Rule-based Tools for the Configuration of Ambient Intelligence Systems: a Comparative User Study

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Abstract

This paper describes a 63-participant user study that compares two widely known systems supporting end users in creating trigger-action rules for the Internet of Things and Ambient Intelligence scenarios. The user study is the first stage of a research agenda that concerns the implementation of a novel conceptual framework for the design and continuous evolution of 'sentient multimedia systems', namely socio-technical systems, where people and many kinds of hardware/software components (sensors, robots, smart devices, web services, etc.) interact with one another through the exchange of multimedia information, to give rise to intelligent, proactive behaviors. The conceptual framework is structured along three layers - physical, inference and user – and is based on an information space of events, conditions and actions, linked together in Event-Condition-Action rules and operating according to the interconnection metaphor. The results of the user study have provided some indications for the implementation of the user layer, suggesting which could be the most suitable interaction style for rule design by a community of end users (e.g. a family) and which issues should be addressed in such a wide context.

Keywords: End-User Development; Internet of Things, Ambient Intelligence; Interconnection; Rule-based Programming; User Study.

1. Introduction

Ambient Intelligence (AmI) is "the vision of a future in which environments support the people inhabiting them" [Sadri, 2011], or, in other words, where environments are active places able to respond to people's requests and behave proactively to satisfy their needs [Riva et al., 2005]. In these definitions, emphasis is mainly put on hardware and software components that make up such kinds of environments, namely on the so-called Internet of Things (IoT) that constitutes the global and invisible computational framework that gives rise to the proactive and autonomous behavior of the environment [Atzori et al., 2010].

In [Cabitza et al., 2014b], this view has been extended by conceiving an intelligent environment as a "sentient multimedia system", which not only encompasses a variety of sensors, actuators, smart devices, web services and intelligent software agents, able to process multimedia information, but also includes "social" components, namely the environment inhabitants, with their perceptive, reasoning and operating capabilities, as well as the social ties that bind them together. This is apparent in the smart home, where not only the smart devices (TV, fridge, washing machine, etc.) and alarm systems have a role in endowing the home with an intelligent behavior, but also, and above all, the household members contribute to this intelligence. They do this both with their decisions in unusual situations and as sources of multimedia information in routine activities, by communicating implicitly or explicitly their feelings, needs and requests to the web of computational nodes.

To model the behavior of such a socio-technical system, a conceptual framework based on the concept of *interconnection* is proposed in [Cabitza et al., 2005]. That idea, which is here refined, is to consider all the actors involved in an AmI environment, i.e., devices and humans, as interconnected with one another through a fluid exchange of *events* (e.g., it is 10.00 PM), *conditions* (e.g., nobody is in the garden) and *actions* (e.g., turn on the sprinklers). Here "intelligence" is obtained, on the one hand, by providing inhabitants with tools for operating on events, conditions and actions, in order to configure and adapt the environment behavior, and, on the other hand, by endowing the system with inference capabilities that allow for a progressive and continuous evolution of the environment itself.

These considerations led us to conceive a conceptual framework for AmI composed of three layers: i) the physical layer, ii) the inference layer and iii) the user layer. The *physical layer* includes all the physical devices that operate with their sensors and actuators and inter-operate through a shared information space especially devoted to collect events, conditions and actions. Many proposals exist in the literature for this layer [Cook et al., 2009], in particular for the different sensing modes and sensor data analysis (e.g. [Benini & Poncino, 2003]). Works in the literature about IoT often discuss technical aspects related to the physical infrastructure [Atzori et al., 2010].

The *inference layer* is aimed at linking events and conditions with actions with the help of some intelligent reasoning processes. The inference layer has also reached a maturity level where artificial intelligence techniques are often proposed for its implementation (e.g. [Bikakis & Antoniou, 2010; Castelfranchi et al., 2012; Sadri, 2007]). In particular, rule-based approaches are usually adopted (e.g. [Augusto et al., 2008; Shafti et al., 2013]); they consist of a rule base that stores Event-Condition-Action (ECA) rules and a rule engine, which manages rules according to proper inference techniques and rule selection strategies.

The *user layer* is the current focus of our research agenda concerning the development and experimentation of the conceptual framework. It represents that part of the system where inhabitants interact with the environment implicitly or explicitly, often in response to the events occurring in the environment and/or condition changes, and are called on to modify the behaviors that the environment should carry out for assisting or satisfying the users, thus creating personalized, interactive, and multi-modal experiences. The second aspect, namely behavior modification of the environment over time and according to new users' preferences and needs, is the most interesting from an advanced Human-Computer Interaction (HCI) point of view. Indeed, it requires the adoption of interaction metaphors and tools suitable to end users who are not expert in software and hardware technologies, but who are the actual experts of the domain to be shaped, whether it is a house, an office, a factory, etc. [Schmidt, 2015]. For these reasons, to build the user layer of the proposed framework, we advocate the adoption of an End-User Development (EUD) approach [Lieberman et al., 2006]. In particular, we focus on a wider definition of EUD that regards end users as "developers", who make their smart environment evolve as they evolve [Cabitza et al., 2014a; Fogli & Piccinno, 2013]. Once again, from the literature analysis it emerges that the ECA rule-based paradigm turns out to be suitable also for the configuration and adaptation of smart devices and intelligent environments by non-expert developers [Cabitza & Gesso, 2014; Ur et al., 2014] and thus could be considered as a possible EUD solution.

In 2014, a preliminary user study was performed, which was aimed at investigating two main issues related to the user layer [Cabitza et al., 2015]. The former issue regarded the kind of tasks that household members could be interested in performing to adapt the behavior of a smart home to their needs. The latter issue concerned the identification of which visual tool for ECA rule definition is more promising to allow the members of a traditional household to carry out the tasks mentioned above. After a survey we selected two mature relevant visual tools, namely Atooma (www.atooma.com) and IFTTT (www.ifttt.com), and these two were compared in our user study.

The study was then extended, in order to cope with some limitations concerning the population size, the genre distribution and the background and skills of the end users. In particular, besides identifying which tool is perceived as the most usable one, we are now interested in also investigating if these tools can be actually used by people without any particular experience in computer programming. In this respect, our study contributes to the increasingly rich literature on how to make users more tightly connected to their digital tools and appliances, as well as more capable of exploiting the inference capabilities of these devices. Visual interfaces, metaphors of direct manipulation by end users and multimedia systems to provide a rich feedback to the users are under consideration and scrutiny to verify if they can be integrated in the development of better sentient multimedia socio-technical systems.

This paper describes a user study, whose goals can be synthesized as follows: i) determining which tool, between Atooma and IFTTT, is preferred by end users; ii) understanding which differences exist in the performance and perceived usability between users with a background in computer science and users without this background. Both results are important for the next step in our research agenda, which concerns the design and development of a suitable user layer for our conceptual framework.

The paper is structured as follows: Section 2 discusses the related works; Section 3 reports a preliminary analysis of the existing tools for implementing the user layer; Section 4 describes the user study and its results and, finally, Section 5 concludes the paper.

2. Related Works

Traditional research in AmI mainly focuses on hardware solutions (smart devices) or on artificial intelligence (AI) techniques aimed at endowing an environment with intelligent behaviors [Sadri, 2011]. As to the latter aspect, literature work concentrates for example on user profile learning [Cook et al., 2006], recognition of recurrent behavior patterns [Bahadori et al., 2004], combination of temporal and probabilistic reasoning [Augusto & Nugent, 2006], agent and multi-agent architectures [Castelfranchi et al., 2012; Sadri & Stathis, 2009]. Given the goals of our paper, in the following we focus on literature works that discuss the user interface of AmI environments.

2.1. EUD approaches in AmI and IoT

As to the user layer, the idea to provide end users with a tool for programming their environment has been discussed in literature for many years [Blackwell, 2004; Dahl & Svendsen, 2011; Dey et al., 2006; Litvinova & Vuorimaa, 2012], even though the proposed toolkits and languages often require users to have some programming skills. This is also witnessed by the field study described in [Demeure et al., 2015], where different home automation systems have been tested for a long period in 10 households. In this study, it emerges that these systems are managed by only one member of the family, who assumes the so-called 'guru' role and who happens to be a male adult and knowledgeable in computer science. Other family members simply delegate system modification tasks to the guru, since, given the user interfaces and the computer-oriented languages available, they are not capable of doing them.

For these reasons, as observed in [Mavrommati & Darzentas, 2007], AmI should lead to new HCI paradigms, which require the development of tools that facilitate use and configuration by end users without computer programming knowledge. To this end, Demeure et al. propose Activity Theory as a conceptual framework for introducing EUD in smart homes, by stressing the socio-technical nature of such AmI systems and the need of enabling inhabitants to build their own tools and make them evolve with their needs and experience [Demeure et al., 2014]. This is in line with our conception of AmI environments as sentient multimedia systems able to co-evolve with a community of inhabitants [Cabitza et al., 2014b].

Other studies are aimed at understanding the reasons underlying the need for end-user programming in ubiquitous computing environments [Kalofonos & Wisner, 2007], while several frameworks and proposals are provided in the IoT area, which is strictly connected with AmI and often confused with it. For instance, in [Cvijikj & Michahelles, 2011] the authors describe different toolkits for enabling end users to participate in the IoT. These toolkits, such as iStuff, d.tools, LilyPad Arduino, etc., actually allow end users to create their smart objects and make them able to interact on the net; however, this is not as designing IoT scenarios in their entirety, as one should think when configuring the behavior of an intelligent environment. Making a step further, Barricelli and Valtolina conceptualize IoT as an ecosystem of sensors, applications, social media, recommendation systems and people, all operating and interacting around a user [Barricelli & Valtolina, 2015]. However, this approach considers tools for IoT as single user applications, where each user configures and manages his/her IoT environment "in isolation". Indeed, Barricelli and Valtolina's view, as well as that of other research scholars working in the IoT and AmI areas, puts a single user in the center of this ecosystem. With reference to the smart home, Crowley and Coutaz regard it as an ecosystem of smart objects providing services [Crowley & Coutaz, 2015], even though they underline the key role of end users for smart home controllability and maintainability. By extending this view, we conceive AmI as a totally distributed concept, in terms of both its technological components and its social components (inhabitants). However, proposals for EUD techniques able to cope with this concept are still lacking. Even in the ethnographic study carried out with real families by Davidoff and colleagues [Davidoff et al., 2006b] it is highlighted how EUD systems for smart homes are usually designed for one single user, who is in charge of controlling the home. For example, in the frame of the AutoHAN project [Blackwell, 2004], the "Media Cubes" programming language is proposed to define the behavior of some smart things available in an intelligent environment: it exploits infrared remote controls representing abstract functions, which can be physically arranged to create complex operations. In the e-Gadgets project, a visual editor has been developed where end users can define "synaptic associations" (cause-effect relationships) between smart appliances available in a home [Mavrommati et al., 2004]. On the other hand, Davidoff et al. underline that more than one person usually inhabits a smart home, and thus a multi-user approach must be adopted to deal with household activities that are inherently collaborative. As a consequence, some design principles for the development of smart homes, which address, among others, collaboration and competition issues, are proposed in [Davidoff et al., 2006a].

2.2. Solutions based on the ECA rule-based paradigm

Deepening the interaction paradigm, we have observed that most of the works that present EUD tools and environments for AmI and IoT are based on the ECA rule-based paradigm. However, the main problem is that the user interface layer provided for rule creation is often not suitable to end users' knowledge and skills: for instance, the systems described in [Zhang & Brugge, 2004] and [Cabitza et al., 2005] both use

JESS as the basis rule specification language, whose formal syntax is obviously not adequate to the competencies and mental model of end users. A similar problem affects the language proposed in [García-Herranz et al., 2008] or the toolkit more recently proposed in [Kubitza & Schmidt, 2015]. Actually, three different graphical user interfaces for rule creation are illustrated in [García-Herranz et al., 2010]. However, even though they appear as promising to overcome the limitations of other proposals, no experimentation on their usability and intuitiveness has been carried out yet. More recently, Coutaz and colleagues have presented SPOK (Simple PrOgramming Kit), which combines rule-based and imperative programming, but it is still under development and its suitability to end users has not been demonstrated yet [Coutaz et al., 2014]. In the same way, Barricelli and Valtolina have proposed an extension of the ECA paradigm pairing it with the use of formula languages [Barricelli & Valtolina, 2015]; but, also in this case, a graphical interface suitable to end users without computer programming expertise is still under development.

On the other hand, the work presented in [Dahl & Svendsen, 2011] describes a usability study with 16 participants, which compares three composition paradigms for smart environments: i) *filtered lists*, where condition-response compositions are obtained by selecting conditions and responses from respective lists; ii) *wiring composition*, which is based on the metaphor of coupling and wiring together separate user interface components; and iii) *jigsaw puzzle composition*, where users specify compositions by combining puzzle-like user interface elements representing trigger or response components. From this study, it emerges that the approaches based on wiring and jigsaw puzzle present issues concerning composition readability and overview; whilst, filtered lists communicate more effectively the overall picture of compositions. However, participants judged jigsaw puzzle composition as the most playful and engaging type of interaction.

The jigsaw metaphor, originally introduced in AmI by Humble and colleagues [Humble et al., 2003], has been explored also by the study described in [Danado & Paternò, 2014], which proposes a mobile EUD environment allowing end users to program smart things. This user study demonstrates that the jigsaw metaphor is more intuitive than other visual metaphors such as Lego®, Meccano® and bricks, and other EUD approaches such as natural language and workflow. Among commercial systems for AmI, Zipato (www.zipato.com) exploits the jigsaw metaphor for rule composition.

The filtered lists metaphor has been recently promoted in the frame of a variety of commercial, public and research systems, and thus some user studies have been carried out involving tools such as IFTTT, Atooma, Tasker, Locale, and others. For instance, Ur and colleagues presented a 226-participant usability test demonstrating that the average user of IFTTT can successfully create trigger-action rules (a simplified version of ECA rules where only one event or condition – trigger – is admissible, as well as only one action can be activated) [Ur et al., 2014]. Mehandjiev et al. have instead compared IFTTT with their ACOM interface for mobile devices [Mehandjiev et al., 2015]; however, only 8 participants have been involved in the accomplishment of a limited number of tasks, and thus the results favoring ACOM are not statistically significant. The study described in [Lucci & Paternò, 2014] compares Tasker, Locale and Atooma, since, differently from IFTTT, all these tools allow the creation of rules with more complex antecedent and consequent parts. In this study, even though Tasker resulted the best tool in terms of expressiveness, Atooma obtained a higher number of successful performances than Locale and Tasker, and thus resulted easier to use by end users.

Given the above results, in order to choose the most suitable approach for the user layer of our conceptual framework, we have further investigated some existing user interfaces for ECA rule creation based on the filtered lists metaphor. Indeed, contrary to the jigsaw puzzle metaphor, filtered lists seem representing a better compromise between expressiveness and simplicity [Dahl & Svendsen, 2011], thus appearing a more suitable approach to collaborative and distributed development of ECA rules, to be managed by the underlying distributed inference engine foreseen in our framework.

3. A preliminary analysis of tools for ECA rule design

The first step of our research agenda related with the implementation of the proposed conceptual framework has been the exploration of different solutions for the user layer. In particular, we have started such exploration by considering a variety of user-oriented tools in the AmI and IoT research areas. The idea is to take inspiration for the design of an interaction style that is compatible with the interconnection metaphor of our conceptual framework and able to address some challenges that the framework brings about: adequate balance between simplicity and expressiveness of rules, pleasantness of the user experience during rule creation, overall readability of the configuration of the AmI environment, openness to environment and/or community extensions over time, rule definition and modification by different users, management of conflicting rules.

In this preliminary analysis, we have thus chosen a set of tools based on the ECA paradigm and filtered list style of interaction, where rules can be created by selecting proper triggering events and/or conditions from available lists and consequent actions from another. The selected tools are reported in Table 1.

Tasker (http://tasker.dinglisch.net/) is an Android application supporting the creation of tasks based on contexts in user-defined profiles. Spacebrew (http://docs.spacebrew.cc) is an open source software that allows the creation of complex rules by following the publisher-subscriber model proposed in distributed system design. A preliminary analysis of these two tools revealed that for the composition of rules end user has to know low-level information usually suitable to expert programmers. Specifically, they require at least, basic knowledge of some computer science concepts, such as variables and strings in the case of Tasker, and publisher and subscriber in the case of Spacebrew. In addition, in the last case, the user has even to know Javascript programming language. Therefore, we have excluded them from the comparison, due to their higher complexity and expressive power.

Twine (http://supermechanical.com/twine), WigWag (http://www.wigwag.com), Locale (http://www.twofortyfouram.com) and We Wired Web (https://wewiredweb.com) are commercial systems; therefore, testing them was not feasible. SPOK is an interesting tool reported in literature [Coutaz et al., 2014], but it is not available yet for use by third parties.

Consequently, the remaining two tools, IFTTT and Atooma, which are free and easily available on the Web and/or Android marketplace, were considered in the user study reported below.

Table 1. List of commonly available tools for ECA rule design, based on the filtered list interaction style.

Tool	Rule structure	Notes
Tasker	If-condition(s)-then-action(s) rules	Commercial product
Spacebrew	Publisher-subscriber rules	Open source application
Twine	When-then rules	Commercial product
WigWag	When-then rules	Commercial product
Locale	Conditions-Settings rules	Commercial product
We Wired Web	Trigger-Action rules	Commercial product
SPOK	If-condition(s)-then-action(s) rules	Not available for third parties. It requires appropriate hardware.
IFTTT	If-condition-then-action rules	Free Web application/app
Atooma	If-condition(s)-then-action(s) rules	Free Android app

4. User Study

The user study aimed at comparing the two considered free tools for ECA rule construction, i.e. IFTTT and Atooma, in carrying out EUD activities in the smart home. Furthermore, two different groups of participants, one with a good background in computer programming, the other lacking this background, were involved in the study in order to investigate whether such background have an influence in task performance and perceived usability. Thus, our goal included two research questions:

1. Determining which tool, between IFTTT and Atooma, better supports end users in creating rules for the smart home.
2. Verifying whether people with no expertise in computer programming can use the tools efficiently and effectively.

4.1. Tools Evaluated

IFTTT ("If This Then That") is a Web application and a mobile app (Android and iOS) that allows users to create rules in the form "if *trigger* then *action*", where both trigger and action can be chosen from a list of channels. Channels include calls to a variety of Web services (e.g. GMail, Twitter, Flickr) and smart devices (e.g. WeMo Insight Switch, ThermoSmart, Google Glass, Nike+). Each rule in IFTTT (called "recipe") may contain only one trigger and one action. For example, a recipe could be: *"If any event starts in your google agenda, then set temperature to __°C"*. It would exploit the Google Calender channel in the trigger and the ThermoSmart channel in the action. Each channel used in a recipe must be properly set by providing values for its parameters (e.g. event in the calendar and desired temperature in the example). Rules can be shared and re-used within the IFTTT's community. Figure 1 shows two screenshots of the application: on the left the list of channels are visible, whilst the right image shows the definition of a recipe.

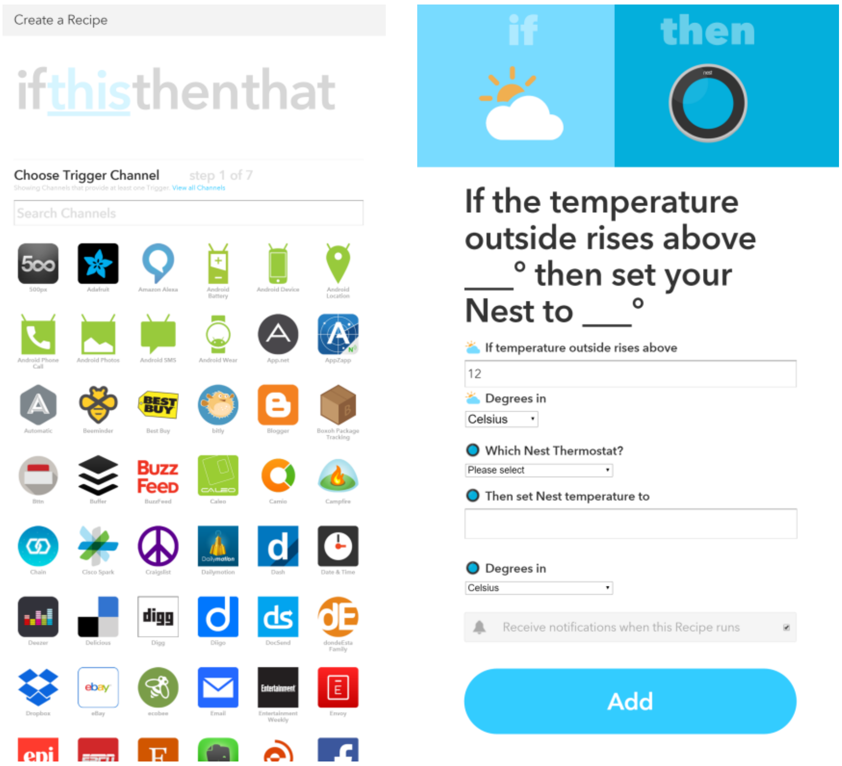

Figure 1. Creating an IFTTT recipe.

Atooma is a mobile application (Android and iOS) that allows the user to define trigger-action rules similar to IFTTT recipes, with the difference that the trigger and action parts of the rule (here called Atooma) may include up to 5 elements. These may represent calls to several Web services, smartphone sensors, and smart things, which are classified in five categories, each one identified by a color: mobile (pink), apps (purple), objects (blue), plugin (green), files (orange). Rule creation is supported by a visual interface, where circle colors allow a fast selection of the desired service category (see Figure 2 for an example of creation of a rule).

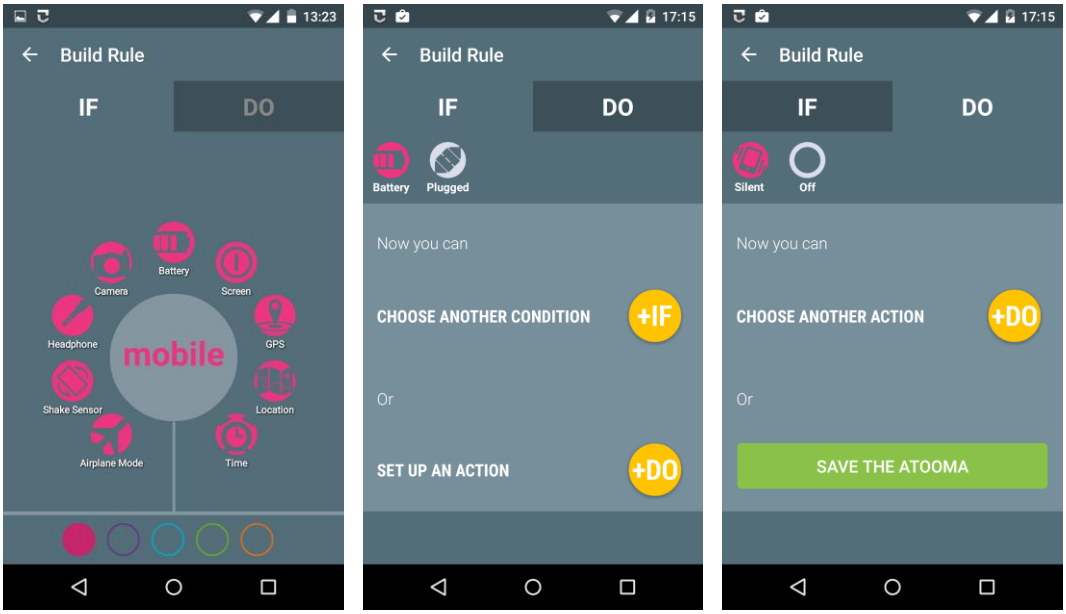

Figure 2. Creating an Atooma rule.

4.2. Participants and Design

The user test involved a total of 63 participants: 43 students (33 male, 76% below 24 years old) of the Informatics and Digital Communication (IDC) Bachelor degree course (in the following *IDC group*) and 20 students (8 male, 90% below 24 years old) of the Business Economics Bachelor degree course (in the following *BE group*). Both degree courses are of the University of Bari. Students in the IDC group come from two different classes that participated in the study as part of an assignment for their HCI course: 15 students attended the course in the first semester of the 2014/2015 academic year and the remaining 28 students attended the course in the first semester of the 2015/2016 academic year. The study was carried out in four laboratories: the IDC group was observed in two laboratories of the Taranto Campus, while the BE group in two laboratories of the Department of Economics.

The 15 students of the 2014/2015 academic year were involved in a preliminary activity aimed at defining the tasks to be executed during the study. They were divided in 4 groups and each group participated in a focus group to define a set of tasks to be carried out by a family in a smart home with the given tool.

The tools were evaluated by applying the co-discovery exploration technique [Kemp & Gelderen, 1996]. At the Taranto Campus, the 43 students of the IDC group were divided in 21 groups (20 groups composed of 2 students and 1 of 3 students). At the Department of Economics, the 20 students were grouped in 10 groups (each group was composed of 2 students). Atooma and IFTTT were evaluated in a within-subjects design. All the groups carried out the 12 tasks defined in the task definition phase, by using the two tools in a different order to avoid potential learning effects [Graziano & Raulin, 2012].

4.3. Method

The user study consisted of a *Task Definition* session and a *Task Execution* session. The former, aimed at defining the tasks to be executed in the study, took place on November 25th 2014. The latter, where the defined tasks were executed through the two tools, was carried out in three different days, i.e., December 2nd, 2014 and November 4th, 2015 at the Taranto Campus and November 5th, 2015 at the Department of Economics of the University of Bari. In the following, a detailed description of the method used in the two sessions is provided.

4.3.1. Task Definition

Fifteen students of the Informatics and Digital Communication Bachelor degree, attending a HCI course in the 2014/2015 academic year, were involved in the task definition session, by adopting the focus group approach. A 15-minute presentation describing concepts about the typical smart home (e.g. the Google House) was first given to all these participants. Then, the 15 students were divided in 4 groups (3 groups composed of 4 students and 1 group of 3 students) and each group worked separately in a different university laboratory with the following goal: identifying the most significant tasks for a smart home to be performed by a family. To drive the discussion in the focus groups, four personas [Rosson & Carroll, 2002], corresponding to four possible family members, were previously defined by two experimenters (i.e., HCI researchers):

1. Carla, the mother, 42 years old, two sons, employed part-time at the municipality, uses the PC at work and uses office productivity software proficiently; she owns a smartphone and uses few installed apps;
2. Luigi, the father, 48 years old, physician, uses a software for patient management at work, he also has got a smartphone that he uses extensively;

3. Giada, a daughter, 12 years old, student, uses a PC at the school lab and she has got a laptop at home for leisure; she uses a smartphone, mainly to chat with friends;
4. Eugenio, the grandfather, 72 years old, retired, he uses a PC for Web searches about his interests and has been given a smartphone that he uses sometimes, but mainly for calling.

The focus groups lasted one hour and a half. At the end of the focus groups, the tasks defined by the participants were collected and discussed in a collective brainstorming session, where each group presented its tasks to the other groups and to the experimenters. The brainstorming session lasted 1 hour.

At the end of the task definition session 114 tasks were defined. One experimenter analyzed the set of identified tasks, in order to classify them on the basis of the actual feasibility of the proposed tasks with the currently available mass-market technology. The other experimenter double-checked 65% of the classified tasks for reliability, leading to 85% agreed classifications. Then, the remaining discrepancies were solved by discussion. This led to identifying three task categories:

1. *Feasible tasks*, i.e., tasks that end users can actually execute in a smart home thanks to the available technology or simulating the use of some possibly available device. Examples of feasible tasks are: “If mother Carla is late and she is still in the office, activate washing machine”; “If father Luigi gets a text message containing ‘urgent’, switch off the TV, warn the patient of the next appointment of a possible delay and show the route to reach the message sender’s house”; “If daughter Giada moves from a room to another, switch off the light bulb and the video surveillance camera”; “If grandfather Eugenio is getting home, close the windows and switch on the heating plant”.
2. *Conditionally feasible tasks*, i.e., tasks that end users could carry out with the intervention of experts, who provide them with specific software or device installations. An example of such an identified task is “Show the person, who is ringing the intercom without going to the door”; the execution of this task requires the intervention of at least an electrician to install a camera on top of the door and connect it to the network and to the intercom. Another example is “Suggest the meal to be prepared according to the available ingredients and time, guaranteeing at the same time a variety in the personal diet”; in this case, this task requires at least the design and the implementation of a database to store all needed data and of artificial intelligence algorithms for generating feasible and suitable suggestions.

3. *Not yet feasible tasks*, i.e., tasks that end users cannot execute with the current technology, neither with the help of experts. Examples of such tasks are “Recycle automatically the garbage” and “Wall changing their transparency according to weather phenomena”.

Specifically, participants defined 70 feasible (61%), 23 conditionally feasible (20%) and 21 not yet feasible (19%) tasks for the four profiles. Table 2 summarizes the frequency (*f*) and percentage (*%*) of categorized tasks for each persona chosen for the user study.

Table 2. Frequency and percentage of the identified tasks for each persona.

	Feasible Tasks		**Conditionally feasible tasks**		**Not yet feasible tasks**	
	f	***%***	***f***	***%***	***f***	***%***
Persona 1: "mother"	20	29%	5	22%	5	24%
Persona 2: "father"	22	31%	8	35%	4	19%
Persona 3: "daughter"	13	19%	6	26%	5	24%
Persona 4: "grandfather"	15	21%	4	17%	7	33%
Total	**70**	**100%**	**23**	**100%**	**21**	**100%**

At the end of this analysis, we selected a total of 12 tasks (i.e. 3 tasks for each persona) to be executed with IFTTT and Atooma. The three tasks in each group were of increasing difficulty: while all three tasks required to verify only one condition, the first task was intended to launch one action, the second task two actions and the third task three or more actions. This choice of considering only single-condition tasks was motivated by two main reasons: i) participants had rarely shown in the tasks proposed the need to have multiple conditions (i.e. conditions combined with AND/OR operators); ii) IFTTT does not permit multiple “AND” conditions, and, thus, to be able to compare the two tools, the same tasks had to be considered.

4.3.2. Task Execution

The task execution session was carried out in two different laboratories for each site: the Taranto Campus and the Department of Economics of the University of Bari. In 2014, a first bunch of 7 groups at the Taranto Campus were asked to reach two different university laboratories: 4 groups worked in a laboratory and the remaining 3 groups in another laboratory. In 2015, the same has been done with a second bunch of 14 groups at the Taranto Campus and with a third one of 10 groups at the Department of Economics of the University of Bari, which were equally divided in two laboratories in both cases. Summarizing, a total of 31 groups participated in the task execution session.

The task execution session included 4 steps, for a total of 1 hour and 40 minutes, distributed as follows:

1. a demonstration of the tool to be evaluated (10 minutes);
2. a training session, in which the participants got familiar with the tool (10 minutes);
3. a session of use of the tool to carry out the 12 tasks (75 minutes);
4. a session to fill in an online post-task questionnaire (15 minutes).

The four steps were iterated for each tool. According to the within-subjects design, 16 groups used first IFTTT and then Atooma, whilst, the remaining 15 groups used first Atooma and then IFTTT.

Following the co-discovery exploration technique [Kemp & Gelderen, 1996], during Step 3 of the task execution session, participants recorded on a booklet the start and end time for each task, the implemented solution for accomplishing the task and their possible comments. In addition, two experimenters observed the participants and took notes on the most significant events, the most interesting and meaningful participants' comments, etc. Finally, task execution was also audio-taped.

Step 4 included a validated translation of the System Usability Scale (SUS) questionnaire [Borsci et al., 2009] and additional open-ended questions where respondents could write down their impressions on both the strengthens and weaknesses of the tool used in the test. In particular, a final question was proposed in order to obtain participants’ explicit preference between Atooma and IFTTT.

The SUS is a closed-ended questionnaire encompassing 10 items, or statements, to be evaluated by the respondents on an ordinal Likert scale from "strongly agree" to "strongly disagree". After normalization and aggregation of responses, the SUS tool provides a single score ranging from 0 to 100 for each tested system, whereas a conventional threshold of 70 is proposed in [Bangor et al., 2008] to consider its overall usability passable. This questionnaire was chosen for its reliability, brevity and wide adoption in similar contexts of usability assessment. In our case, the SUS-related assessments were recorded on a 6-value ordinal scale with an opt-out category for neutral or uncertain respondents; the even scale was adopted to limit the central tendency bias [Foddy, 1993; Klos, 2012] and at the same time to allow for the display of sufficient spread in the distribution for the agreement variable, thus providing more variance for the non-parametric analysis of the responses; the opt-out option was implemented to limit potential response noise around the middle values. However, to calculate the SUS score, we downsampled the responses to a 5-point scale recoding values accordingly. This allowed us to analyze the subgroup of the uncertain respondents (i.e., those whose responses were summated into the new middle value) while also being backward compatible with the vast literature adopting the SUS.

4.4. Data Coding

The data gathered during the task execution session came from the experimenters' notes and the end users' booklets, which were substantially extended by audio-analysis. The two researchers transcribed the audios and independently double-checked some 65% of the material. The initial reliability value was 82%, thus the experimenters discussed the differences and reached a full agreement.

4.5. Results

This section presents the findings of the user study by first reporting the quantitative (time, accuracy and SUS score) and qualitative results obtained to compare IFTTT with Atooma on the entire population of participants. In this way, we aim to answer the first research question. Then, a deeper analysis of the quantitative and qualitative results is carried out by considering the two groups of participants (IDC and BE) separately, in order to highlight possible biases due to the computer programming background of the first group. This allows us to answer the second research question.

4.5.1. Comparison between IFTTT and Atooma

The first goal of the user study was aimed at identifying which tool, between IFTTT and Atooma, better supports end users in carrying out tasks for a smart home. An analysis on the *time* spent to carry out the task was therefore performed. Specifically, an independent-samples t-test was adopted to compare times of execution in using either Atooma or IFTTT for each task. A significant difference was found only in regard to two tasks (no. 1 and no. 6): in the former the participants had just "to switch the washing machine on"; the latter task was conditional, in that users had "to switch the TV off, if an urgent SMS arrived". In both cases Atooma required less time to complete the task (for no. 1 Atooma M=5.7 m, SD=3.6 m, IFTTT M=11.2 m, SD=8 m, $t(37)=-2.9$ $p=.006$; for no. 6 Atooma M=5.2 m, SD=2.5 m, IFTTT M=8.4 SD=3.8, $t(28)=-2.8$ $p=.008$). These results suggest that the two tools do not differ much in regard to the effort required to build the necessary rules by which the typical tasks can be supported, although Atooma was easier to use in two cases, a very elementary one and a conditional one.

We also conducted an analysis on the *accuracy* in performing the given tasks. A Z-test was performed to compare the average number of failures (errors in coding the rule) done while using either Atooma or IFTTT for each task. For no task a significant difference in the number of errors between the two tools has been detected, nor any tendency that any tool would induce more (or fewer) errors than the other. Unfortunately, errors were quite common for both tools. This could relate to the learnability of both tools, that the SUS does not allow to distinguish from usability [Borsci et al., 2009] (unless scores for items 4 and 10 are extracted [Lewis & Sauro, 2009]).

The overall usability of each of the two tools was finally evaluated through the SUS questionnaire. We obtained 126 assessments, 63 for each tool (each participant assessed both tools). An exact binomial sign test indicated that, for Atooma, respondents expressed a clear tendency for every item, that is for each item a large majority of respondents chose values from only one half of the available interval: the smallest majority gathered 80% of the respondents for the last item, on learnability, claiming disagreement with the sentence about "the need to learn a lot of things before being able to get going with this system". Much greater variability was detected by performing the same test in regard to IFTTT. To this respect, no item received a statistically significant preference from the respondent sample: the biggest majority was detected to express agreement with items 3 and 1, i.e., perception of unnecessary complexity and need to learn many things respectively, with 73% of respondents agreeing.

An independent-samples t-test was conducted to compare the SUS score for Atooma and IFTTT. We detected a very significant difference in the SUS average scores for Atooma ($n=58$, $M=69.8$, 95% CI=±4.23, $SD=16.2$) and IFTTT ($n=62$, $M=37.9$, 95% CI=±4.65, $SD=18.3$,) conditions; $t(118)=10.1$, $p < .000$. This result suggests that Atooma is more usable than IFTTT according to the SUS scale; moreover, since its cumulative score is practically equal to the conventional threshold (70, [Bangor et al., 2008]) it can also be considered of acceptable quality. On the other hand, we could not detect any difference between the two applications according to gender (female vs. male, $p=.66$) nor age (below 24 vs. above 24 years, $p=.52$). Slight (but not significant) age-related differences could be detected concerning the easiness of use for Atooma ($U=10.5$, $p=.07$) and to the learning curve of IFTTT ($U=10$, $p=.06$). This convinced us that weighting the response set was not necessary, even if the male respondents were predominant (65% vs.

35%) and the subjects aged below 24 were more than those above 24 (76% vs. 24%). Concerning the Chi-square based analysis of the hesitant respondents: for Atooma they do not show any clear tendency for either extremes of the scale; conversely, for IFTTT they show a clear tendency only regarding item 1, i.e., prospective frequency of use (0 vs. 6 toward frequent use, p=.031).

Differences are significant also at the level of the single item of the SUS questionnaire, which, as said above, were rendered with an even ordinal scale. A Mann-Whitney test indicated that the ordinal assessment for each SUS item was always better for Atooma than for IFTTT. In particular, for each item in Table 3 we report the tool that was associated with the highest score, the number of asterisks indicate the degree of significance of the detected difference between the two tools.

Table 3. Results from Mann-Whitney test.

SUS item	Tool with highest score	Degree of significance	*U* value	*p* value
Prospective frequency of use	Atooma	***	655	.000
Excessive complexity	IFTTT	***	617	.000
Easiness of use	Atooma	***	616	.000
Need for support	IFTTT	***	656	.000
Level of integration	Atooma	***	966	.000
Level of inconsistency	IFTTT	***	1300	.001
Velocity of learning	Atooma	***	797	.000
Cumbersomeness	IFTTT	***	485	.000
Confidence	Atooma	***	612	.000
Slowness of learning	IFTTT	***	973	.000

The result demonstrating that the participants appreciated more Atooma than IFTTT was confirmed also by the analysis of the open questions requiring participants to explicitly indicate pros and cons of both tools. The participants of both groups appreciated the ECA rule-based paradigm, implemented in both tools, since it allows them to easily automatize their daily activities. Participants observed that IFTTT provided much more channels than Atooma, even if the latter was found more easy to use and intuitive. Another important advantage of IFTTT, which both groups reported, was the possibility to use the tool via different platforms (Android, iOS and desktop via Web). Differently, Atooma can be easily used on Android-based applications, while its version for iOS systems presents various interaction problems.

On the other hand, during task execution through Atooma, participants discovered the possibility to combine more than one condition (trigger) in the same rule and they appreciated a lot such a peculiarity. In fact, one of the major disadvantage of IFTTT concerns the fact that it permits to create recipes composed of only one condition triggering only one action. Thus, in order to perform the tasks requiring the launch of two or more actions, participants had to create multiple recipes. In addition, participants complained about the channel registration: indeed, IFTTT requires to activate the channel and possibly install the app encompassed in it, resulting thus in a boring and sometimes useless activity when they discovered that the registered channel was not the right one. This is confirmed by some participants' comments during task execution: "*You cannot use these applications if you do not already know them*" and "*Is it possible that I must register to a channel only to have details about it?*"

On the other side, Atooma was appreciated for its attractive interface, which is simple and intuitive. It presents icons and features that its users are familiar with, since they are already provided by smartphones. Furthermore, in Atooma the rules are classified in categories, thus resulting in a good memorability, even if the available objects that can be considered in Atooma rules are very few compared to the objects that may be used in IFTTT recipes. Participants appreciated very much another Atooma feature: it gives clear explanations about where the user is, what he/she has to do, etc.

The last question of the administered questionnaire required the participants to provide their opinion about IFTTT vs. Atooma. Most of participants (95%) preferred Atooma, since it was judged to have the most immediate and organized layout, it allows combining more than one condition in a same rule and does not require to activate any object before its inclusion in a rule.

4.5.2. Influence of participants' background

The second goal of the user study was investigating whether the background in computer programming could influence the perception of usability, or task completion time. In both cases we could not detect any significant difference between the IDC and BE groups (Informatics and Economics, respectively). For task completion, the p values resulting from the statistical hypothesis tests varied from a minimum of .08 (task 4) to a maximum of .97 (task 2); in regard to the SUS score, the p value was .83 ($t(118)=-.21$).

Also from a qualitative perspective, the analysis of the three last open-questions of the online questionnaire did not generally show any difference between the two groups related to the participants' educational background condition. Differently from the IDC group, participants of the BE group explicitly appreciated the fact that IFTTT offers different recipes, which can be reused. The IDC group mentioned another disadvantages of IFTTT that is the impossibility to launch an action at a specific time.

Regarding the advantages of Atooma, both groups mentioned the same tool peculiarity, such as simplicity and attractiveness of its interface, the possibility to combine more than one trigger that launch two or more actions. However, one of the Atooma disadvantages, mentioned only by the IDC group, was related to the fact that Atooma does not allow its users to modify an existing rule: users are constrained to create a new one even when they want to slightly modify a rule.

From the analysis of the answers to the last question of the questionnaire, where participants had to provide their preference between Atooma and IFTTT, we can derive that all participants of the IDC group preferred Atooma. Indeed, these participants judged Atooma as the most usable, thanks to its simple, immediate and attractive interface and thanks to the fact that it does not require to activate any object in order to use it. One participant affirmed: "*Atooma, without any doubts. In half time I created more sophisticated and effective rules than with IFTTT. I believe I will use it during my daily life*".

Surprisingly, in the BE group, 3 out of 20 participants preferred IFTTT to Atooma for its huge quantity of channels available. A participant said: "*Even though Atooma is more intuitive and efficient, I found it more limited than IFTTT, which instead allows to do many things*".

5. Discussion and Conclusion

The main objective of this work was to explore the feasibility of an EUD approach to the configuration and management of AmI environments. This represents the first step in our research agenda concerning the development of a novel conceptual framework for the design and evolution of AmI environments, here conceived as sentient multimedia systems [Cabitza et al., 2014b]. In particular, we explored a variety of user-oriented tools in the AmI and IoT research areas by looking for EUD tools for ECA rule creation based on the filtered-list metaphor. In such a set of tools we chose two freely available and widely known tools, i.e. IFTTT and Atooma, with which we carried out a comparative study. The study involved 63 participants, belonging to two different populations of target users.

The study showed that no difference exists between IFTTT and Atooma with reference to time and accuracy, even though the users appreciated the user interface of Atooma much more than that of IFTTT.

This is also apparent from the SUS composite score, which actually provides an evaluation of the *perceived* usability of the systems. These results could be compared with those obtained in the study presented in [Ur et al., 2014], which involved a higher number of participants (226), distributed across a wider age range and with varied cultural and skill backgrounds. This study provided evidence that the average user can successfully carry out trigger-action programming with IFTTT, also when it is extended with the possibility of creating multiple triggers and actions. We have enriched these results by comparing IFTTT with another tool, leading to the identification of a simpler and more appealing user interface. To substantiate these results, we have also examined separately the behaviors and responses of two different user populations, by demonstrating that the background in computer programming does not have an effect on the use of the systems and the preference for Atooma.

From our study, further important indications emerged for the design of a tool for EUD in AmI:

1. the tool should be multi-platform (web-based, Android, iOS, etc.);
2. the tool should allow the combination of more than one trigger and more than one action in the same rule;
3. the tool should offer a huge variety of services and devices to be used and combined in the triggers and actions of the rules;
4. the rules should be shared within a community and easily tuned by the end user, who decides to use them for his/her own sake;
5. triggers and actions offered in the tool should be categorized according to the users' objectives;
6. triggers and actions should be accompanied by a clear description, without requiring their previous activation or installation;
7. last but not least, the user interface of the tool should be not only easy to use, but also attractive and engaging.

On the basis of the above results, we are working on a new EUD tool for AmI, whose user interface is inspired by the Atooma style of interaction. This system is aimed at encompassing most of the above features and addressing at least two further issues: *perception of relative advantage* and *long-term sustainability*. The former regards a known principle from the diffusion of innovation model theory [Emani et al., 2012], in which for users to perceive an innovation as having an impact on their daily life, they need to have clear in their mind how this innovation gives them an advantage with respect to the traditional counterparts, whatever these are. In the smart home context, this could mean, for instance, that setting up a home lighting policy should be as easy as switching a light on manually (or easier!). To support the perception of relative advantage, our current research direction is the involvement of the maieuta designer in the appropriation of the tools for EUD [Cabitza et al., 2014a; Cabitza et al., 2014b], that is, someone that could train the users to become more independent of IT professionals, by providing them with a method to understand and domesticate the technology rather than with a set of related notions.

The latter aspect, long-term sustainability, regards the need for users to find the interaction with, and the shaping of, their intelligent environments convenient and engaging, even after the expert has left them alone with their own smart system. This means that the user layer must allow the users to make the AmI environment co-evolve over time with their needs and with the new technologies available [Fogli & Piccinno, 2013]. However, this opens up another consideration: the user layer should allow the overcoming of the concept of "single device programming" in favor of the collective and participatory development of a sentient multimedia system, for the sake of a community of users (e.g., a family), who could directly or indirectly intervene in such a development, by exploiting a variety of social mechanisms, from collaboration to competition, from delegation to reciprocity. To address these aspects, in [Benzi et al., 2015], we have proposed the idea of a collaborative system for AmI, enriched with gamification techniques. However, such a wide view of the user interaction with AmI environments requires coping with a further problem: interconnecting devices and people. Giving the latter the possibility to intervene simultaneously in AmI activation and configuration may give rise to incoherencies and conflicts. Therefore, different strategies should be designed to solve this kind of problem and be integrated in the EUD tools available for the end users to build ECA rules.

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