [16, 21] (Duffy, 2003; Fong *et* al., 2003)" (392).

Sandry (2015) and Li and Chignell (2011) combine those suggested by Breazeal (2002, 2003) and Fong *et* al. (2003):

> Robots capable of engaging in meaningful social interactions with people (e.g. [1, 2] (Breazeal, 2003; Fong *et* al., 2003)). This new breed of robots is called "socially interactive robots" or "social robots" [1] (Breazeal, 2003). (Li and Chignell, 2011, p. 125)

Other authors combine two or more definitions to produce a more comprehensive definition. The Preface to the Special Issue edited by Li et al. (2011) begins with a definition that is also given on the webpage of the *International Journal of Social Robotics* (IJSR), and that lists five requirements:

> Social robots are autonomous robots that are able to interact and communicate among themselves, with humans, and with the environment and are designed to operate according to the established social and cultural norms. The main requirement for such robots is intelligence, which forms the basis of human robot interaction. Many design requirements should be considered for social robots. Among these are the abilities to: 1. recognize the presence of a human through its senses such as vision, touch and sound; 2. engage in physical acknowledgment such as holding or touching; 3. use physical motions and gestures; 4. express and/or perceive emotions and 5. engage in a conversation (333)

Table 1. Summar of the main dimensions underlying the definitions of social robot

	Typology			Attributes		Interaction with			Context		Main functions			
	Machines	Application	Autonomous agents	Physical	Cognitive functions	Social and communicative	Other	Environment	Humans	Other robots	Immediate	Society/ Culture	Task execution	Assisting humans	Problem solving	Social interaction
Duffy	*		*	*				*			*	*	*			
Deutenhahn	*		*		*	*			*	*	*	*				*
Breazeal			*		*	*		*	*		*		*			*
Bartneck			*			*		*	*		*					*
Hegel	*	*				*			*							*
JSR						*			*	*						
Welch			*			*		*	*							
Li and Chignell						*			*							*
Sandry	*					*			*	*						*
Li *et al.*			*			*		*	*	*			*			*
Yan *et al*	*					*		*	*				*			
Frennert									*							*
Wolfbring	*								*	*				*		
Barile and Sugiyama	*	*					*									
Shaw-Garlock							*								*	
Sabanovic																
Castro-Gonzalez			*						*					*		

After a brief overview of the most accepted definitions in the literature, Yan et al. (2014), conclude that:

A social robot is a robot which can execute designated tasks, and the necessary condition turning a robot into a social robot is the ability to interact with humans by adhering to certain social cues and rules (85).

Frennert and Östlund (2014) take an opposite stance to earlier definitions in the literature:

Currently, definitions of social robots do not acknowledge that they are culturally embedded and that variants of cultural traditions will come into play in the HRI relationship [8, 29] (Turkle, 2011; Suchman, 2006). […] the definitions have a deterministic view of robots, in which the user has the passive role and sociality is seen as a characteristic of the robot. From an STS [Science and Technology Studies] perspective, definitions are not neutral by nature but come with inherent values [24] (Hackett et al., 2008). […] As such, social robots are not viewed as neutral or as tools of human purpose but as meditating artefacts between humans-and-humans and humans-and-nonhumans [8, 29] (Turkle, 2011; Suchman, 2006). From this point of view, the characteristics of the HRI will depend on the context in which the robot operates (300-1).

Then there is the exemplary definition by Wolbring and Yumakulov (2014), who pool several contributions into a comprehensive definition that is added to those suggested by Shaw-Garlock (2011), and by Fong et al. (2003):

Social robots are complex machines that are envisioned to engage in meaningful social interaction with humans and with each other [1-15] (Sekiyama and Fukuda, 1999; Giron-Sierra et al., 2000; Dautenhahn, 2002; Fong et al., 2003; Duffy, 2003; Dautenhahn, 2002; Tapus et al., 2007; Heylen et al., 2012; Leite et al., 2011; Yumakulov et al., 2012; Angulo et al., 2012; Mordoch et al., 2013; Louie et al., 2012; Flandorfer, 2012; Shaw-Garlock, 2011) […] Social robots are technologies designed to engage with humans on an emotional level through play, sometimes therapeutic play, and perhaps even companionship" [15] (Shaw-Garlock, 2011) (462).

Some authors provide alternative definitions of social robots, not directly linked with any of those above. In particular, after quoting Breazeal's definition (2002) in the opening section of her paper, Shaw-Garlock (2009) concludes her reflection with a new, future-oriented, definition:

In short, social robots of the twenty-first century are creatures which merge disparate elements of the biological and technological into an image that is situated at the outer boundary of human and nonhuman interface. They are at once provocative expressions of the height of human, scientific, and technological prowess as well as complex sites that demand reconceptualised ontological categories, stories, and language (257).

The definition proposed by Šabanović (2010) a year later is also explicitly future-oriented:

In these future-oriented discussions, social robots often represent "technological fixes" [39] (Volti, 2006) – applications of technology meant to solve social problems that are non-technical in nature – for a variety of pressing issues in contemporary society (439).

Then, Castro-González et al. (2011) suggest a definition largely focusing on the skills that social robots should possess:

Social robots are intended for interacting with humans and assisting them in several tasks. It is desired that such tasks are accomplished by them without surveillance and this idea implies a certain level of autonomy (427).

On the whole, social robots are described as autonomous agents, complex machines or technological applications. The fundamental feature of social robots as autonomous systems thus remains crucial, though their degree of autonomy is never discussed or problematized (Beer et al., 2014). Details relating to the physical embodiment and humanlike characteristics (e.g., communication, sensation, responsiveness) of social robots are little emphasized, but they are apparently required to act, interact, and be socially intelligent in a humanlike way. This means that social robots have to be capable of appropriately engaging in social interactions by adhering to specific contextual cues.

A strong functional component emerges too. The definitions emerging from our review underscore that social robots have to perform tasks, solve social problems, and assist humans. They therefore have to be defined and designed according to the particular functions they are expected to serve. What makes an "ordinary" robot "social" lies in the fact that it meets one or more, specific and contextual social needs.

6.2 Scientific definitions retrievable online

The first result for "social robot" on Google Scholar dates back to 1908. As expected, however, there has been a constant and sizable increase in the number of times it has been mentioned since the late 1990s (Figure 2). The most influential definition – echoing the picture seen for the previously mentioned scarcely and moderately pertinent scientific articles – is Duffy's (2003), which received 485 citations and appeared on the first Google page. In his paper of 2003 (cf. also Duffy, 2004, 2008; Duffy et al., 2002), Duffy quotes from his PhD thesis (Duffy, 2000), and from a previous co-authored work (Duffy et al., 1999) (53 citations, second Google page), defining a social robot as:

> A physical entity embodied in a complex, dynamic, and social environment sufficiently empowered to behave in a manner conducive to its own goals and those of its community (177-8).

A widely acknowledged contribution comes from Breazeal and Scassellati (1999) (397 citations, first Google page), who used "social robot" in the title of their paper but did not define it properly. In subsequent years, Breazeal devoted several reflections to this topic, stressing the role of sociality and "anthropomorphization" as fundamental characteristics of a social robot (e.g., Breazeal, 2004, p. 297 citations, fifth Google page; cf. also Breazeal, 2002).

Following Breazeal's lead (2003), Lee et al. (2006a) (162 citations, first Google page) said of social robots that:

> They can autonomously interact with humans in a socially meaningful way (754).

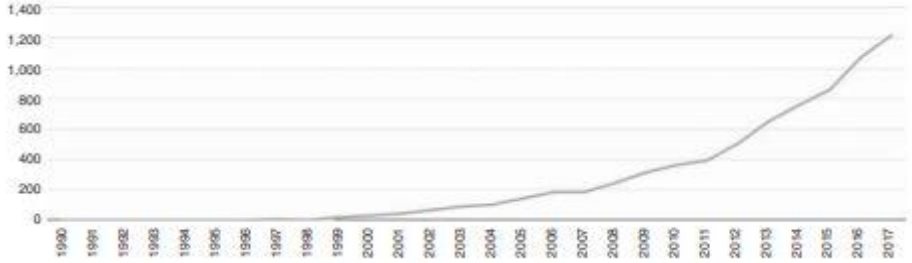


Figure 2. Trend for the results of the term "social robot" in Google Scholar

Notes: The x axis indicates the years considered; the y axis indicates the number of results. Please note that the points represent the absolute volume of results

In another paper of the same year, Lee et al. (2006b) (121 citations, first Google page) better explained that:

> Social robots are a new type of robot whose major purpose is to interact with humans in socially meaningful ways […] In other words, social robots are designed to evoke meaningful social interaction with their users. For example, David, in the movie "A.I." directed by Steven Spielberg, is a social robot whose main purpose is to share emotional bonding (especially the feeling of love) with human beings. In reality we have not seen such a sophisticated social robot as David. Nevertheless, the movie successfully informs the public of the possibility that social robots could be as successful social actors as human beings (962).

Another influential definition of social robot was advanced by Bartneck and Forlizzi (2004) (161 citations, first Google page):

> A social robot is an autonomous or semi-autonomous robot that interacts and communicates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact (592).

This definition was also recalled by Salichs et al. (2006) (85 citations, first Google page), who added:

> A social robot has attitudes or behaviors that take the interests, intentions or needs of the humans into account (2).

Alongside the most influential definitions, there are contributions that review the definitions to be found in the literature. Fong et al. (2003) mentioned features of social interaction, capabilities and abilities, including communication and the perception/expression of emotions (cf. also Billard and Dautenhahn, 1997; Dautenhahn, 1994, 1995, 1998, 2002), and quoted another definition proposed by Dautenhahn and Billard (1999):

> 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.

Hegel et al. (2009) published an updated review of the most acknowledged definitions of social robot (i.e., those suggested by Duffy, Fong et al., Breazeal, and Bartneck and Forlizzi), and proposed their own definition:

> A social robot is a robot plus a social interface. A social interface is a metaphor which includes all social attributes by which an observer judges the robot as a social interaction partner (174).

Despite their heterogeneity, the definitions extracted from the scientific literature have some features in common. Overall, social robots are described as autonomous or semiautonomous physical bodies that generally possess human or animal-like qualities. In particular, these embodied agents perceive and respond to environmental cues, engage in social interactions, communicate, cooperate, learn, make decisions and

perform actions. All these abilities become "social" inasmuch as they are enacted by robots and evaluated by humans according to the community's goals and social norms.

6.3 Popular definitions of social robot online

Google Trends showed a discontinuous but growing interest in this topic (Figure 3). Looking at the data available from January 2004 to March 2018, it was a regular feature of searches worldwide, with a frequency peaking in July 2013 and a generally rising trend as of January 2012 (data retrieved on April 10, 2018).

Keying the string "social robot" in Google produced about 145,000 results (as at April 10, 2018). The most relevant links in the pages considered included: websites that provided Scientific and popular definitions online definitions of social robots (e.g. encyclopedias, dictionaries, glossaries) (accounting for about 10 percent of the results considered); websites of research groups, laboratories or projects aimed at developing social robots (about 20 percent); websites about robotic products (about 20 percent); and links to newspaper articles, popular magazines, and blogs (about 50 percent altogether) addressing such technological innovation. In these last 50 percent of cases, the focus was always on the artefacts and/or on scientific research, but no definitions of the social robot were ever provided. Any definitions were therefore provided mainly by online encyclopedias and dictionaries. Wikipedia was the first website retrieved, and provided the following definition:

A social robot is an autonomous robot that interacts and communicates with humans or other autonomous physical agents by following social behaviors and rules attached to its role. This definition suggests that a social robot must have a physical embodiment […] (cf. https://en.wikipedia.org/wiki/Social robot retrieved on April 10, 2018).

Other definitions from generic and technological glossaries were:

A type of robot that has a body, can sense its environment and respond to it, has some understanding of social beings (cf. Dictionary.com http://dictionary.reference.com/browse/socialrobot retrieved on April 10, 2018).

An AI (artificial intelligence) system, such as an android, that is designed to interact with humans and possibly also with other robots. A social robot may be remotely controlled […] Other social robots are autonomous systems with local AI that allows them to interact independently in response to cues from people and things in their environment […] (cf. WhatIs.com http://whatis.techtarget.com/definition/social-robot retrieved on April 10, 2018).
An autonomous robot that interacts and communicates with humans by following the social rules attached to its role. This definition implies that a social robot has a physical embodiment (cf. IGIGlobal.com www.igi-global.com/dictionary/social-robot/27481 retrieved on April 10, 2018).

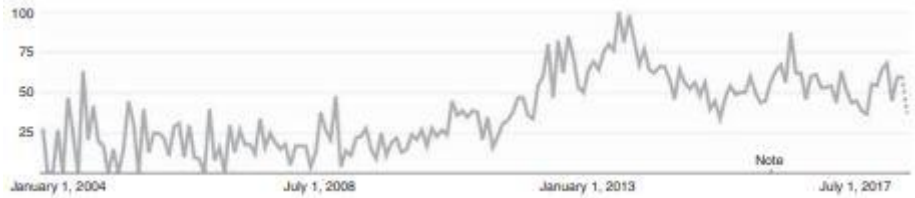
Though they differ in other respects, the popular definitions available online tend to emphasize certain main features. In a nutshell, a social robot should:

(1) be an autonomous system;
(2) have a physical body;
(3) sense and respond to environmental cues;
(4) interact with humans (or other robots); and
(5) understand and follow social rules.

The first two characteristics are less problematized in the popular online references

than in the scientific literature, whereas the three latter features are in common between scientific and lay definitions.

Figure 3. Trend for the web searches of the string "social robot" in Google



Notes: The x axis indicates years; the y axis indicates the number of web searches. Please note that the points represent the search interest relative to the highest points on the chart and do not convey the absolute search volume.

7. Discussion

This study examined scientific and popular definitions of the social robot, a construct that some say will characterize the next technological revolution and is destined to become part of the layperson's daily practices (Fortunati, Esposito and Lugano, 2015).

In the scientific sphere, our analysis of articles published in the International Journal of Social Robotics and retrievable from Google Scholar shows an increasing number of articles about social robots since the late 1990s. The most often cited definitions seem to be those emerging in the late 90 s and just after the turn of the century (e.g., Duffy, Brezeal, Lee). Our in-depth analysis of the contributions in this specialist journal showed that: some articles just spoke of "social robots" without clarifying the concept, while others adopted the above-mentioned definitions, sometimes drawing on other scientific sources too; and, since 2014–2015, greater attention has been paid to producing new and more explicit definitions of what makes a robot "social." Taken together, these findings suggest two different strategies at work in the scientific sphere. The first strategy consists in devising new definitions (and theories perhaps) by retrieving and merging various definitions already available in the scientific domain. The strength of these new definitions stems mainly from their combining different conceptualization processes. The second strategy involves developing visionary, forward-looking definitions. Finding it impossible to produce genuinely new definitions for the present, some scholars move on to what a social robot should be or will be in the future. While the first strategy strives toward a consensus within the scientific community regarding what social robots are (e.g. "complex machines"), the second embeds connotative meanings, implicitly expressing values and attitudes, by envisaging "a society of robots or humans" based on the "intelligence" of the new artefacts, for instance. This second strategy clearly distinguishes social robots from other machines by anchoring their novel element to the psycho-social domain, using terms such as "intelligence," "partner," "provocative," "biological," "empowerment" and "society."

Together with the explicit content of the definitions examined, a number of implicit relationships emerge with other scientific fields, especially as regards the capacity for interaction attributed to social robots. This resonates with studies in the two adjacent domains of social software systems and psychology. The former stresses that "sociality cannot be designed; it can only be designed for" (Bouman et al., 2007, p. 2). In this sense, "the term 'social robotics' envisions a 'natural' interaction of such

devices with humans, where 'natural' is interpreted as the ability of such agents to enter the social and communicative space ordinarily occupied by living creatures" (Esposito et al., 2014, p. 624; Fortunati et al., 2013). The capacity for interaction attributed to social robots also resonate with current psychological theories on sociality. According to Tomasello (2014), what distinguishes the way humans think from that of other animal species is that only humans can adopt different, and even conflicting perspectives: "This perspectival ability results from individuals' attempts to coordinate with others during collaborative and communicative interactions (given cognitive processes of shared intentionality)" (p. 192).

Here again, albeit only implicitly, scientific definitions of social robots point to the core element of humans' unique forms of cooperative communication, and ability to assess their own thinking in relation to the standards of "others" (what is known as social self-monitoring). Further research is definitely needed to investigate to what extent scholars (explicitly or implicitly) believe that being humanlike is what makes a social robot "social."

Moving from the scientific to the public sphere, a first finding of our analysis concerns the growing interest of the general public in social robots in recent years. The term "social robot" seems to have gradually entered the public discourse. This popular interest in the construct has not grown in parallel with the expanding scientific debate, however. Google Trends shows a relative peak of interest in 2013, which can hardly be interpreted as reflecting what was happening in the scientific sphere. Clearly, "there are other actors competing in this domain, such as critical scientists, politicians, the media and NGOs" (Veltri, 2015, p. 244) that affect public interest toward the issue (cf. Fortunati, Esposito, Sarrica and Ferrin, 2015; Fortunati, Cavallo and Sarrica, 2018; Taipale et al., 2015; Vincent et al., 2015).

As for their content, we found more precise definitions of social robots in the scientific literature than in the popular online sources, especially regarding the abilities expected of a social robot, and their specific purposes in everyday life situations. The scientific definitions also problematize the notion of (partial or full?) autonomy and the materiality of social robots more than the popular definitions.

Our analysis showed that scientific and popular definitions of social robots have several features in common, however, confirming that the micro-genesis of definitions tends to combine expert and lay knowledge (Flick et al., 2002; Šabanović, 2010). This shared representation of social robots concerns their autonomy, their capacity to interact with humans (through language and the expression and comprehension of emotions), and their ability to work for humans. In short, in both scientific and popular definitions, social robots are conceived not as mere executors, but as agents with a degree of autonomy that depends on their material features and computational processes. That said, popular online definitions tend to frame social robots as fully autonomous agents, while the scientific literature underscores the fact that they are purpose-built artefacts, entities that execute specific tasks and are only functionally autonomous. This is a very important issue because for robots to be fully autonomous would have important implications for their connotative meanings: if robots were fully autonomous, they could limit human freedom and decision-making. This difference suggests that a decontextualization and selection of information could lead to the introduction of negative connotations, and potential conflicts between the public sphere and the scientific world.

A second element common to the scientific and popular definitions of social robots concerns their bodily materiality, which enables them to co-work and co-alter the world

at the material level. Again, this denotative element can be interpreted in a potentially conflicting way. Disembodied robots can work for and assist humans too. By contrast, a sizable part of the debate in the mass media has focused on the risks of Industry 4.0 robots replacing humans at work and creating unemployment.

A third key element shared by scientific and popular definitions has to do with social interaction. Social robots should ideally engage in social interactions. In other words, they are considered as part of society, "a society of robots and humans" (Dautenhahn and Billard, 1999, p. 366). They should interact with humans, with other robots, and with the environment (Bicchi, 2015). A good example comes from the introduction of a robot in a small community in Tuscany (Italy), which led to new community practices (relational changes), the need to establish new traffic laws, e.g., who has right of way (ideal artefacts), and new road signs (material artefacts) (Bevilacqua et al., 2015). On the one hand, placing the emphasis on social interaction helps to exclude a number of exchanges between humans and robots in which the relational aspect is null, as in scripted behaviors (Schank and Abelson, 1975). On the other hand, however, further research is needed to explore whether and how this facet of the definition of a social robot will be accepted and translated into the popular knowledge domain. As already noted, this could be a strongly disputed point in connotation processes because it will affect institutional, social and personal domains of life (Taipale et al., 2015). As Höflich (2013) emphasized, we need to consider how individuals change within human-robot interactions, and also how this changes their human-human interactions in the presence of robots (or in group-robot interactions). While the scientific definitions of social robot take into account both the immediate context and the societal/ cultural setting, the latter seems to be rather neglected in the popular definitions analyzed, leaving it up to other actors to connote this fundamental feature of social robots.

Our findings have several limitations deriving from the data sets we considered (which were limited in scope and time), from distortions in the data due partly to filters and the opacity of the algorithms involved in the online tools we used, and partly to internet access being influenced by digital literacy and language mastery issues. Further studies will therefore be needed to thoroughly investigate the recursive social semiosis in the scientific and public spheres, and between the two public knowledge domains.

Despite these limitations, our results confirm the key part that scientists play in the denotative processes, through naming and classifying new objects, while leaving the door open to recursive processes – especially as regards the connotative components of representations. As for the values, attitudes and perspectives embedded in the definitions analyzed here, potential conflicts seem to lie behind the social-interactive features associated with social robots, which implicitly make them humanlike. This issue demands a more careful consideration of the transformations beyond human-machine interaction. Decontextualization and selection of information, which are at the core of objectification processes, may also lead to conflicts regarding the materiality and autonomy of robots in the social arena.

Our findings have several practical and research implications. Exploring and comparing the scientific and popular definitions of the social robot confirmed that the scientific world is still in the process of establishing its own definition, and that the two knowledge domains influence one another's definitions of this construct. Rather than focus only on clarifying and merging previous definitions, scholars also implicitly refer to other scientific domains, and adopt shared values and assumptions in defining what a social robot should or will be. This approach affords the freedom of thought essential

to innovation, but also introduces connotative assessments of the object that need to be made explicit and carefully addressed when planning future research and "technological fixes." Indeed, as Šabanović (2010, p. 440) pointed out, "robot design is influenced from its very inception by the cultural assumptions of designers […] The social context of design regulates the relations of production and defines notions of social interaction that are built into robots." By clarifying and problematizing the concept of robots, and the interweaving of scientific and popular definitions, designers can open their mind to innovation. For the future to be invented from a human rather than a technology-driven perspective, the shapes, functions, and features of robots should not be taken for granted (Vincent et al., 2015; De Toni and Rulliani, 2018).

Future research on the construction of social robots should also be reinforced by considering other sources of information that influence popular understanding of such devices. In this study, the focus was on online definitions of the social robot, but other sources should be examined as well to broaden the field and overcome the sectorial limitations of the web. Such sources could include printed newspapers, TV and radio programs, for instance, which contribute to the socialization of new technologies and their connotation by adults and the younger generations (Fortunati, Esposito and Lugano, 2015; Fortunati, Esposito, Sarrica and Ferrin, 2015).

Finally, far from adopting a top-down and technocentric perspective, it is important to acknowledge that any efforts to refine the definition of a social robot come up against an impassable limit: only their users will ultimately decide what makes a robot "social." Practices, domestication, reinvented robot design methods, or the self-production of social robots (with the help of a 3D printer, for instance) will continue to decide the shape of these new objects and the meanings associated with them. Further research will need to continue to monitor and analyze not only the proposed definitions (framed within SRT), but also the attitudes to social robots, and the process of their diffusion and appropriation, which will transform and co-construct this technological artefact in years to come.

Note

1. An example is the Social Robotics Laboratory on the master's degree course in "Multimedia Communications and Information Technologies" at the University of Udine (Italy).

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