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Co-performance: Conceptualizing the Role of Artificial Agency in the Design of Everyday Life

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ABSTRACT
This paper introduces the notion of *co-performance*, with the aim to offer Human-Computer Interaction (HCI) researchers and practitioners a new perspective on the role of artificial agency in everyday life, from automated systems to autonomous devices. In contrast to 'smartness,' which focuses on a supposed autonomy of artifacts, *co-performance* considers artifacts as capable of learning and performing next to people. This shifts the locus of design from matters of distributions of agency at design time, to matters of embodied learning in everyday practice for both human and artificial performers. From this perspective, co-performance acknowledges the dynamic differences in capabilities between humans and artifacts, and highlights the fundamentally recursive relation between professional design and use. Implications for HCI design practice are unpacked through reflections on smart thermostat design in light of historic changes in roles between humans and heating systems, and changing ideas of appropriateness in everyday practices of domestic heating.

Author Keywords
Theoretic foundations; theories of practice; co-performance; artificial agency; autonomous devices; smart thermostats.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Smart technologies make a range of promises: to solve societal issues like energy use or waste by compensating for human flaws, to make life easier by taking over work and responsibilities from people, and to enable new forms of indulgence by promoting a seamlessly integrated and harmonious free-labor life [78]. This 'smart utopia' [78] is at odds with the reality of everyday life, which is instead messy and unpredictable [18]. In particular in the context of the home, technologies and their hidden assumptions are shown to have unintended consequences on everyday life (e.g. [3, 4, 11, 17, 44, 57, 80]). In order for design to be sensitive to its impact, better understanding is needed of the role played in everyday life by the artefacts we make. For HCI researchers and practitioners, this means a better understanding of the decisions made in the design process about (a) the role of the *artificial agency* of computational artefacts, and (b) how this role should be allowed to *change*, under the idiosyncratic and varied circumstances of everyday life.

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The turn to practice in Human-Computer Interaction (HCI) latches onto this need of better understanding the increasingly complex relation between people and computational artefacts in everyday life [45]. Theories of practice, a group of theories drawn on in the practice turn, are attractive to HCI for the explicit role they attribute to the material world and its relation to the social. However, there are also limitations to the extent to which a practice orientation can be further operationalized in HCI design practice. One reason is that within discussions of the 'material' informed by current theories of practice, there is little distinction between different kinds of technologies: a chair, a door or a thermostat are all considered as having the same status. Moreover, humans are considered as the sole performers of practices. This 'human-centered' view on the subordinate role of artefacts is predominant in HCI interpretations of practice theory. In Fernaeus et al. [23] for example, people are repeatedly referred to as users that act, give meaning and decide, while artefacts are simply 'resources for action' meant to 'play a part' in the systems used by people. Similarly, for Kuutti and Bannon [45], the human actor is clearly positioned as 'the one who produces practices in action,' while the materiality of the world is seen as 'resources for the realization of practices.' Artefacts make a practice possible and may contribute to changing it, but it is humans that 'appropriate and shape these artefacts.'

This subsidiary role that is being attributed to artefacts does not sit comfortably with the realities of ubiquitous computing and the developments of machine learning. It is obvious that computational artefacts, equipped with sensors, processing equipment, programs and actuators can be viewed to act outside of the direct presence and awareness of people. Therefore, an open question remains: 'what are artefacts for practices, and what are our possibilities [as HCI researchers and designers] in influencing what happens through changing the artefacts?' [45].

This paper introduces the HCI community to the notion of *co-performance* [41], a modification of the practice theoretic framework that considers computational artifacts as capable of learning and performing a social practice (e.g., cooking, washing the laundry or heating the house) together with people. In contrast to the idea of 'smartness' that is focused on a supposed autonomy of the artifact, we argue that the agency exerted by the artifact's performances is the result of a process of *embodied learning* that takes place through situated and sustained interplay with humans, i.e., 'in practice.' The aim of this paper is to explore the potential of co-performance in helping designers step away from 'human-centered' narratives of smartness and autonomy. In this narrative the artefact is subservient to the realization of social practices 'scripted' at design time. Instead, we argue, the locus of design can be shifted towards solutions that allow for a fundamentally recursive relation between design and use. In these solutions, human and artificial roles can then gain more room to change, according to the situated and evolving complementarity of capabilities and doings, 'uniquely' human and 'uniquely' artificial. This entails acknowledging computational artifacts as performers of practices in their own right.

The paper begins with a review of emerging notions and conceptualizations of artificial agency in HCI. The review highlights that judging what represents an appropriate interplay between people and computational artifacts remains a challenge for HCI design practice. We argue this is a matter of how artificial agency, and hence the role of computational artifacts, is conceptualized. In the subsequent section, we link these state-of-the-art conceptualizations in HCI to notions of agency and appropriateness in practice theory. We thereby elaborate a new vocabulary and introduce the notion of co-performance. Next, we use the example of historic changes in domestic heating and related assumptions in the design of smart heating systems to illustrate co-performance by example. We focus on the home because here matters of agency and appropriateness are particularly complex due to the social and cultural messiness of domestic living. Moreover, heating is one of the oldest realms of everyday life in which roles were shifted between humans and artefacts. It therefore provides a long-term perspective on relations between changing use practices and professional design practices. We close by sketching a research agenda for how a co-performance perspective may provide new conceptual and practical resources for the design of an appropriate interplay between people and computational artifacts in everyday life.

ARTIFICIAL AGENCY AND APPROPRIATENESS IN HCI

Ideas of the active role that artefacts can take in everyday life are shifting in HCI. While third wave HCI is becoming less interested in research aimed to replicate human intelligence and qualities [6, 83], interest is growing in the new capacities for action that are configured at the intersection of humans and machines [81] or, more in general, humans and nonhumans [15, 27, 74, 82, 84, 89]. With this new direction, new questions arise: What should this interplay look like? What should be considered appropriate in such new and emerging relations?

Investigating human-nonhuman relations as entangled interplay

Forlizzi and DiSalvo's [24] study of the iRobot's Roomba vacuum cleaner, for example, describes the nature of the relationship between Roomba owners and the machine as one that comes about in the interplay between owners' expectations, the actions of working out the machine's methods of operation, and the orchestration of the conditions under which the machine does its work in a given environment.

As noted already by Taylor [83], such relations are not limited to mechanical robots. Longitudinal studies of smart home devices exhibiting some capacity to interpret and respond to human behavior argue that nonhuman actions and human purposes are entangled and worked out in the continuous orchestration between humans, machines and environments ([25, 62], both cited in Taylor [83], see also more recently [75]). Similarly, analyses of computational systems as actors in the construction of publics – intended as organizations of humans and nonhumans (animals, plants, atmospheres, buildings, etc.) – exemplify a growing interest in the entangled character of agency in HCI [38].

Exploiting different capabilities in human-nonhuman collaboration

Expressing a growing need in HCI for understanding future partnerships between humans and computational artefacts, a range of recent publications [22, 31, 50, 51, 66, 86] approach humans and computational artefacts as collaborators in achieving human originating purposes.

For example, in Rozendaal's prototype of a jacket for veterans suffering from post-traumatic stress disorder (PTSD), the veteran and the jacket collaborate towards the designed goal of reducing stress and anxiety [66]. The jacket mirrors the stress level of the wearer through biofeedback, by actively helping the wearer to relax through deep abdominal breathing, and by inhibiting the veteran's movement when stress levels become too high to control. As such, the jacket is intended to prevent irrational or even aggressive behavior. Veterans need to rely on the jacket to calm down. However, in collaboration with the jacket, veterans may learn to internalize this competency.

An example of a more open-ended collaboration is Freaky [47]. This is a mobile system that senses and responds to a user's heart rate, helping them interpret their emotions. Here, the machine learning model used to represent emotions enables people to have a relationship with the device as a separate entity, which is nevertheless related to them. This blurs the line between the human and the machine in the construction of emotions: "was there something emotionally relevant or perhaps just a physiological event picked up by Freaky?" (p. 616). Informed by a relational perspective on machine learning [46], Freaky promotes a crafting of human-machine relations that remains open to ontological surprises.

Exploring agency through an orchestration of roles between humans and computational artefacts

Growing explorations of human/nonhuman agency that deliberately redistribute roles between the two focuses on the unique perspectives and capabilities of nonhumans as autonomous agents.

In the context of fabrication practices integrating physical and digital components, Devendorf and Ryokai [14] have designed a portable digital fabrication system called *Being the Machine* that guides users in building 3D models from everyday materials by following instructions typically given to 3D printers. By inviting the user to become the machine, Devendorf and Ryokai reconfigure the expected roles of humans and machines in contemporary practices of making, expose the tensions in the "redistribution of control," and explore the creative opportunities generated in this new interplay. Through the development of Arc – a computer numerical controlled (CNC) engraving tool for ceramics – Saegusa et al. [67] further explore how fabrication tools integrate multiple and distinct agencies and roles in the production of form.

Design work focused on non-anthropocentric perspectives and forms of engagement promotes artificial agency as an opportunity to encounter the world in ways that were not possible before. In the City As Learning Lab (CaLL) project, DiSalvo and Lukens [15] explore the use of robotic sensing in support of community engagement. Unique video footage (taken in movement, low to the ground) was captured by the robot and reviewed by participants. This provided unique insights into the interplay of human choice of places in the neighborhood and readings provided by the sensors during the scavenger hunt. Davoli and Redstrom [12] created probes instrumented with sensors and a camera to track and provide photographic details about how packages are shipped and delivered in Sweden. Using the maps and videos as records of what was happening at the back-end of the delivery service, Davoli and Redstrom were able to obtain unique stories of the distribution journeys and how work seemed to be organized. In the Thing Tank project [27, 30], Giaccardi and colleagues instrumented ecologies of objects of everyday use with intelligent cameras and sensors. By using instrumented objects as co-ethnographers with access to unique fields and trajectories, Giaccardi and colleagues were able to generate insights in the types of temporal and spatial attributes and dynamics that inhere among things, and among things and people, within and across specific use practices.

In summary

We see this body of research as the indication of a growing need for understanding the agency and roles that humans and computational artefacts can play in everyday life. But also as an attempt to foreground and articulate how these roles should be understood as appropriate, along a spectrum from the prescriptive (e.g., [66]) to the serendipitous (e.g., [46]), from the political (e.g., [15]) to the generative (e.g., [27]). This related work highlights that taking account of the different roles of humans and computational artifacts in situated action is important, not least for their differences in capabilities. However, the understanding of what represents an appropriate interplay between human and artificial agency remains largely implicit or at best descriptive. It becomes therefore difficult to use in the process of actually designing computational artefacts.

In the following section we introduce the notion of co-performance and explain how it contributes a conceptual framework that may be useful to understand and work with the interplay between human and artificial agency in HCI design practice.

AGENCY, CO-PERFORMANCE & APPROPRIATENESS IN PRACTICE THEORY

Co-performance [41] is a modification of the practice theoretic framework we developed that considerers computational artefacts as artificial body/minds that are capable of performing practices alongside people. Below we explain what this modification implies for the ways in which artificial agency links appropriateness to design practice.

Agency as performance of practices

In theories of practice, agency is considered to be exerted through the performance of practices. Schatzki distinguishes two types of agency. One is the causal type, which is about making, or helping to make something happen. The other type is the performance type, which is a kind of doing that in the situation at hand amounts to *performing* the action, while at the same time carrying on the practice of which it is part [68]. This idea of performing a practice links to the concept of 'practice-as-entity' [73, 90], which is a *socially shared*, *materially embedded* idea of how to appropriately perform a practice. To simplify our vocabulary, we'll refer to this idea as social practice. Social practices persist across space and time, beyond the individual performances that carry them on. This explains, for example how we can refer to something like 'cooking' or 'having a meeting' without having to elaborate on what it entails. More importantly, for the purpose of this paper, the idea of social practice allows for a tracing of careers of practices over time [72], which we will do for domestic space heating in the next section.

To understand agency in practice theory requires an understanding of the 'doings' entailed by the recursive relation between social practices and situated actions – which by Warde and Shove et al. [73, 90] is referred to as 'practices-as-performance.' Again to simplify, we'll refer to this form of doing as performance. Because social practices (e.g., cooking) represent a socially shared, materially embedded idea of what is appropriate to do (and why), it organizes, to a certain extent, each performance of cooking as a social practice. For example, cooking tends to involve using pots and a stove for turning a mix of ingredients into a tasteful recipe. At the same time, however, social practices are made out of the sum of their performances. This matters, because while taking account of a supposed 'blueprint' of appropriate performance, each performance (i.e., each instance of cooking in our example) represents a situated interpretation of what is appropriate performance. For example, when ingredients come pre-mixed in a plastic container, cooking them in a microwave is often more appropriate than on a stove.

Importantly, because situated circumstances vary and change over time, situated performances at times require or simply result in a re-interpretation of appropriate practice: of what works and makes sense [63, 77, 90, 91]. When consistently repeated, new performances reshape a social practice. For example, cooking in a microwave has, through millions of performances over time, become an acceptable form of preparing a meal. Similarly, 'calories' have changed from a novel concept to an integral part of healthy eating. Performances, therefore, are doings that exert agency because they shape social practice.

Compared to current conceptualizations of artificial agency in HCI, understanding performance as agency helps consider both human and artificial doings as relevant to understanding and shaping social stability and change. The next section goes deeper into relations between them.

Human and artificial agency as co-performance

The concept of co-performance considers artefacts as capable of performing and exerting agency *together with people* in the carrying on of social practices.

Practice theorists view social practices as routinized types of behavior consisting of elements. Reckwitz' widely cited definition lists these as 'forms of bodily activities, forms of mental activities, "things" and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge [63].'

Because these elements include particular human traits such as states of emotion and motivational knowledge, artefacts performing part of a social practice cannot be considered performers in their own right. Like Rozendaal [66], co-performance acknowledges that artificial performance gains its meaning from ends pursued by humans. For example, the need for controlling stressed bodies clearly derives from human ends, and cooking is only meaningful because human bodies need nutrition (and pleasure). Without their link to human emotions, ends and purposes, artificial doings have no role in social practice.

This also means that in the end, what is appropriate performance is a human judgment. These judgments can be different from person to person. But an artefact, while designed to and therefore capable of embodying a certain disposition on what is appropriate performance, is not capable of eventually interpreting good or bad, appropriate or inappropriate, acceptable or unacceptable performance. How to proceed appropriately given situated, and in particular unexpected and unusual circumstances is a human, culturally shaped, ethical judgment. Co-performance focuses on the 'appropriateness' of human and artificial performances under situated circumstances. It thus repositions HCI design practice at the nexus of the relation between situated performers and the professionals involved in designing the capabilities and roles that will produce artificial performances. We will explain this further in our reflection on smart thermostat design in the next section. First, we need to say more about appropriateness in co-performance.

Appropriateness in co-performance

As mentioned, social practices are socially shared, materially embedded ideas of *appropriate* forms of action. But they do not exist in the abstract; they exist as embodied knowledge and know-how in the 'body/minds' [63] of their performers, which the concept of co-performance takes to be both human and artificial [41]. This means that change in social practice involves *embodied learning*. Over the course of repeated performances and alongside changed body/minds (e.g., newly developed artefacts with unprecedented capabilities such as smart material composites or machine learning algorithms) – the ideas of appropriate practice embodied in both human and artificial body/minds change. In other words, what is considered appropriate is shaped through repeated co-performances of the practice in which *appropriateness is (re-)interpreted in the situation at hand*, and changes over time.

As we will elaborate in the following section, from a design standpoint, co-performance addresses the question of what is an appropriate interplay between human and artificial body/minds from the perspective of *changing divisions of roles and responsibilities between human and artificial performers*. Their joint performance integrates all the elements referred to by Reckwitz [63] (and summarized by Shove et al. as meanings, materials and competences [73]) in ways that make sense in that situation. By jointly integrating these elements into instantiations of practice that work and make sense, social practice is *co-shaped by humans and artefacts*.

This position resonates with ideas in HCI about the entanglement and reciprocity of nonhuman actions and human purposes [25, 62, 83]. But by focusing on the level of social practice rather than interactions, and on change over time rather than situated action alone, what it offers is a design perspective on the recursive relation professional design practice and use practice. Co-performance highlights that design necessarily continues at use time, and that at design time, it involves the materialization of a particular set of ideas regarding appropriate performance. In the interplay with human performers, the embodied disposition of artificial performers towards 'appropriate' performance may invite certain forms of performance and inhibit others. Important in this interplay are the differences between human and artificial body/minds, and how these can be capitalized both at design time and use time.

In the next section we use the example of domestic heating to illustrate what it might mean, and render for HCI research and practice to conceptualize humans and computational artefacts as co-performers of practices.

UNPACKING CO-PERFORMANCE IN DOMESTIC SPACE HEATING

Historic analysis of practices is a widely used method in philosophy of technology and science and technology studies (STS) to highlight broader implications of technological design (e.g. [21, 26, 44, 69]), which tend to become clear over larger time spans. The following example is about domestic heating, and looks at change over the period of about a century (from the 1920s to the present) in the United Kingdom (UK). Over this period, domestic space heating changed from coal fires to gas fired central heating systems operated by programmable thermostats, and most recently 'smart' thermostats (see Figure 1). The data used for the following analysis was collected through a historic case study on changes in space heating in social housing in the UK (methodological details in [44]), as well as from analysis of a range of design cases of smart thermostats in HCI. The cases were selected from several searches of the ACM Digital Library in between August 2016 and August 2017 using the keywords 'home heating', 'thermal comfort' and 'smart thermostat,' selecting only those papers that describe a detailed design, and are focused on a domestic setting [10, 32, 35, 48, 59, 61, 65, 71, 76]. Other HCI literature has also been considered because it was evaluating the use of smart thermostats [2, 92], or focused on smart thermostat designs for offices [75].

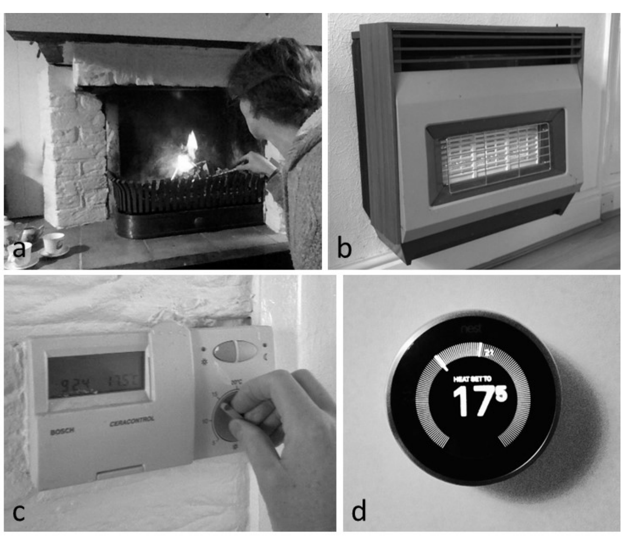

Figure 1: Illustration of different space heating systems: (a) coal fire, (b) simple gas fire, (c) programmable thermostat and (d) smart thermostat

The practice of domestic space heating involves the maintaining of appropriate indoor climate in times of colder weather. Over the past century, ideas of appropriate indoor climates have changed strongly. By today's standards, indoor climates that were normal a century ago would not be considered acceptable. Moreover, current standards demand more heat [44].

As Snow et al. [75] summarize, two typical aims of smart thermostats are 'to provide agreeable thermal comfort to occupants', and to reduce energy consumption of heating (and cooling) systems. Considering changes in heating practices over time is an interesting perspective to reflect on smart thermostat design. It helps to understand how ideas of 'agreeable thermal comfort' are subject to change, as well as how changing standards have had consequences for levels of energy demand for heating.

In this section we use domestic heating as a historical case to consider how roles between human and artificial performers have shifted and human and artificial capabilities have changed over time. This analysis helps us to understand how technological innovations have affected ideas of appropriate indoor climate, as well as rising levels of demand for heat. By doing so, we illustrate and contribute a set of useful principles for the design of an appropriate interplay between people and heating systems, which may also apply to other contexts of technology design.

Differences in capabilities and roles among human and artificial performers shape ideas of appropriateness

With the shift from coal fires to gas central heating, the roles of humans and artefacts in the practice of space heating changed. More specifically, both the act of adding fuel to the fire, as well as the decision of when to turn the heating on, shifted stepwise from humans to heating systems. A focus on detailed differences in *capabilities* between human and artificial performers offers an insightful explanation for how shifting roles between human and artificial performers shape ideas of appropriateness.

In case of gas fired heating, both people and artefacts have the capability to add fuel to a domestic heating system. However, who is allocated this role matters for *how it is performed,* and thus for how the practice is shaped. In the case of coal fires, humans would add fuel in batches. With the spreading of gas infrastructure the act of adding fuel was taken over by gas pipes and valves. Different from coal, gas has the ability to flow. Moreover, once opened, gas infrastructure has the ability to add fuel continuously, any time of day or night. These changes in roles, together with pre-existing, embodied differences in capabilities contributed to the (slow) emergence of the contemporary norm of having heating on during times of occupant's absence and sleep [44].

Moreover, this norm became embedded in following generations of heating designs. The 1961 social housing design guidelines in the UK [60] for example, still assumed the heating system to be off during the night as an implicit norm, while the current EU directive for Eco Labelling of thermostats [20] accepts indoor temperatures to never drop below 16°C. Human performers alone would never have been able to achieve this standard in a sensible way. While there was of course more at play than the new capability of gas infrastructures to add fuel continuously, introducing this artificial role into the practice has contributed to an important, energy intensive change in ideas of appropriate heating.

With the introduction of programmed thermostats – we'll move to *smart* thermostats in a bit – the switching on and off of the fuel supply, and therefore the judgment of when fuel should be added to achieve an appropriate indoor climate, was shifted further to artificial performers. In this process, due to differences in capabilities, the way in which judgments about appropriate indoor temperature are made changed strongly. To judge whether fuel needs to be added, a programmed thermostat takes into account an assumed, repetitive pattern of appropriate temperatures, together with a sensing of the current room temperature. Other aspects of the particular circumstances, such as whether there are people in the room, what they are doing or are about to do, what they are wearing, how they are feeling, what their thermal preferences are and so on, cannot be taken into account by the thermostat. Moreover, when judging the temperature to be too low, humans have the capability to implement an array of alternatives to the adding of fuel to the heating system, such as wearing more clothing, getting active, or closing a window, which the thermostat does not have.

Shifting responsibilities to artificial performers for adding fuel to the heating system thus contributed to a shift from person-oriented to more energy intensive, space-oriented heating practices [42]. Moreover, with this shifting of roles, a range of socially complex aspects of appropriate indoor climates have moved to the background, while the numerical value of the room temperature has been foregrounded. *Not only in the decisions made by the thermostat, but also in human judgments*; today, numerical temperature values play a more prominent role in human judgment of comfort than in times of coal fires. The following section goes deeper into this point.

Artificial reinterpretations of appropriate performance foreground measurable and quantifiable aspects in situated judgments

Like humans, artificial performers integrate elements – sensed temperatures, gas, water, air, radiators, skills of directing and dosing fuel, know-how of transferring heat, etc. – into unique performances. These performances embody interpretations of what is considered appropriate in situated circumstances.

In the messiness of everyday life, what is appropriate for the circumstances is not always straightforward. For example, when a door is left open, the thermostat adds more fuel to the heating system, so that a certain minimum temperature is maintained – while a human performer in that same situation may have closed the door. In other cases, forms of appropriate heating suggested by artificial performers could not be carried out by people. For example in the case of early gas fires, when humans had to learn to switch the heating off (coal fires would go out 'automatically'). Although there is no systematic research tracking this process, it is likely that there were occasions where the heating was accidently, or experimentally left on in absence or overnight. In those circumstances, the practice of heating spaces in human absence was thus suggested as appropriate practice, because it was performed. How this happened exactly is somewhat speculative, but we do know that expectations of entering an already warmed room came to be embodied in both human and artificial performers. This modified practice formed a basis for new, programmable thermostats to heat up spaces in anticipation of occupancy.

The introduction of the artificial capability of continuous fuel supply has arguably led to changes in domestic heating that made it more heat intensive (expectations of certain minimum indoor temperatures, and of always entering a heated space). Pivotal to this path of change has been the decision to shift the judgment of when to heat up a space to the heating system. The judgment of whether it is appropriate to add fuel to a heating system is both technically and socially complex. It involves technical judgments of the thermal properties of the system and space. But also social judgments of expected occupancy, as well as person and situation specific demands for heat. However, as mentioned earlier, ideas of appropriate practice are not fixed, but shaped by everyday performances. Since the judgment of appropriate heating was largely shifted to heating systems, new ideas of appropriateness, entailing spaces heated in quantifiable patterns of temperatures, have become embodied in both human and artificial performers over time.

This way of viewing changes in domestic heating brings up questions. What would have happened if at the point of designing simple gas fires, the then common practice of adding fuel in batches had been kept? An argument to do so would have been to keep the complex, social judgment of whether to add fuel in the hands of situated, human performers. While that decision clearly lies in the past, the speculation offers a novel perspective on the present.

When again focusing on the situated judgment of whether it is appropriate to switch the heating on, it can be said that system designers to this date are struggling to come up with an artificial way of making that judgment in more socially appropriate, 'smarter' ways. Looking at the general discourse in HCI, the focus lies on designing 'smart' thermostats that outperform their 'programmed' predecessors. This is achieved by feeding them with additional, contextual data, such as occupant's activity, sweat [35] and skin temperature levels collected from wearable sensors [10], GPS data from mobile phones [32, 70], in-home motion [48], electricity use [76] and weather information [71]. This data is then used as input for the thermostat's decision to switch heating on or off, as well as for machine learning algorithms designed to discover patterns of activity typical to the specific household. The focus in these designs is to improve artificial capabilities for the performance of appropriate home heating. Even though smart thermostats have the added capability to calibrate predicted patterns of occupancy with measured patterns of occupancy, judging whether performed patterns of heating are appropriate for actual situated circumstances remains something that they cannot ultimately do.

What if instead space heating was designed as co-performed by humans and artefacts? This would open the suggestion that the complex social judgment of when fuel should be added might fruitfully be shifted back to humans. Snow et al.'s [75] 'smarter thermostat' that proposes a system that explicitly shares the decision of when a space needs heating (or cooling) with people is an example where this is proposed, and offers a good argument for why this might make sense.

Technological innovation shifts ideas of appropriateness to professional design practices

It is time to add some nuance to the concept of artificial judgment. Bringing the artefacts' designers into the equation highlights the *de-contextualization* of judgments in cases of artificial performance. When the thermostat makes the decision to switch the heating on or off, judgments of appropriate heating are taken out of the hands of humans in situated circumstances. Instead, they have been made by humans in the development process.

This argument of removal from situated performance shows similarities to Albert Borgmann's device paradigm [8], where he also happens to reflect on the shift from fireplaces to central heating. Central to Borgmann's argument is that with this shift, bodily engagement with home heating has diminished. Besides somewhat romanticizing the hard work, and negative health and environmental impacts of solid fuel heating practices, his concerns regarding a shift of actions to artefacts (or devices in Borgmann's terms) focus on values such as detachment and disengagement. The notion of co-performance sheds a slightly different light on this change, and links the shift to broader dynamics. For example, while Borgmann emphasizes that the fireplace demands bodily presence and engagement, we highlight that the shift to central heating meant that human bodily presence is no longer required to achieve a heated home. This view has the broader, longer term consequence that ideas of what is an appropriately heated home have changed. Like Borgmann, we would like to go deeper into the consequences of the withdrawal of human bodily engagement from the practice. However, while Borgman focuses on the consequences of this disembodiment for the situated performance, *a co-performance perspective draws attention to the link between situated performances and decisions made in the design process*. The humans involved in the development process of the thermostat (professional designers) have ideas about appropriate space heating, which may conflict with those of the humans involved in the situated circumstances (the users).

While ideas of appropriate indoor climates in professional design practices interact with practices of domestic space heating, they are also linked to other practices. For the Heating, Ventilation & Air Conditioning (HVAC) industry, these include related realms of technology development such as HCI, scientific research on indoor climates and health, political and societal practices of carbon emission reductions, practices of housing design, and so on. Concrete examples are the research of Fanger into optimal indoor climate circumstances around the 1970s, which has been highly influential in heating system design [9], as well as concerns surrounding public health and energy consumption [79], the discovery of natural gas and push for domestic gas infrastructure [85], the spreading of the television and increase in education level [44], among others. Further, and that's what we are focusing on in this paper, *ideas of appropriate practice in professional HVAC design practices are shaped by (alleged, actual and anticipated) artificial capabilities*.

Artificial performances matter for how practices change

It is not possible for smart thermostats to know for sure when members of the household will come home (unless people manually tell the thermostat when they are on their way). Nor can they (currently) know what occupants are wearing, how they are feeling and how active they are – all factors that play a critical role in thermal comfort.

Because there are limits to the aspects of situated circumstances that thermostats can take into account in their decision to add fuel to the heating system, they necessarily have to make assumptions. This means that part of the judgment of these situated circumstances needs to be transferred to the design process, where they feature in the form of assumptions and generalizations. For example of when occupants might be home, and what they might wear, feel and do at any moment. Using assumptions to make decisions also means that such artefacts necessarily make mistakes.

In performances where socially complex judgments and responses have been embodied in the artefact, performances facing non-standard situations risk becoming inappropriate. For example, in case of an unexpected party, a member of the household being ill, a traffic jam, and so on. Since non-standard situations occur all the time in the messy and unpredictable context of everyday life [18], this is a common situation. Artificial 'mistakes' are annoying, but they also transform practices constantly. When artefacts perform inappropriately, people can overrule or adjust the artefact in order to restore the performance to be appropriate. For example, the thermostat may manually be switched off at night or during times of absence. Another response is to succumb to the situation and accept the performance of the artifact as quasi-appropriate. This easily happens as standards rise, for example: a rationale is developed in which the previously inappropriate, or unconsidered behavior, such as heating overnight or during absence, is accepted, succumbed to, or even welcomed. Or layers of clothing are removed when cleaning. As such, the practice is reshaped in a way that is more suitable to the capabilities of artificial performers.

The idea of practices materialized into artefacts is not new, and resonates with concepts well known to HCI such as script [1], affordance [40], and technology mediation [87]. However, these other concepts focus on what the artefact steers, invites or inhibits people to do, think, feel or experience. *Co-performance instead views the details of what the artefact does as relevant in itself*. Moreover, it highlights *how technological innovation reshapes practices to suit artificial capabilities*.

A co-performance is also different in from co-adaptation [49], in that it does not promote a way of designing where users remain in control of every aspect of artificial performances. Instead, it calls for a way of designing in which situated human performers and artificial performers judge and shape together the nuances of appropriate performance under the specific circumstances. This point brings us to the final aspect of the relation between professional design and everyday use practices that co-performance brings to the fore.

Shifting of ideas of appropriateness to professional design practices creates a power imbalance

A unique capability of technological artefacts is that they can quite radically change over different generations. As such, updated, redesigned and improved devices and systems can be viewed to embody practice-specific learning acquired over time through repeated co-performances of the practice. This is what we refer to as *recursive relation between professional design practices and everyday use practices*. Heating systems have over time evolved from passive consumers of fuel to autonomous, anticipatory systems that regulate indoor temperatures.

Because these artefacts and their ways of judging and responding to judgments are given shape by a limited number of professionals, these experts have an important role in shaping what is considered appropriate in the lives of large numbers of people. In many cases this is not a problem, and even welcomed. There are many decisions people are happy to delegate to artefacts (and thus to the experts designing them): for example, how much gas to add to the heating system in order to warm up a space by one degree Celsius. But there are other situations, especially those on the margins of the normal and mainstream, where this delegated responsibility can lead to inappropriate judgments and responses by the artefact, which can harm users or society in various ways [36, 56, 57, 78].

With increased proliferation of computational artefacts in the home, a notion of co-performance highlights the risk of a growing power imbalance between 'users' (the situated human performers) and the 'expert' designers of computational artefacts.

When viewed from a co-performance perspective, mainstream approaches in HCI to designing smart thermostats seldom engage critically with ideas of appropriate performance that are embodied in artificial performance. For example, the professional knowledge and know-how embodied in the smart thermostat that everyday life adheres to predictable patterns, that detected movement means human presence, that people desire their domestic spaces to be kept at stable temperatures during occupancy, that homes should remain heated to at least 16°C at all times, that people forget to turn the heating down when they go out, and that they desire to always enter a warm room seems to be taken for granted. While all of these aspects of domestic heating emerged through technological change.

When unquestioned, such assumptions form the basis for further innovations that present these ideas of appropriate practice even more forcefully. An illustrative example manifests in the connection of the NEST smart thermostat to the Jawbone UP®. The Jawbone UP system is one of many wearable devices that use sensors to collect a range of personal data with the aim to 'help people live better by providing personalized insight into how they sleep, move and eat' [37]. Access to the NEST thermostat enables 'making [better lives] reality' by automatically lowering the temperature in the bedroom to a supposedly ideal sleeping temperature when the wristband identifies 'sleep mode' [7]. Through the Jawbone and NEST performing artefacts, ideal sleeping temperatures according to UP lie between 18.3°C and 22.2°C. Moreover, according to this [58] review, the system does not 'allow' a sleep setting below 15.5°C. This idea of healthy sleeping temperatures can be traced back to national health recommendations [54, 55], as well as scientific research into sleep hygiene [33]. However, other, less prominent research is contesting these recommendations [34, 39, 52, 53], and expressing concern about the implications for domestic energy use of normalizing sleeping in a heated space [44].

Co-performance highlights the interplay between expert and everyday ideas of appropriate practice. *The question then arises of whose idea of appropriate practice has, or should have more leverage in the situated performance*. This is not just a practical issue, concerning 'what works' and 'what does not work' under specific circumstances. It also has profoundly *ethical implications* for who has more power and why. Artificial 'doings' are of a different kind than steering or motivating people to do something, just like there is a difference between someone saying or implying that your home is untidy, and them tidying it for you according to their standards.

Moreover, the different, unique capabilities of artificial performers make their suggestions of appropriate performance gain particular authority. First, because artefacts can supplement human performance in previously unimaginable ways and propose new forms of practice that are not possible without them. As such, they make themselves indispensable once these practices are socially accepted. Second, because artificial dispositions of appropriate practice represent expert ideas that tend to be based in scientific evidence, these have a certain authority. And third, because judgments made in the design process and embodied into the artefact cannot be directly contested.

IMPLICATIONS OF A CO-PERFORMANCE PERSPECTIVE FOR HCI DESIGN PRACTICE

The growing idea that artificial intelligence as embedded in computational artefacts of everyday use can contribute to better lives is, naturally, a widely held idea among those active in the field of HCI. The idea that computational artefacts are the solution for a wide range of human flaws is stronger in some sub-communities of the field, while others recognize that forms of living and societal issues can be (partly) rooted in the way certain technologies are designed and spread in everyday life [18, 29].

We argue that the concept of co-performance shows potential to be developed into a range of design approaches and tools that can aid designers of computational artefacts critically weigh what their technologies are or should be capable of, acknowledging that what is an appropriate practice (or more simply, what works and make sense) varies over situations and changes over time. *A practice theoretic framework can help HCI researchers and designers work with this idea of appropriateness and how it changes through co-performance between humans and computational artefacts*. Part of this appropriateness lies in the ways in which human and artificial performers can play parts that suit their capabilities. But it is more complex than that, because a practice also reshapes to suit the capabilities of its performers, as we have seen in the example of domestic space heating. So part of the appropriateness also has to do with the margins designers leave to the interplay between everyday/expert and situated/de-contextualized ideas of appropriate practice that play out in situated performances.

Facilitating appropriate performances

In contrast to an idea of smartness, which focuses on a supposed autonomy of the artefact and leaves little room to the situated intelligence of humans, co-performance considers artefacts as capable of learning and performing tasks and judgments next to people, within broader social dynamics. Considering artificial agency as performing practices alongside people means that artefacts can now be conceptualized using some of the same categories and vocabularies previously used only for human performers. For example, human bodies have particular characteristics that at least for now, make them particularly suited for certain tasks, such as moving around the house and picking up varied objects. They are able to make judgments and operate with certain flexibility and capabilities of improvisation that computational artefacts presently lack. However, we could imagine that in the future, connected to multiple databases, artificial performers will be able to operate in a context so wide to escape human capabilities of comprehension and 'adjustment.'

A co-performance perspective could help the HCI community concerned with artificial intelligence and broader matters of human-nonhuman symmetry to articulate and devise frameworks and tools that facilitate designers to *discern and integrate different capabilities, uniquely human and uniquely artificial, into appropriate roles and co-performances.*

Designing for recursiveness between professional design practice and everyday use practices

Viewing computational artefacts as co-performers of practices together with people makes a direct link between decisions made in the design process and use practices carried out in everyday life. All this requires conceptualizing everyday life and technology development as a collection of interrelated practices. Viewing artefacts as co-performers of practices provides a way to understand the multiplicity of design practices into everyday life, as urged by DiSalvo [16], and make explicit the situated decisions that have been delegated from the everyday use practice to the development practice.

Viewing artefacts as co-performers within collaboratively pursued ends highlights the recursiveness between design practice and use practices because design decisions are based on often long-term historic, and therefore culturally varied, processes in everyday life. Performances of artefacts are not determined by decisions made in the design process only, although some frames and trajectories are shaped by these decisions. As suggested by Giaccardi et al. [30] performances of computational artifacts expose forms of practice that is difficult to express in terms of just design or use (on the role of artefacts in research and design see also [5, 19, 64]). Artefacts reveal trajectories and frames that are to a greater or lesser extent open to modification, especially by more skilled everyday designers [13, 88].

A co-performance perspective could help the HCI community to formulate design methods apt to *determine the desirable dimensions of openness of the technology and thus repair performances by the artifact that are deemed inappropriate under situated circumstances* (cf. [43]).

Promoting an ethics of co-performance

Considering computational artefacts as co-performers of practice next to people, and focusing on matters of co-performance and appropriateness rather than autonomy and distribution of agency (or delegation), helps frame and mobilize the link between everyday use practices and professional practices of design. This promotes *a design ethos and form of design practice that recursively bridges design time and use time*.

In the early days of AI, Suchman exposed and criticized the tendency of HCI designers to view humans too much in terms of machines [23]. However, we argue that the opposite is also risky, where technologies are discussed too much in human terms (e.g., as smart) and create unrealistic expectations. By developing a co-performance vocabulary that explores the possibilities of (future) technologies to complement people's capabilities in new and rich forms of everyday practice, the concept of co-performance shows potential to promote "ways of framing and solving problems collaboratively" with computational artifacts which capitalize on their different capabilities [28, 30]. If computational artefacts can be designed to complement humans by taking on roles that suit their unique capabilities, then new and emerging technologies offer possibilities for new co-performances and forms of practice. Thinking in terms of complementary capabilities asks for a co-performance vocabulary - one that *acknowledges artificial performers as a category in their own right and not as (poor) imitations of human ones*.

CONCLUSIONS

In this paper we have introduced the concept of co-performance as a novel perspective on the role of artificial agency in everyday life. Interest in what is often referred to as smart and autonomous devices, and more recently embedded artificial intelligence, has grown in HCI. Increased proliferation of such computational artefacts in the messy and unpredictable settings of everyday life, however, poses significant challenges. To address these challenges, we have reflected on smart thermostat design. We have done so from the perspective of historic changes in both human and artificial performances and roles, in relation to the social practice of domestic heating. Through the links that can be made between changes in ideas of appropriate indoor climates, we have unpacked the main tenets of co-performance and offered the beginnings of a new research agenda.

Considering the interplay between humans and artefacts in everyday life is not new, but linking it to the conceptual framework of social theories of practice in HCI allows to conceptualize the relations between people and artefacts in a wider context, which includes the relation between everyday use and professional practices of technology development. Co-performance opens new avenues for HCI researchers and designers to (1) *develop richer accounts of the dynamic role of computational artefacts in everyday life, and by implications related design practices;* and (2) *develop new design theory and strategies that thoughtfully take into account differences in capabilities between human and artificial co-performers, and show sensitivity to the power dynamics involved when different ideas of appropriate practice come together in situated performance*.

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