Robots and the Complexity of Everyday Worlds

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1. Introduction[1]

For decades robots were caged in factory shop floors and laboratories. Although roboticists have referred to the idea of robots solving "real world problems" since at least the 1980s, actually dealing with worlds has become common in robotics only over the course the past 15 years.
This activity is closely connected to an upsurge in state funding of research programs that investigate opportunities for the everyday use of robots. The EU launched the robotics promotion program "SPARC" with a volume of over €700mio in 2014. The "National Robotics Initiative" in the US will have distributed about $500mio by the end of 2020. Similar programs are in place in Japan and South Korea. Furthermore, several grand challenges and research competitions such as the "DARPA Robotics Challenge" (2012-15) address the development of robotic technology for everyday life.
The scope of these new robotic applications is as wide as people's everyday needs. Scenarios range from self-driving cars to robotic companions for entertainment in private households. Robots for elderly care and nursing homes are one of the most prominent funded technologies in societies threatened by demographic change.
This boom involves different, partly converging, fields of research such as service robotics, search and rescue robotics, human-robot-interaction (HRI) and social robotics (Bischof, 2017). These fields cannot be understood as homogeneous, despite sharing a common vision of developing robots for everyday uses. By engaging worlds of everyday life, these research areas face a new kind of problem that challenges the established theories, methods and cultures of robotic research and engineering.

In this article we discuss the nature of these problems as "wicked problems" and their implication for roboticists dealing with everyday worlds. Therefore, we address the "wickedness" of dealing with everyday worlds on a conceptual level. Based on this, we explain the "complexity gap" (Meister, 2014) of social situations and robotic capabilities by referring to Latour's notion of "complicating the complex" (Latour & Hermant, 2006).
Conclusively, we present empirical analyses of robotic projects showing that the challenge of dealing with everyday complexity evokes two strategies: on the one hand the reduction of complexity, e.g. by laboratory experiments, and on the other hand the resumption of complexity, e.g. during robotics competition. Both are dynamically connected and influence both the actual phenomenon of human—robot interaction, as well as the scientific research thereof.

2. Everyday Worlds as a "wicked problem" for Robotics

The problems that arise when robots are deployed in everyday worlds cannot solely be understood as technical challenges, e.g. in terms of obstacle avoidance. Leaving the factory buildings and laboratories does not only add a new set of tasks for the machines, it challengers the scientific – sociologists of science say: *epistemic* – foundations of the field.

By definition, robotics for everyday worlds wants and needs to get closer to its object. This has required a number of technical innovations. A key area was the autonomous navigation of machines in "unstructured" environments, as robots for everyday scenarios are typically

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mobile. They had to be able to maneuver safely and reliably through corridors and offices or even through densely crowded museum halls. Indeed, with the development of powerful navigation algorithms and models for real-time path planning (Thrun, 1998; Fox et al., 1999; Roy et al., 1999) a boom in new everyday use cases can be observed. The development of safe robot joints and manipulators which can regulate their force more specifically or have sensitive feedback mechanisms led to similar effects.
In this context, the work on the reliability of robots in everyday environments has been understood as a technical challenge. There are new variables to which the system must be able to react reliably. These variables must first be determined and need experimentally evaluated threshold values and models for operationalization. Certainly, their solution requires creativity and joint negotiation processes. Above all, these are problems that *can* be solved satisfactorily by means of engineering and computer science.

However, this machinability in technical dimensions cannot be applied to all the challenges that arise when robots are required to perform functions outside factory buildings or laboratories. Due to its intended use in everyday worlds, robotics is no longer exclusively concerned with technical systems. Instead it becomes a discipline which is concerned with *socio*-technical systems such as architecture or urban planning. Architects do not design buildings as an end in itself, but as parts of social and cultural practices such as working, eating, or leisure. Robotics and architecture now share a similar kind of problem: that of the resistive – some say: wicked (Rittel & Webber 1973) – nature of the predictability of human activity in socio-technical systems. Here different kinds of expertise intersect: Scientific, engineering, political, social and aesthetic interests are interwoven and sometimes conflicting. Architects and designers have developed methods and capabilities to understand how people move through space. Robotics needs similar knowledge for the domain of social interaction.

Constructing robots for use in everyday worlds is an enormous challenge for a technical discipline. Everyday worlds and social interactions with so-called "untrained users" are an absolute borderline case for the theoretical, methodical and technical instruments of robotics. Making robots work in everyday worlds also challenges the understanding of the role of the roboticist (Bischof, 2018).

3. Dealing with the Complexity of Everyday Worlds in Technical System Design

Although seemingly mundane to us as humans, everyday worlds are characterized by a specific complexity mainly grounded in the ways people create meaning and coordinate their activities. Our hypothesis is that the "robotization" of everyday situations requires the computational and epistemic processing of the complexity and contingency that is typical of everyday worlds. The characteristics of a social situation must necessarily be somehow discretized in a computational process and this happens in specific circumstances, which literally *complicate the complex* (Bischof & Heidt, 2018).

3.1 The Complexity of Everyday Worlds

What is the complexity of everyday worlds? We answer this question using three basic characteristics of social interaction. In selecting them, it is important to show what needs to be considered beyond theories that conceive human-robot interaction as an exchange between only two entities. Thereby, we reject the tendency in the current debate that conceptualizes human-robot interaction only as dyadic exchange between two entities on a micro level. Beyond a theoretical debate about this paradigm, our aim is to give a pragmatic perspective from a sociological and anthropological standpoint that shows how certain fundamental structural elements of interaction organize everyday worlds. The following ideas do therefore not form a specific theory but are rather core components of an interpretative paradigm common in the disciplines of anthropology, ethnology, and sociology.
We want to highlight three basic factors which are constitutive for the complexity of interactions in everyday worlds: 1) indexicality, 2) reciprocity of expectations and 3) double

contingency. These emphasize the non-trivial efforts that humans undertake to ensure that interactions work.

1) Indexicality means that a term or action referred to is only understandable in its context. This has firstly a conceptual-referential dimension, which is rooted in a semiotic understanding (Peirce, 1932) of the world: The meaning of an action or a term is always only understandable in a semantic network of further terms with which it is related (index). The term “workmanship”, for example, can mean quite different things in its concrete use, depending on whether it stands in the semantic network of “poor”, “quality”, or “guarantee”. The second dimension of indexicality follows an interactionist perspective (Garfinkel 1967) and is even more difficult to model: The meaning of actions and terms depends on their historically grown and/or active communicative use.
A famous example for indexicality from the philosophy of language, which is the base for this concept, are Wittgenstein’s “language-games”. Wittgenstein used the term to highlight that language’s meaning is woven into actions. The famous concept was intended “to bring into prominence the fact that the speaking of language is part of an activity” (1953, p. 27) which creates meaning. In line with this, we want to highlight indexicality as a basic factor for the complex interactivity of everyday worlds: Actions and communication cannot be understood without their context, which is not a container in which it is located, but rather metadata which is given and referenced to in every everyday interaction.[2]

2) Reciprocity of expectations explains how people create understanding and common ground in mutual interaction (Goffman, 1971). We learned through indexicality that meaning does not follow solely from the linguistic signs of words or phrases. It is tied to past interactions, joint experiences and constant renegotiations. These – especially in the form of “common sense” (Schütz & Luckmann, 1980) – become constitutive expectations for everyday interaction, but not in the sense of simply applying rules. The focus of the constitution of meaning lies on the interactive and sequential structure of communication. Syntax and semantics alone do not provide a sufficiently precise basis for intersubjective coordination of action. The inter-subjectively coordinated interpretation activity of the actors forms the constitutive prerequisite of every interaction. The coordination of mutual expectations, i.e. to check whether one is on the same page, is called reciprocity of expectations.
In one of his most famous breaching experiments, Garfinkel has shown that the work of interpreting the negotiation of meanings does not only occur episodically but permanently, constituting even a normative expectation placed on all participants in interaction: People react very sensitively to repeated demands for the clarification of the meaning of everyday expressions that are usually taken for granted. It is assumed that one thinks along and interprets the statements of the other correctly – even if one does not know what exactly is meant. Not following this behavior is considered as either bad intention or simply insanity, for example when one replies to the everyday question “How are you doing?” with “Do you mean physically or mentally?”.

3) Double Contingency is a concept we borrow from systems theory (Luhmann, 1982): Contingency describes a state that is neither necessary nor impossible. For social situations that means that they are fundmentally characterized by openness and uncertainty. Even if we are familiar with a given situation and know the context of an action, we cannot automatically predict how the interaction will continue. If we add the reciprocity of expectations, we find that contingency doubles because we must consider that both sides have mutual expectations and that those are not necessarily met. Communication in this sense is not self-evident and even unlikely (Luhmann, 1987, pp. 148-190).

[2] In the philosophy of language, ‚indexical‘ is used in a more restricted sense. We are using ‚indixical‘ in a broader sense more oriented towards symbolic interactionism.

By highlighting these three factors, we stress that seemingly mundane everyday interaction is, in its conditions and implementation, not trivial but complex. In this work, we have not described the tradition and methods of the theories working with this everyday complexity. We rather show that there are established social-theoretical concepts for the analysis of interactions, which should be related to human-robot interaction, as e.g. Compagna and Boblan have argued (2015).
It is important to underline that these three factors do not offer universal solutions for studying human-robot interaction. Instead, they emphasize that the complexity of everyday worlds is genuinely bound to their actuation in concrete situations.

Alač, Movellan, and Tanaka (2011) provide a striking example of the complexity of interactive coordination in human-robot interaction. The authors followed a team of roboticists and examined their efforts to test robotic behavior with preschool children. In one episode, which was meant to probe the allure of the robot, a researcher was seated on a rocking chair next to a robot and simulated reading a book. The children showed immediate interest in the scene. As they entered, they approached the researcher, pointed to the robot and asked for an explanation for what they saw. However, the researcher feigned indifference and did not react to their gestures. Gradually, the toddlers started to adopt this attitude of willful negligence, which Alač and colleagues (2011) called the "ignoring game" (p. 911): They minimized the attention paid to the robot while engaging more and more in other activities. Even when the robot physically moved, the children noticeably ignored it and finally left the room.
The incident illustrates that the assumed sociality of the robot was highly dependent on the interaction in the situation (Pentzold & Bischof, 2019). Although a number of potential uses had been technically inscribed and formed part of the toy robot's sensorimotor equipment, they remained latent and were not enacted. In this case, voluntary disregard prompted users to ignore the material object. In this process of ignoring, the children actually demonstrated their interaction competence and followed a common orientation, which the experimenter had involuntarily specified.

3.2 Reducing Complexity to Complicatedness

As a consequence of those three presented aspects, the complexities of everyday worlds – namely indexicality, expectations and contingency – are difficult if not impossible to formalize mathematically (Lindemann, 2016). Nevertheless, roboticists who build machines for such situations have to find workarounds to deal with them. Roboticists are forced to formalize contingent excerpts of the everyday world or to fall back on formalizations from other sciences. Sociologists of technology would say, those open connections and situated meanings must become fixed in technical action chains (Rammert & Schulz-Schaeffer, 2002).

In order to avoid a normative connotation of the terms, we would like to point out that "complexity reduction" does not mean a per se deficient process. Complexity reduction is necessary to enable interaction; even more it is inherent to acting at all: Without reducing the contingent set of actions, no action can be made. Consequently, human communicators too are dependent on making mutual understanding possible by means of typifications and relevance settings (Schütz, 2004). The empirical question for sociologists is which interactive techniques and procedures help to establish and secure interaction in everyday life (Garfinkel, 1967, p. 53).

The central conceptual difference between everyday worlds and current computational technology can be described with the Latourian difference between complex and complicated. This difference lies in the number of variables relevant for interactions and, as already indicated above, the difficulty of "calculating them" (Latour & Hermant, 2006, p. 30).
Discrete computability as a critical threshold for complexity is at odds with conventional concepts of complexity. Complexity is classically defined by the number of elements in a system and their interdependencies, such as in management (Ulrich & Fluri, 1995). In contrast, Latour's concept of complexity is based rather on the simultaneity of options characterizing

the complexity of everyday worlds, forcing decisions and reductions in complexity in modeling it for technology.

Complexity in human-robot interaction would then not be an ontological question about the complexity of the robot per se. Instead, it is a question of strategies with which the complexity of certain situations can be reduced in robotic technology in order for them to become capable of acting in everyday worlds. Latour's definition of complexity poses an empirical question regarding non-human actors: How is this reduction of complexity embedded in chains of action and objects?

Latour proposes the term “complication” to describe this complexity reduction. Complication can be understood as the transition from complex to complicated. It consists of determining a finite number of (computable) variables to divide a complex situation into successive steps of a discrete operation.

This differentiation between the modes of complexity within everyday worlds and within computers does not mean that it is impossible to build social machines. We would like to stress that the interactionist theoretical perspective on socio-technical systems does not establish a substantial difference between man and technology. On the contrary, it raises our awareness of the interactive mediations and production of sociality by people, matter and technology. Human-robot interaction is not determined by the materiality of its artefacts, but by the functionality of the combination of elements into an “artificial cause-effect relationship” (Rammert, 1989, p. 133). Complexity reduction is thus the transformation of a given reality into a contingent reality, i.e. the abstraction of concrete situations into repeatable, typical situations.

The complication of complexity is the fixation of an operation – and this is not exclusive to technology design. A human call center agent, for example, follows a mechanized chain of operations to narrow down the caller's problem and offer assistance. The call center agent's questions and possible answers are usually defined in a software system through which the agent clicks while on the phone with the customer. The communication behavior of the call center agent has thus been reduced by preselection to a level of complexity that allows it to quickly identify typical problems – as does the Siri voice software. Call center agents and chatbots or voice assistants are completely different entities, but the principles of the mechanization of dialogues are the same (Schüttpelz, 2013, p. 43).

Robots play an intermediary role in the question of reducing the complexity and capacity of everyday worlds: They are more adaptive and versatile than, for example, bridges (Winner 1980), but technically and conceptually far from capable to deal with complexity in the way humans are. A robot is only able to function within a relatively small corridor of interpretation, which is given to it mainly by the roboticists building it.

4. Modes of Dealing with Complexity in Human-Robot Interaction

In the following we show how roboticists deals with the explained “complexity gap”. How do they make their robots fit for the interpretation-dependent and interactive everyday worlds outside the laboratory? In our own empirical studies in the field of human-robot interaction, we have encountered two major strategies in dealing with complexity that we reconstruct in the following.

4.1 Reduction of Complexity in the Laboratory

One way of dealing with the obstacle of translating everyday complexity for computers is found in laboratorization processes (Knorr Cetina, 1988). Everyday application scenarios are most often translated into laboratory situations, at least at some point of the robotics research process. In standardized experiments, effects of the interaction of human and robotic behavior

are tested, whereby the social situation is not only spatially but also temporally detached from its actual context (Knorr Cetina, 2002, p. 46).
The goal to building machines that work in actual everyday worlds thus becomes a laboratory science. Standardized evaluation studies and laboratory experiments – often carried out as "Wizard of Oz" designs (Riek, 2012) – have become the most important quality criterion for scientific publications within HRI. This finding is surprising in that such experiments are not genuinely part of the repertoire of engineering and computer science research and are also negotiated in a conflict-like manner. It is no longer enough to build a working robot, its effects on specific aspects of the human-robot interaction must be statistically proven.

From our point of view, the domination of standardized experimental methods is based on three epistemic properties of these methods: First, experimental studies generate legitimacy. Statistics imply the figure of the interchangeable observer, which suggests context-different validity conditions of statements and is easier to transfer into other epistemes. Secondly, the controlled environment of a laboratory experiment serves the (limited) functioning of the robot. In particular, research robots are fragile objects. For experiments in actual everyday worlds, many robotic platforms are simply not yet robust enough. Thirdly, the modes of research funding and their evaluation considerably enhance the importance of laboratory experiments.

In order not to be misunderstood: The methodical and methodological approach of laboratory experiments is quite reliable and plausible in a standardized research logic. Our point is that this approach adequacy and implications for actual everyday worlds – and their complexity as unfolded above – are not carried out sufficiently within HRI. Thus, the process as such is considered objective, although the crucial steps – e.g. the definition of the research goal, the desirability of the interaction and the interpretation of the data – are inevitably made by human researchers and based on their understandings of everyday worlds. The selectivity and contextuality of these decisions are usually not part of the representations of the results. This has several effects on the results of the experiments on human-robot interaction: The tested situation is in itself a reduction of complexity as it excludes unpredictable interventions and events by third parties or technical issues of real-world situations. The staged performances of the experimental setup or the experimenter, as well as interventions and methodological deficiencies of the implementation, are often hidden in these experiments (see Alač et al., 2011).

We understand the phenomenon of widespread laboratory experiments as a reaction to the problem of the complexity of everyday situations in robotics developments. In our eyes, this is not per se dysfunctionality, but a *necessary* reduction of the complexity and contingency of social situations for the research process. The described experiments create their own laboratized reality. The fit of the laboratory worlds with the "real-world problems" to be solved remains initially unclear and undetermined. The specific complexity of everyday worlds thus comes back into play when the machines are supposed to function in such unstructured environments.

4.2 Epistemic means for (re) incorporation of complexity

If robotic researchers were to orient themselves exclusively to laboratory experiments, they would fail to achieve the self-imposed goal of leaving the laboratories and developing machines suitable for everyday use. Consequently, the development processes feature attempts to include instances in which social complexity and contingency reoccur.
There are occasions when the machines are specifically exposed to coincidences, failures, and even falling over. In addition to the use in museums or open-door day, field trials and competitions are a central element within the research landscape. Those opportunities are, according to our argument, an intermediary between the laborites and the complexity of real worlds.
Competitions, such as the RoboCup, are specifically used to circumvent the 'laboratized reality'. In addition, other incidents in which the laboratory situation is used as an excuse for

errors, such as allegedly or actually switched off subsystems, battery problems or the like are excluded. Martin Meister, for example, describes: “I have seen many situations in labs where researchers tried to push a robotic research platform out of the door, explaining that the navigation module is at the moment under revision.” And concludes: “But in the game, excuses – other that in a laboratory environment – are ruled out” (Meister, 2011, p. 8). Within the competitions such procedure is excluded, thus promotinga test under 'real conditions'. These conditions are especially interesting for competitions which engage with human-robot interaction, e.g. the RoboCup@Home. Although the test subjects are instructed to keep still and only to do or say what the robot can understand, the organizers' intention is “to foster natural interaction with the robot using speech and gesture commands” (RoboCup, 2009). This allows more complexity and contingency than the usual laboratory situations in which the user is calibrated to make the interaction happen (Lipp, 2017).
The element of surprise lost by the overfitting of the laboratory is counterbalanced by the unexpected nature of field tests and competitions.
In contrast to the (nearly) fully contingent field trials, competition offers more contingency than the laboratory allows, but it remains a 'tamed contingency'. The competitive environment is less complex than an everyday environment. The halls in which the competitions take place appear complex in contrast to the laboratory, but the environmental parameters are comparatively stable. In contrast to other field situations, they are also well documented (Maibaum & Derpmann, 2013).

According to our argument, the development of robots for everyday-world applications is characterized by two complementary strategies: First reducing complexity and secondly (re)incorporation of complexity, each having its respective paradigmatic location, the laboratory and competition arena. The necessary reduction of the complexity of everyday-world interactions in laboratory research alternates with phases of resumption of complexity and contingency, such as competition. This interplay of complexity reduction and resumption seems to be epistemically functional. At the same time, it does not seem to be an intentional structure in the sense of a reflected methodical decision. Rather, it remains (like many other solutions in the field) an implied "workaround" of the core challenge, dealing with everyday complexity.

5. Conclusion

Now that robots are leaving their cages in factory shop floors and laboratories, they are confronted with human everyday worlds. With this transfer from being exclusively concerned with technical systems to building socio-technical systems, everyday worlds become a wicked problem of robotics: They are interpretative, highly context dependent and products of constant interactive negotiation.
The key to understanding and modelling this wicked problem is acknowledging the complexity of a human interaction. We stress three basic factors, which are constitutive for this complexity: indexicality, reciprocity of expectations, and double contingency. Although it is in the nature of these factors that they cannot be formalized, roboticists are forced to translate them into complicated, rather than complex, formalizations. We have shown that these formalizations are not only computational but epistemic in the sense of how HRI as a field is approaching the complexity of everyday worlds. The main strategy here is the laboratization of social interaction to reduce complexity. But in going beyond the reduction we also saw a reintegration of complexity outside of the laboratory, for example in the competition arena, that is ‘tame contingent’.
Our findings stress the importance of incorporating social theory into human-robot interaction research and development on two levels: Firstly, by referencing to the interpretative paradigm we have shown the extent to which everyday worlds, in particular their functioning and normality, are based on interactive production and coordination of meaning between actors. Secondly, we have shown how ambivalently a socio-*technical* discipline like HRI deals with this complexity of seemingly mundane interactions. It is dependent on reduction but must also seek moments of resumption of complexity in order to make the machines function in actual

everyday worlds. We do not argue for a fundamental shift in HRI research and development. As we have seen, many HRI practitioners are already incorporating everyday complexity in often rather implicit ways. But we argue for a new sociological sensitivity, especially regarding to the interpretative paradigm, allowing us to understand and situate human-robot interaction as a practice of meaning-production and coordination in given social worlds, rather than a coordination process between two singular entities “human” and “machine”.

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