Devices, Information, and People: Abstracting the Internet of Things for End-User Personalization

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Abstract. Nowadays, end users can take advantage of end-user development platforms to personalize the Internet of Things. These platforms typically adopt a *vendor-centric* abstraction, by letting users to customize each of their smart device and/or online service through different trigger-action rules. Despite the popularity of such an approach, several research challenges in this domain are still underexplored. Which "things" would users personalize, and in which contexts? Are there any other effective abstractions besides the *vendor-centric* one? Would users adopt different abstractions in different contexts? To answer these questions, we report on the results of a 1-week-long diary study during which 24 participants noted down trigger-action rules arising during their daily activities. Results show that users would adopt multiple abstractions by personalizing devices, information, and people-related behaviors where the individual is at the center of the interaction. We found, in particular, that the adopted abstraction may depend on different factors, ranging from the user profile to the context in which the personalization is introduced. While users are inclined to personalize physical objects in the home, for example, they often go "beyond devices" in the city, where they are more interested in the underlying information. Our findings identify new design opportunities in HCI to improve the relationship between the Internet of Things, personalization paradigms, and users.

Keywords: End-User Development · Internet of Things · Trigger-Action Programming · Abstraction · Diary Study · Context.

1 Introduction

Through a network of physical objects always connected to the Internet, and a multitude of online services such as social networks and news portals, the Internet of Things (IoT) already helps society in many different ways, e.g., through applications ranging in scope from the individual to entire cities [6]. Smart devices and online services, in particular, are increasingly pervading the environment and are often utilized together [21], therefore opening up new possibilities for end-user personalization. In this context, End-User Development (EUD) empowers users to program the joint behaviors of their devices and services in various areas, like the home, the car, or for a healthy lifestyle. Several works in the literature (e.g., [14,18,16]) demonstrate the effective applicability of EUD techniques for personalizing different contexts, particularly for the smart home [20,12]. In the broader IoT context, end users can nowadays personalize their ecosystems of devices and services by using cloud-based EUD platforms like IFTTT[1] and Zapier[2], typically by composing trigger-action rules like

> "IF the entrance *Nest* security camera detects a movement, THEN blink the *Philips Hue* lamp in the Kitchen."

Such platforms, however, present their own set of issues, e.g., in terms of interoperability [9] and expressiveness [17]. Within them, in particular, users are forced to compose trigger-action rules with a unique, *vendor-centric* abstraction, with which they must specifically refer to every single device or online service needed to execute the intended behaviors. While such an approach allows users to have a fine-grained control, it forces them to define several rules to program their ecosystems, i.e., every device or online service needs to be programmed in a specific way. Furthermore, it requires users to know in advance any involved technological detail, e.g., the manufacturer or brand of all the involved "things." A number of previous works tried to overcome the aforementioned issues by focusing on the underlying tools [16], notations [3], and/or visual programming paradigms [13]. Despite these recent efforts, several research questions about end-users' personalization needs and attitudes are still underexplored.

Which "things" would users personalize, and in which contexts? What are the most effective alternatives to the contemporary *vendor-centric* abstraction? Would users adopt different abstractions in different contexts? To answer these questions, we report on the results of a 1-week-long diary study in the style of a contextual inquiry with 24 participants living in 16 households. The study consisted of two semi-structured interviews and a period of time in which participants noted down trigger-action rules arising during their daily activities. In the study, we encouraged participants to think of scenarios, both regarding their "physical" and "virtual" worlds, in which they would have liked to personalize the behaviors of their devices and online services, and we gathered more than 200 trigger-action rules composed by the participants during the week of study.

Results show that users would define triggers and actions by adopting *different abstractions* in *different contexts*, with personalization needs that go beyond the smart home and include other smart environments and the "online" world as well. Participants of our study, particularly in the case of programming experts and tech-enthusiasts, used a *device-centric* abstraction to personalize different IoT entities, ranging from domestic appliances to car accessories. Through an *information-centric* abstraction, instead, participants went beyond physical devices by shifting their focus to the underlying information, e.g., to personalize their personal plans and appointments, news, and messages. Participants also

[1] `https://ifttt.com/`, last visited on April 20, 2021
[2] `https://zapier.com/`, last visited on April 20, 2021

envisioned their direct involvement in trigger-action rules by defining *people-centric* behaviors. With triggers such as *"when I enter home in the evening"* or *"if me and my friends have free time"*, for example, they explicitly positioned themselves (and other people) *inside* the personalization. An analysis of the contexts in which participants envisioned their personalizations further demonstrates that users would adopt multiple abstractions. We found, for example, that participants mostly used *people-to-information* rules for their health and wellbeing, by connecting a trigger that directly involves the individual to an action for obtaining or manipulating an information. In the smart home context, instead, participants extensively used *device-to-device* rules to customize the joint behavior of different devices or systems. Furthermore, participants used *information-to-information* rules to personalize information when the context was the city or their "online" world.

To encourage further research on the evolving fields of End-User Development and Internet of Things, we release the dataset collected during the study[3]. Furthermore, we discuss our results by identifying new design opportunities in HCI to improve the relationship between the Internet of Things, personalization paradigms, and users. Adapting EUD interfaces to different abstractions may reduce the gap between expectations and reality, thus breaking down barriers and increasing the adoption of EUD for an effective personalization of the IoT.

2 Background & Related Works

The core idea of adopting end-user development for IoT personalization is to empower users to take advantage of *ecosystems of interoperable smart objects and services* [1], by letting them combine flexibly, i.e., according to their situational needs, the behavior of different entities [13]. In this context, platforms such as IFTTT and Zapier have become popular [17]. Through Web editors, users can typically define trigger-action rules, i.e., they can define sets of desired behaviors in response to a specific event. Trigger-action programming is indeed one of the most popular programming paradigm adopted in EUD: it has been largely used for introducing personalization in different contexts, e.g., the smart home [20,12], and it offers a very simple and easy-to-learn solution for creating IoT applications, according to Barricelli and Valtolina [1]. For these reasons, in our study, we chose the trigger-action programming paradigm to explore end-users' abstractions in personalizing their IoT ecosystems.

Despite their growing popularity, existing platforms for IoT personalization present their own set of issues. The expressiveness and understandability of IFTTT rules, for instance, have been criticized since they are rather limited [20,17,21]. By discussing metaphors and programming styles for EUD, in particular, Paternò and Santoro [19] state that the possibility to compose complex events and actions is limited in contemporary platforms for IoT personalization, and they propose a new design space to include several additional

[3] The dataset is available at `https://bit.ly/3gmU1Ec`

aspects, with a particular focus on different kinds of (contextual) triggers and actions. In platforms like IFTTT and Zapier, indeed, users are forced to compose trigger-action rules with a unique, *vendor-centric* approach. This clearly poses interoperability challenges, as users are required to know in advance any involved technological detail to execute the intended behaviors. In the forthcoming IoT world, however, new "things" will not always be knowable a priori [22] but they may appear and disappear at every moment, e.g., as with public services in a smart city. As a result, little social and practical benefits of End-User Development in the IoT have emerged [13]. A number of previous works tried to overcome the aforementioned issues. Baricelli and Valtolina [1], for instance, proposed an extension of the trigger-action paradigm that incorporates recommendation systems, other users, and the social dimension. Brich et al. [3] reported on the comparison of two different notations, i.e., rule-based and process-oriented, in the smart home context, showing that trigger-action rules are generally sufficient to express simple automation tasks, while processes fit well with more complex tasks. Desolda et al. [13] reported on the results of a study to identify possible visual paradigms to compose trigger-action rules in the IoT, and presented a model and an architecture to execute them. Ghiani et al. [16] proposed a method and a set of tools to personalize the contextual behavior of IoT applications. Differently from the described approaches, where the focus is on the underlying tools, notations, and/or programming paradigms, we focus on the different abstractions that users would adopt to personalize their devices and services.

Previous work mainly explored end-users' personalization needs and abstractions in limited scenarios, e.g., the smart home [20,3], analyzed rules of existing platforms *off-line* [21], or explored pre-built conceptual models in a few minutes with a questionnaire prompt [7]. In our work, we claim that multiple abstractions besides the *vendor-centric* one are possible and needed to empower users personalize their IoT ecosystems, and that such abstractions may depend on the context in which the personalizations are introduced. Only few recent works explore the personalization of IoT ecosystems through the lens of abstraction. Ur et al. [20], for instance, found that the way users express triggers ranges from events related to sensors to more abstract behaviors that involve multiple devices. In their study, the authors asked participants to "imagine that you have a home with devices that are Internet-connected and can therefore be given instructions on how to behave," therefore adopting a device-oriented abstraction [7]. By exploring triggers and actions that go beyond devices, instead, Corno et al. [8] proposed EUPont, an ontological representation of End-User Development in the IoT for creating context independent IoT applications based on the users' final goals. Instead of turning on a Philips Hue lamp or opening the bedroom's blinds, for example, with EUPont users can directly ask the system to *illuminate* the room. Despite the aforementioned works, it is still unclear which abstraction users would prefer, and whether such an abstraction depends on the context in which the personalization is introduced. As demonstrated by the work of Clark et al. [7], the way a system is presented to the user can have a priming effect on the initial mental models formed by users. Stemming from such an assumption, which highlights how critical it is to consciously choose abstractions in the design phase, we decided to explore abstractions in IoT personalization *in-the-wild*, with the aim of going beyond the contemporary *vendor-centric* approach.

3 Diary Study

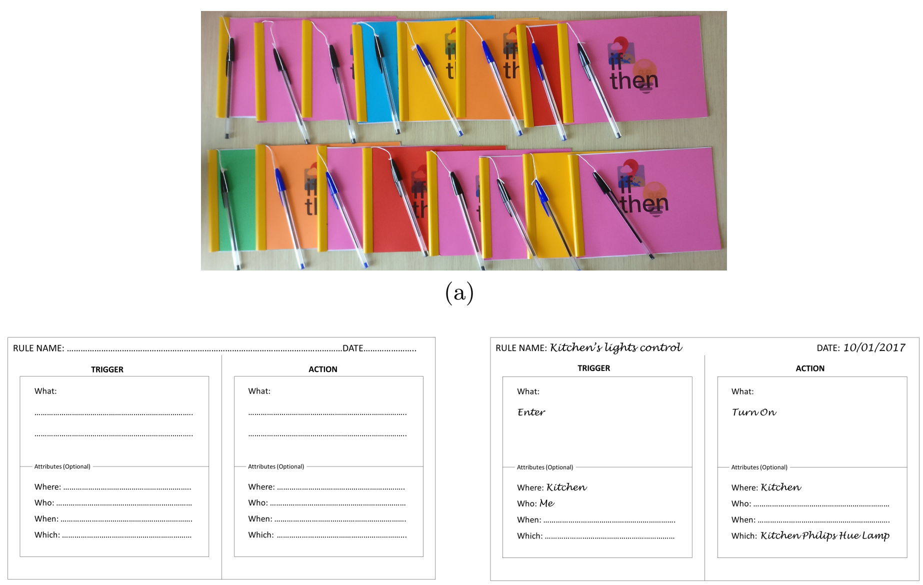
We devised a diary study in the style of a contextual inquiry to end-users' personalization needs and adopted abstractions in the IoT. Although diary studies suffer from the problem that they are tedious for the recorder, they have high ecological value as they are carried out *in situ*, in the users' real environments [11], and they can offer a vast amount of contextual information without the costs of a true field study [4]. Our aim was to investigate:

(a) how far-reaching are end-users' needs in personalizing the IoT;
(b) whether other abstractions besides the contemporary *vendor-centric* one are possible, and
(c) whether the adopted abstraction(s) depend on the context in which the personalizations are introduced.

Participants Due to the sensitive nature of the study, consisting in multiple home visitations, we recruited 24 participants from our social circle through direct e-mails and messages. To motivate participants for the study, we drew a prize worth more than 250 € among those who accepted. We tried to balance the population with respect to the following characteristics: age, gender, living situation, and occupation. The mean age of the participants (15 male and 9 female) was 31.71 years ($SD = 11.47$, $range = 19 - 57$). Overall, 18 participants lived in a shared household, i.e., in couple or with more than 2 other inhabitants, while the remaining 6 participants lived alone. The participants' occupations reflected a very varied population. Our study involved office workers (7), students (6), primary school teachers (3), farmers (3), factory and construction workers (3), an entrepreneur, and an airplane pilot. We also asked participants to answer some initial questions about their technological affinity. On a Likert-scale from 1 (Very Low) to 5 (Very High), participants stated their level of technophilia ($M = 3.83$, $SD = 1.09$) and programming experience ($M = 1.58$, $SD = 0.92$). Only 2 participants out of 24 had already used platforms like IFTTT.

Rule Notation and Composition Kit To allow participants to define IoT personalizations in their daily lives, we created a *composition kit* with which users could freely note down trigger-action rules arising during their daily activities at home or outside. We chose to adopt the trigger-action paradigm due to its simplicity and its popularity in the context of End-User Development [1]. As done by Brich et al. [3] in the smart home context, we built a pen and paper kit to avoid artificially restricting the elicitation process to a specific user interface.

The *composition kit* consisted on a home-made book and a pen (Figure 1(a)). To express trigger-action rules in the study, we defined a *rule notation*. To focus on the research goal without introducing unnecessary complexity for end users, we adopted the simplest form of the trigger-action programming approach, i.e., each rule contains exactly one trigger and one action. As suggested by Ur et al. [20], we allowed participants to enrich each trigger and action with multiple restrictions. In particular, the rule notation is inspired by the work of Desolda et al. [13], where the authors chose to follow a *5W* model for defining triggers and actions. The original *5W* model is adopted in several domains, such as journalism and customer analysis, to analyze the complex story about a fact through the following keywords: **W**hat, **W**ho, **W**hen, **W**here, and **W**hy. We adapted the model in our notation by specializing the meaning of each keyword to our domain, and by replacing the **W**hy with the **W**hich keyword (Figure 1(b)). In particular, **W**hat is used for describing the trigger or the action, while **W**ho, **W**hen, **W**here, and **W**hich are used as social, temporal, spatial, and technological constraints, respectively. To compose trigger-action rules, the book contained 20 pages with the *rule notation* template (Figure 1(b)). Furthermore, it contained a brief manual, and some rule examples (Figure 1(c)).



(a)

(b) (c)

Fig. 1. Figure 1(a) shows the kits we used for the diary study, composed of a booklet and a pen.Figure 1(b) shows the template reported on the 20 book's pages for composing trigger-action rules, while Figure 1(b) reports one of the rule example reported in the book. In the reported examples, we intentionally used different abstractions to avoid biases.

Study Procedure To start the study, we set up a first appointment at the participants' home[4]. The appointment took about 30 minutes. At the beginning, participants were introduced to the general idea of EUD in the IoT. First, the IoT paradigm was introduced, along with some examples of devices and online services. Then, participants were taught about the trigger-action programming approach and the adopted *rule notation*, with some practical examples of trigger-action rules in different contexts and with different levels of abstractions. Finally, we gave the *composition kit* to the participants: they were instructed to take the kit with them in all their daily activities, and to record as many trigger-action rules as possible until the second appointment one week later. At the end of the study, we revisited participants in their home for a second appointment that took about 30 minutes. At the beginning of the appointment, participants were asked to show the trigger-action rules they had defined by explaining their mental process retrospectively. The focus of this phase was to understand whether the noted down trigger-action rules were correctly representing the ones participants envisioned, and to identify which abstractions participants used. Then, we concluded the study with a debriefing session. Our aim was to understand why participants used a given abstraction, and to investigate whether participants were aware of the implications of using a particular abstraction. All home appointments were audio-recorded. In case of households with more than one inhabitant, the two appointments were conducted separately.

4 Results

Thanks the study, we collected 233 freely recorded trigger-action rules and more than 25 hours of audio recording. In this study, we report on the different abstractions adopted by our participants in their trigger-action rules, we describe the contexts in which the participants' personalizations have been envisioned, and we study the relationships between these contexts and the adopted abstractions. We support qualitative outcomes with quantitative results. To further explore our data, we also divide participants in four groups, on the basis of a) their *programming expertise*, i.e., by considering experts those participants that declared a programming experience greater than 3, and b) their *enthusiasm towards technology,* i.e., by considering enthusiasts those participants that declared a technophilia greater than 3 (in both cases, out of a Likert-scale of 5). Results are shortly discussed where necessary, while insights and new design opportunities are presented in the next section.

On average, each participant contributed to the study with 9.71 rules ($SD =$ 3.74). Programming experts tended to record more rules with respect to participants with limited programming experience ($M = 11.34$, $SD = 4.04$, *vs.* $M = 9.47$, $SD = 3.75$, respectively). The technophilia, instead, did not affect the number of collected rules: both tech-enthusiasts and non enthusiasts recorded, on average, a very similar number of rules ($M = 9.81$, $SD = 3.43$, *vs.* $M = 9.50$, $SD = 4.57$, respectively).

[4] The study was conducted before the COVID-19 pandemic.

4.1 Personalizing the IoT Through Different *Abstractions*

To explore which abstractions end-users would adopt in personalizing their IoT ecosystems, we firstly analyzed the recorded triggers and actions, along with the participants' explanations collected in the final appointment, with the aim of determining clusters. To classify triggers and actions, in particular, we adopted the categorization proposed by Clark et al. [7] in the smart home context, according to which a personalization may fall in one these categories:

Device-centric A personalization whose subject is the physical medium with which it is executed. In our context, device-centric triggers and actions specified a device either directly in the **W**hat field or in the **W**hich field. A device-centric trigger, in particular, represents an event that is recognized by a physical object, while a device-centric action is the execution of an automatic behavior on a physical object. Participants, for example, used a device-centric abstraction to detect when the *garage door* closes (P1), to monitor the *car's* speed (P15), or to discover when there is an electrical failure in the *home lighting system* (P6).

Information-centric A personalization whose subject is the underlying information, regardless of the physical medium with which it is manipulated. In our context, information-centric triggers and actions specified such an information either directly in the **W**hat field or in the **W**hich field. A data-oriented trigger, in particular, represents an information that becomes available, while a data-oriented action is an information to be automatically obtained. Participants, for example, used an information-centric abstraction to monitor *their university exams* (P2), to detect when a *dangerous web site* has been visited (P14), or to manage *Facebook's notifications* (P12).

When rules were expressed in an ambiguous way, we used the qualitative data collected during the home appointments to disambiguate participants' intentions. During such a process, we found a large group of triggers that did not follow a device-centric nor infomation-centric abstraction. While these triggers resembled the "fuzzy triggers" discovered by Ur et al. [20] in the smart-home context, they also shared an additional characteristic, i.e., all of them envisioned a direct involvement of the participant in the personalization. We therefore defined an additional abstraction:

People-centric A personalization where users, their actions, and/or feelings are at the center of the interaction, independently of any physical and virtual medium. In our context, people-centric triggers had typically an empty **W**hich field, and they explicitly mentioned an individual or a group of individuals either directly on the **W**hat field or in the **W**ho field. Participants, for example, used a people-centric abstraction to trigger an event whenever *they arrive* at home (P8), to monitor *family members* (P20), or for more futuristic ideas, e.g., to detect when *they are hungry* (P20).

Participants demonstrated to prefer the *device-centric* abstraction when defining triggers (103 times), but they consistently used the *information-centric* and the *people-centric* abstraction, too (70 and 60 times, respectively). In defining actions, instead, participants adopted the *device-centric* and the *information-centric* abstractions in a similar way (121 and 112 times, respectively). Interestingly, although we could easily imagine people-oriented actions (e.g, "wake me up"), we did not find any collected actions that followed such an abstraction. We did not find any significant statistical difference on the adopted abstractions between participants' groups, i.e., programming experts *vs.* non experts and tech-enthusiasts *vs.* non enthusiasts, although interesting qualitative trends emerged. For what concerns triggers, programming experts and tech-enthusiasts demonstrated on average their preference towards including devices in their personalizations. Programming experts, for example, recorded on average 6.00 *device-centric* triggers ($SD = 5.29$), while they used the information-centric abstraction 2.67 times on average ($SD = 2.16$) and the people-centric abstraction 2.33 times on average ($SD = 2.08$). On the contrary, people with limited programming experience and enthusiasm used the 3 different abstractions in a similar way. Non-enthusiast participants, for example, recorded on average 3.36 *device-centric* triggers ($SD = 3.29$), 2.87 *information-centric* triggers ($SD = 2.03$), and 3.12 *people-centric* triggers ($SD = 2.23$). Such results seems to suggest that people that already know how to program and love technology prefer to maintain control over their IoT ecosystems. When considering actions, instead, differences are less prominent and no explicit trend emerges: independently of their programming expertise and technophilia, participants defined actions both with the *device-centric* and the *information-centric* abstraction.

The abstractions used by participants for defining triggers and actions lead to different types of rules. Table 1 describes the retrieved rule types and presents some examples. From *device-to-device* rules, i.e., rules with both the trigger and the action expressed with a *device-centric* abstraction, to *people-to-device* rules, i.e., rules with a *people-centric* trigger and an *information-centric* action, participants personalized their IoT ecosystems in very different ways.

4.2 The Right Abstraction for the Right *Context*

By looking at the collected trigger-action rules, and, in particular, by analyzing the **W**here fields, we found that participants introduced personalizations in different contexts. By means of 94 different trigger-action rules, participants often personalized the behaviors of their home, thus confirming the user's interest in home automation [3]. In 20 cases, in particular, participants defined rules to control home appliances, ranging from the coffee machine to the fridge. In some cases, participants referred to multiple appliances in the same rule. P19, for example, defined the following rule: *"[if] the dishwasher, the washing machine, and the oven are all turned on at the same time, [then] a limiter automatically deactivates other not essential appliances, to avoid failures in the home lighting system."* This highlights a gap between end-users' mental models and the contemporary *vendor-centric* abstraction. The latter, in fact, typically allow users to program one appliance at a time. Other prominent rules in the smart home context were recorded to control lights (12), doors and windows

Table 1. The abstractions used by participants lead to different types of rules, from *device-to-device*, where rules involve devices, only, to *people-to-information*, where triggers that directly involve users are used to obtain or manipulate information. The reported rules have been rephrased for the sake of readability.

	Description	Examples
Device To Device	Rules to execute an action over a physical entity when something happens or is detected by another physical entity.	"[If] the *tensiometer* detects that the soil is dry, [then] turn on the *irrigation system*" (P11)
Device To Information	Rules to obtain or manipulate an information when something happens or is detected by a physical entity.	"[If] the *sensor* detects that it's raining, [then] warn me through a *WhatsApp message* or a *SMS*" (P18)
Information To Device	Rules to execute an action over a physical entity when a new information is available.	"[If] the *weather conditions* change while I'm driving, [then] the *car radio* starts playing songs that better fit with the new conditions" (P6)
Information To Information	Rules to obtain or manipulate an information when another information is available.	"[If] my *bank account* exceeds a threshold, [then] propose me safe *financial investments*" (P11)
People To Device	Rules to execute an action over a physical entity when an individual perform a generic action or her conditions change.	"[If] *I'm hungry* at night, [then] lock *the fridge* and the food storage" (P3)
People To Information	Rules to obtain or manipulate an information when an individual perform a generic action or her conditions change.	"[If] *I wake up*, [then] read the *newspaper headlines*" (P12)

(9), and the temperature of the environment (7). Also in this case, participants specified triggers and actions in different ways. With the rule *"[if] the temperature on the thermostat drops below a given threshold, [then] set the thermostat temperature to a predefined value,"* for instance, P15 referred to a specific device (the thermostat) both in the trigger and in the action. Instead, the rule *"[if] my daughter is coming home in the weekend, [then] automatically warm her room"* of P21 generically referred to the heating system of his daughter's room. Despite the popularity of the home context, participants also personalized other smart environments, such as their gardens and courtyards (25), their car (23), and their workplace (17). The car, in particular, was mentioned in rules with different purposes. In this rule of P15, for instance, the car is considered as the main focus of the personalization: *"[if] my boyfriend or I exceed the speed limit by car, [then] decrease the car speed within the limit."* This rule of P3, instead, considers the car as a specific context: *"[if] I'm using the smartphone while I'm driving, [then] block it."* In addition to environments under their strict control, e.g., the home and the car, participants also envisioned rules in the city context (19 times), thus defining triggers and actions that involve environments, devices, and services that could be potentially accessed by all the citizens. P19, for instance, would like to be notified on her smarthpone when pollution exceeds a given threshold, while P22 would like to be warned when there is a nearby car accident. Besides "physical" environments, we found that participants' rules frequently involved their online world (36 times) and their health and wellbeing (19 times). With rules such as *"[if] I publish a post on a social, [then] post it on all the other social networks"* (P4) and *"[if] my car insurance is about to expire, [then] perform a market research on the web"* (P14), participants personalized social networks, news, and their "online" information in general. For their health and wellbeing, instead, participants often defined automatic notifications to be received whenever their health parameters changed, e.g., *"[if] I have some hearth problems, [then] send me a notification"* (P12).

We also studied the relationship between the context and the type of the rule. Our aim was to investigate whether the adopted abstraction depended on the context in which the personalization was introduced. Figure 2 shows how many times (in percentage) participants used a given rule type in a specific context.

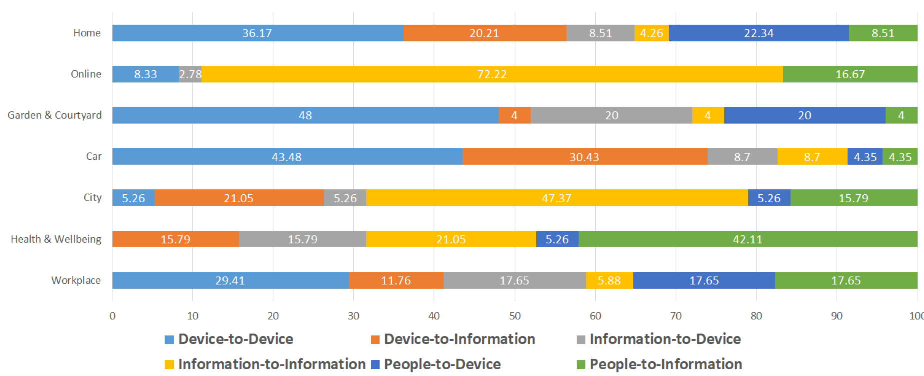


Fig. 2. How many times (in percentage) participants used a given rule type in a context. While *device-to-device* rules were prominent in the home context, participants were more interested in information rather than devices in the city context. Furthermore, participants defined *people-centric* triggers in all the contexts, especially in their workplace, their home, and for their health and wellbeing.

By analyzing the figure, interesting patterns emerge:

– In the home, garden & courtyard, car, and workplace, i.e., the "physical" contexts under their strict control, participants extensively used *device-to-device* rules (36.17%, 48%, 43.48%, and 29.41%, respectively). In such contexts, also *information-centric* and *people-centric* triggers and actions were typically associated with physical devices or systems, while *information-to-information* rules, i.e., personalizations involving information, only, were

rarely used (4.26% in the home, 4% in the garden & courtyard, 8.7% in the car, and 5.88% in the workplace).
- In the city, participants were more interested in information rather than devices. Only 5.26% of the rules were of type *device-to-device*. On the contrary, participants defined *information-to-information* and *device-to-information* rules in 47.37% and 21.05% of cases, respectively. Furthermore, while in the other physical environments the *people-centric* abstraction was frequently associated to devices, in the city participants preferred *people-to-information* rules (15.79%).
- Not surprisingly, the *information-centric* abstraction was prominent in the online context, and it appeared in the 91.67% of the related rules in total. *Information-to-information* rules, in particular, were the most common, and were defined 72.22% of cases.
- Participants used the *people-centric* abstraction in all the contexts. With the exception of the car (8.7%) and the online context (16.67%), all the other contexts were personalized through *people-centric* behaviors in more than 20% of cases. In the majority of the rules for the health & wellbeing context (47.37%), for example, participants used *people-to-information* (42.11%) and *people-to-device* (5.26%) rules. *People-to-information* rules were also frequently used in the workplace (17.65%), in the online context (16.67%), and in the city (15.79%). In other contexts such as the home and the garden & courtyard, the *people-centric* abstraction was more often involved in *people-to-device* rules (22.34% and 20%, respectively).

5 Design Opportunities for Personalizing the IoT

We believe that our findings may have a significant impact on the design of new interfaces for personalizing the IoT. By knowing the abstractions end users would adopt and in which contexts, researchers and designers may propose new solutions to break down barriers and increase EUD adoption in the IoT.

Adapting to Different Abstractions Researchers and designers in the field of end-user personalization in the IoT need to be aware that users would define their trigger-action rules by adopting *different* abstractions depending on their programming experience, their enthusiasm towards technology, and the contexts in which the personalization is introduced. Instead of using a single, *vendor-centric* approach, participants of our study ranged from a *device-centric* abstraction, with which they "programmed" their physical entities, to other abstractions that go beyond physical devices, i.e., *information-centric* and *people-centric*. With *information-centric* triggers and actions they focused on the underlying information, while with *people-centric* triggers participants explicitly positioned themselves (and other people) *inside* the personalization. This variety of adopted abstractions highlights a huge gap with the contemporary EUD solutions, and opens the way to new design opportunities. By embracing different abstractions as a part of their system design space, in particular, designers may explore *adaptive* interfaces. The way a system is presented to the user, in fact, can have a priming effect on the initial mental models formed by users [7], thus influencing how they update their understanding of it based on newly-acquired knowledge [2]. Different strategies could be adopted. On the one hand, novel EUD solutions could provide users with the possibility of choosing the preferred abstraction. On the other hand, they could explicitly prime the user towards a specific abstraction. By reasoning on the "user profile," for example, an EUD interface could empower programming-experts in personalizing specific devices, while it could assist users with no or limited programming experience in personalizing their IoT ecosystems through *information-centric* and *people-centric* behaviors. As reported in our work, such an adaptation should also consider the context in which the personalization is introduced. To customize users' environments, e.g., homes or workplaces, designers of EUD interfaces should empower users in easily personalizing physical components, be they single devices or more complex systems. For other contexts, instead, EUD interfaces may be automatically adapted to different abstractions. When customizing the "online" context, for example, EUD interfaces could shift their abstraction towards the underlying information, while they might allow users in defining *people-centric* triggers for their health & wellbeing.

Sharing User's Preferences and Habits Similarly to previous works exploiting a similar methodology (e.g., [3]), we only observed few rules (5, 2.15%) impossible to be executed, at least in the near future, with contemporary technology. All of them included "futuristic" triggers like *"when I'm hungry"* or *"when I'm curious about something."* The usage of a constraint-free study methodology, however, poses questions about the technical feasibility of the composed rules. While a trigger defined with the contemporary *vendor-centric* abstraction can be monitored via a specific device or online service, indeed, this is not true for *people-centric* triggers, for example, as they could be executed and adapted in different ways at run-time. The *"when I enter home"* trigger, for instance, could be monitored through a door that has been opened, or through a security camera detecting movements, among the others. When asked, in the final appointment, whether they would accept an intelligent system to automatically execute these "generic" triggers and actions, 17 participants out of 24 (70.84%) answered yes, at least in some cases. This seems to be partially in conflict with previous works in the smart home context [5,10] that demonstrated that users do not want to lose control over the system. P14, for example, said: *"I want the lights to be automatically turned off, I don't care how to detect that I left the room ."*

Participants, however, pointed out that they would accept automated solutions for simple use cases, only, e.g., to control lights and temperature, and clearly excluded fully automated solutions. P24, for example, said: *"I don't want a black box: for generic triggers and actions, I would like the possibility to interact with the system, to define my preferences and eventually change the system's choices."* Also other participants envisioned an interaction with the system with the aim of sharing their preferences and habits. We claim that such an interaction is fundamental to *guide* the execution of generic behaviors, thus avoiding black-box solutions and maintaining a certain degree of control over the system. This is particularly true for the *people-centric* abstraction, with which our participants went beyond devices and information by defining triggers and actions that strongly depended on their tastes and feelings, e.g., *"when I'm hot"* (P3) and *"set my ideal water temperature"* (P22).

6 Limitations

There are some limitations to be considered in our work. While we balanced our participants according to different characteristics, e.g., occupations, programming experience, and tech-enthusiasm, our study involved a small sample of 24 users, and all our participants came from the same cultural background. Further analysis involving larger and varied samples are needed to assess the generalizability of our findings to other populations. As such, our study provides a sample of typical size for qualitative studies. Another limitation is related to the study design. The examples adopted in the initial appointment, in pariticular, may have influenced the abstractions participants adopted. The rule notation as well may have biased participants. Results, however, highlights consistent differences in the adopted abstractions. Finally, it has to be kept in mind that a diary study as the one we devised does not allow for making any assumptions about how seriously users would engage with real-world devices, systems, and online services, that are obviously a lot harder to set up and maintain than a piece of paper. Nevertheless, using a diary empowered our participants to be creative without any restriction, and allowed us in pursuing our goal, i.e., eliciting the abstractions end users would adopt with no regard for current technological constraints.

7 Conclusions

The expected growth of the Internet of Things opens new possibilities for end users: they can already personalize their devices and services on the basis of their personal needs. End-users personalization is particularly important since people are often forced to improvise, in order to tackle with unexpected changes in their life. Moreover, users would like to address these changes creatively, while adapting existing solutions to solving their issues at hand [15,20]. Contemporary EUD platforms in the IoT, however, present their own set of issues, and as a consequence, different gaps between users' expectations and reality emerge [13].

In this work, we tried to close these gaps by exploring, directly with end users, the *abstractions* they would adopt in personalizing their IoT ecosystems. The way a system is presented to the user, in fact, can have a priming effect on the initial mental models formed by users, and the abstraction used by a system is strictly related to its adoption [7]. By reporting on the results of a diary study with 24 participants, we show that users would adopt different abstractions by programming devices, information, and people-related behaviors, and we demonstrate that the adopted abstraction may depended on different factors, ranging from the user profile, e.g., her programming experience, to the context in which the personalization is introduced. While users are inclined to personalize physical objects in the home, for example, they often go beyond devices in the city, where they are more interested in the underlying information. Furthermore, through *people-centric* triggers, users would explicitly position themselves (and other people) *inside* the personalization, independently of the context.

Our findings point to new design opportunities in HCI to improve the relationship between the Internet of Things, personalization paradigms, and users. By embracing different abstractions as a part of their system design space, designers may explore EUD interfaces that go beyond the contemporary *vendor-centric* approach, able to adapt their abstractions and to share users' habits and preferences.

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