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METAPHORS FOR THE END-USER AUTHORING OF WEB OF THINGS AND CROSS-DEVICE APPLICATIONS

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Abstract

The rapid development in technology has led to the exposure of IoT based smart devices to people. Smart devices, such as smart TVs and smartwatches are no longer a luxury but have started becoming an integral part of people's lives. Moreover, this current proliferation of smart devices has prompted researchers to investigate the combined use of multiple devices leading to the development of applications which are cross-device as well as based on IoT. Since the users' needs are constantly evolving, end-user authoring tools have started coming into existence. The success of such authoring tools resides on their ability and ease to allow end-users to author complex environments. These authoring tools often rely on metaphors to elucidate the programming concepts.

Metaphors have always been helping humans in conceptualising abstract concepts. Their presence and usage is not only limited to a literary tool in languages, but has been expanded to every domain of life for an easier interpretation of things. For example, the usage of *desktop* or *laptop* as a metaphor for computers is well established.

The objective of this thesis is to find the best metaphors for the end-user authoring of applications in the domain of IoT and cross-device interactions. This is accomplished by an analysis of related work in these two research domains. In addition, extensive user studies have been conducted to better understand the metaphors which are popular amongst users. After an analysis of user studies some mock-ups of an authoring tool which is based on the patterns analysed during these studies are presented. Last but not the least, a prototype of an end-user authoring tool for IoT and cross-device has been developed based on these mock-ups.

Acknowledgements

As everything has an end, this stage of my life has come to an end. However, usually the good memories remain along with the experience and knowledge. This work might not be the best, I understand, but I really enjoyed it. It was a totally different experience full of stress, hope, faith and most importantly, fun!

First of all, I would like to thank my promoter Prof. Dr. Beat Signer for giving me an opportunity to write a thesis at the WISE lab and to provide feedback on my thesis and presentations. The next person I want to thank is my supervisor, Audrey Sanctorum for her guidance, support, last-minute feedbacks and motivation without which this thesis was not possible. A special thanks to my parents for their love and support throughout my life. Thank you both for always believing in me and allowing me to go after my dreams. I would also like to thank my flatmates Anas, Mohammed and Monir for making sandwiches, buying me groceries and at last pushing me too hard to complete this work. Thanks to Ahmad, Eugene and Mario for their presence in the WISE lab and support during tough times.

Thanks to God for supporting me, gifting me patience and helping me to finish this chapter and every chapter in my life.

Contents

1 Introduction

1.1 Internet of Things

In last two decades, there has been tremendous progress in the field of information technology and embedded system which has provided us with a myriad of small computers. The enormous growth has enabled the shrinkage of the size of computers as well as reduction in the price of these devices. The Internet is now not only bound to desktop computers, but improvements in wireless communication have made the Internet to reach out to these small embedded devices. The growth and progress has extended the boundary of these physical devices and enabled us to access the virtual world. As the Internet has expanded to these small computers, which we refer to as things, the term used to refer to the Internet today is popularly known as the Internet of Things (IoT). IoT devices have made computing truly ubiquitous and there has been a gradual change from the Internet of Computers to the Internet of Things [20]. The IoT has gained much popularity in a very short time. It has been marked as one of the emerging technologies by Gartner's hype cycle as shown in Figure 1.1. Gartner's hype cycles are a popular way to represent the emergence, adoption, maturity and impact of specific technologies [1, 12].

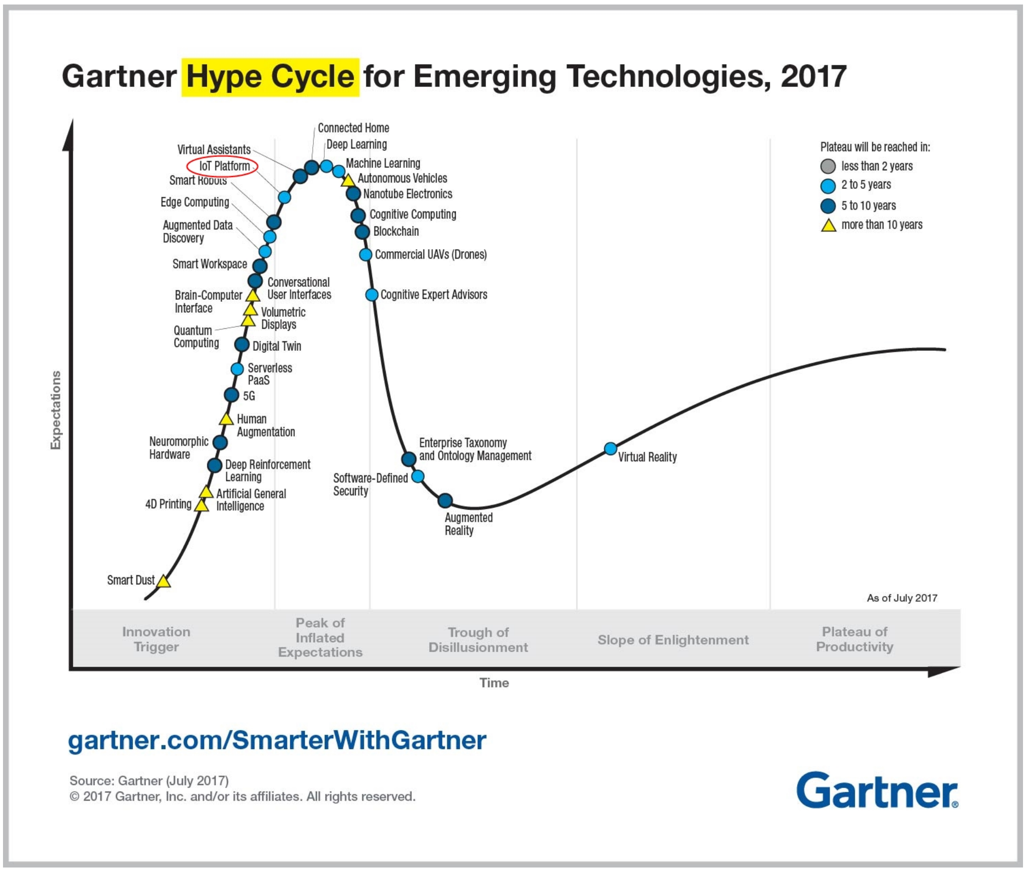


Figure 1.1: IoT in Gartner's hype cycle 2017

1.2 Web of Things

Thanks to the development in wireless sensors and networks, and connectivity, more and more physical devices are now being amalgamated to the virtual environment by using different networking protocols. In order to make an efficient utilisation of the data provided by these physical objects by specific applications, it is common practice to use some standardised open protocols for data transfer and sharing. One of the popular methods is to create an abstraction layer for scalability, interoperability and data transfer by using the Web [20]. This protocol's concept involves the full integration of smart things and their services by the adoption and re-usability of technologies and patterns which are commonly used to manage traditional web content. This concept is known as the Web of Things. More specifically it involves the configuration of tiny servers in small embedded devices to follow the REST architectural pattern which is commonly used to create loosely coupled services on the Web. The Web of Things is considered an application layer to the IoT devices in a similar way as the Web is considered a layer on top of the Internet. The Web of Things uses popular web standards such as JSON, HTTP, REST or WebSockets [13, 33].

1.3 Cross-Device Interactions

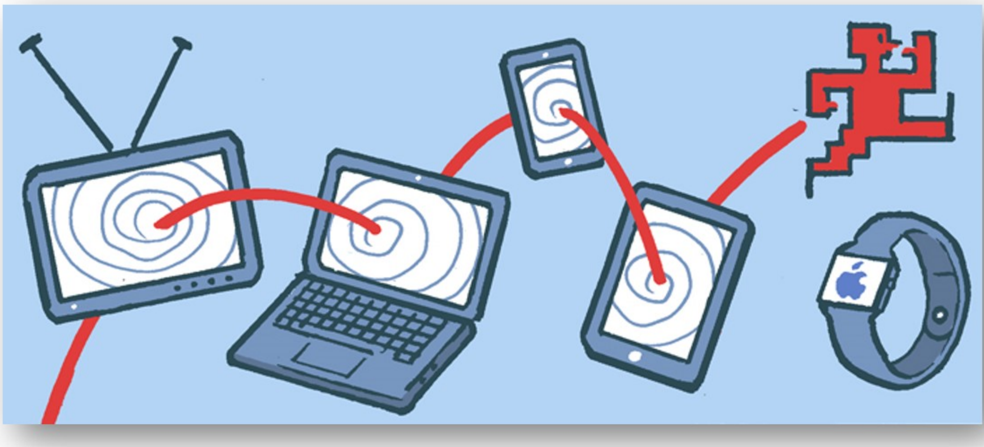


Figure 1.2: Cross-Device applications

The current era can be called the digital era. These days people read the morning news on their tablets, check emails on their phones while commuting to their workplaces and use their desktop PCs when at work. At night, they watch movies on their home media consoles. This has promoted the development of applications which are present on multiple devices and can synchronise data across devices. These applications are knows as cross-device applications and they help in facilitating an improved user experience. Some examples of such applications include Spotify[1], a music streaming service which works on desktops as well as smartphones, Google pay[2] which works on smartwatch as well as smartphone to facilitate payments via Near Field Communication (NFC).

[1] https://www.spotify.com
[2] https://pay.google.com

1.4 End-User Authoring

Most people today have familiarised themselves with the basic functionality of user interfaces and flow. With technological advancement and the appearance of new devices, the needs of new users have emerged and existing user needs have evolved. The demands of people have been growing at a high pace and mostly the demands are individualistic. In this digital era, the variation amongst the demands of people for applications is growing rapidly. With personalised medicine and personalised playlists (spotify), people have started feeling the need for personalised software applications. Design and development teams are unable to address these demands for personalised applications and can only focus on the common demands of people as they have to focus on obtaining a return on investment. Due to this, specific needs of users usually remain unsupported. Thus, there is a need for the end-user authoring of applications. There is a shift which is expected to happen for the goal of interactive systems and services which will evolve from making system *easier to use* and *easier to develop for the users* [18]. The main motive of end-user authoring is—to provide power to the end-users so that they can define and tailor custom functions which will allow them to satisfy their task-specific needs.

1.5 Problem Statement

There are many authoring tools which exist in the market today. Some of the popular ones are IFTTT[3], Zapier[4] and Flow[5]. Unfortunately these authoring tools do not allow end users to explore their full potential as they usually have limited functionality which allows users to develop only simple rules. The tools which allow advanced customisation (Node-RED[6]) are usually too complex to use by end users. In order to provide abstraction for complex concepts used in these applications, metaphors are being used. Research is being conducted to find metaphors for end-user authoring tools in IoT and cross-device applications. However, to our knowledge, researchers are not focussing on combination of both domains—IoT and cross-device applications—when it comes to development of end-user authoring tools. Also, most end-user authoring applications are being developed without the involvement of end-users themselves. We aim to find the most suitable metaphors to be used

[3] https://ifttt.com
[4] https://zapier.com
[5] https://flow.microsoft.com
[6] https://nodered.org

in end-user authoring applications focussing on both IoT devices and cross-device applications. We aim to do this by involving end users in our research.

1.6 Contributions

In this thesis we have investigated and found the most suitable metaphors which can be used in end-user authoring tools for IoT and cross-device applications. We have achieved this by conducting extensive user studies. We have included two types of participants in these studies over people having different professions and backgrounds. We have mainly classified participants into two classes, participants having experience with computer programming and others who have never been exposed to computer programming. On the basis of this investigation, we have developed some mock-ups for the authoring tools and also developed a small prototype of this authoring tool.

1.7 Thesis Outline

The remainder of the thesis is structured as follows. First, related work focussing on end-user authoring tools in the field of cross-device and IoT applications is explored in Chapter 2. Inspired by our investigation of related work, a methodology for conducting user studies is prepared which can be seen in Chapter 3. To make it close to perfect, pre-studies have been conducted and using their results the study methodology has been refined. Details about these improvements and demo studies are elaborated in chapter 3. Chapter 4 details about the process of user studies with observations from the conducted experiments. In chapter 5 we present some mock-ups which is followed by the discussion of a user prototype. Finally some interesting work for future as well as conclusions about the presented work are given in Chapter 7.

2
Background

With the emerging popularity of IoT devices and the easier accessibility of these devices to the general mass, a lot of research is being done in the development of end-user authoring tool for applications related with IoT and cross-device interactions. However it is seen that this research has mainly been done for context-dependent applications. In this section, we are going to focus on the past work which has been done related to end-user authoring in IoT and cross-device applications. We also focus on the metaphors which are being used for end-user authoring of these applications.

2.1 Internet of Things Applications

As success of any technology happens only when this technology brings significant value to users and to the society, active research is being conducted towards end-user authoring of IoT applications.

One example of this type of research can be found in Danado and釘Peternó's work [5].The authors are demonstrating 'jigsaw' as the *metaphor* for a end-user development tool in their *Puzzle* Framework.

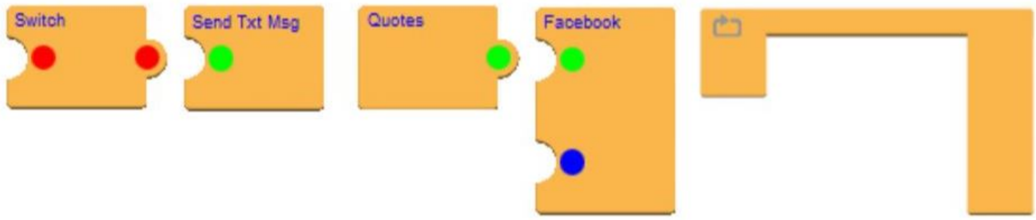


Figure 2.1: Puzzle: end-user authoring platform

Puzzle, is a web-based platform to create applications including web services, phone functions and smart things, which further focuses on connecting applications to web services, native phone functions and existing smart things. The decision to go with the jigsaw metaphor is taken based on a similar approach being used in MIT's app inventor[1] and Scratch[2], a visual programming language and online community focussing mainly at children. Scratch is based on the work of Resnick et al. [27]. Puzzle is based on web technologies – HTML, CSS and Javascript which allows it to be used across most touch-based mobile devices. In puzzle, users are allowed to connect functional building blocks which posses the ability to exchange data with each other in an arranged fashion though a series of top-down left-to-right coupling of pieces. According to the authors, the left-to-right fashion provides a feel of pipeline of flow of information. Thus, we can say that the application is also focussing on *pipeline* metaphor. Further, every jigsaw piece can receive as well as send information. Usually the piece which is receiving information has an inner circle and the piece sending information has an outer circle, as highlighted in Figure 2.1. Each input or output circle is coded with a colour to display the possibility to join or connect two pieces. Two pieces can be joined only if the colours from the output and input match. Thus, authors are using colours to display compatibility of different services or actions. The development of Puzzle is done via an iterative approach. The authors performed some early prototyping during the development of Puzzle which also involved usability testing [4].

Unfortunately the usability testing performed by the authors is based on a small number of participants. The evaluation which focussed on users' ability to create applications by using jigsaw metaphor involved just six users (having non IT-related jobs). Considering an application which is focussing on end-users and is based on principles of user-centred design (UCD), usability testing should have been performed with a large number of participants.

[1] `http://ai2.appinventor.mit.edu`
[2] `https://scratch.mit.edu`

Also, no user studies were performed before selecting jigsaw as the metaphor for their application.

Davidyuk et al.[6] are focussing on different application composition approaches for creating applications composed out of web services, resources associated with mobile devices, displays and various augmented everyday objects. In their work, they are performing an in-depth analysis of most influential applications platform. Along with this, they are also studying metaphors and the frequency of their usage in the GUIs of applications. They are claiming that the *jigsaw* puzzle, the *pipeline* and the *join-the-dots* metaphor are the ones which are frequently being used in user interfaces of interactive applications.
In the pipeline metaphor, applications are related and displayed as a directed graph. Single services are shown by the nodes and communication channels are represented as links (pipeline) between nodes. The authors have focused on the benefits of the pipeline metaphor. According to them, pipeline's ability of organisation as complex structures makes them useful for developing applications where multiple services or logics needs to be combined. Complex applications can be designed using the pipeline metaphor which definitely seems to be a powerful visual programming paradigm, but it has a steep learning curve. Thus, as mentioned by the authors, the pipeline metaphor is mainly used in tools focussing on expert users. Examples of these tools can be found in Rycerz's [30] work on Mapper and in CollaborationBus [11].
Davidyuk et al. [6] claim jigsaw as the most used metaphor. It is mentioned that puzzle has the ability to express more configurations as compared to the pipeline metaphor. However they do not fail to understand the downside of puzzle which is the limited interfaces (sides) of puzzle. Some applications where this metaphor is being used is the Accord prototype [28, 15], Action builder editor [21], Google Blockly[3], Scratch[4] and in the work mentioned before of Danado and Peterno's in Section 2.1. Discussion about join-the-dots metaphors starts from explaining an assumption that is made for this metaphor according to which the devices are on a canvas and each device is surrounded by clusters. Services accessible from the environment are displayed as nodes. Users connect devices to the different services. Pering et al.[26, 25, 36] in their writing about pervasive collaboration and composition platform are using the join-the-dots metaphor in their GUI used to create compositions by sharing resources with combination of a simple line drawing metaphor as shown in Figure 2.2 .

[3]https://developers.google.com/blockly
[4]https://scratch.mit.edu

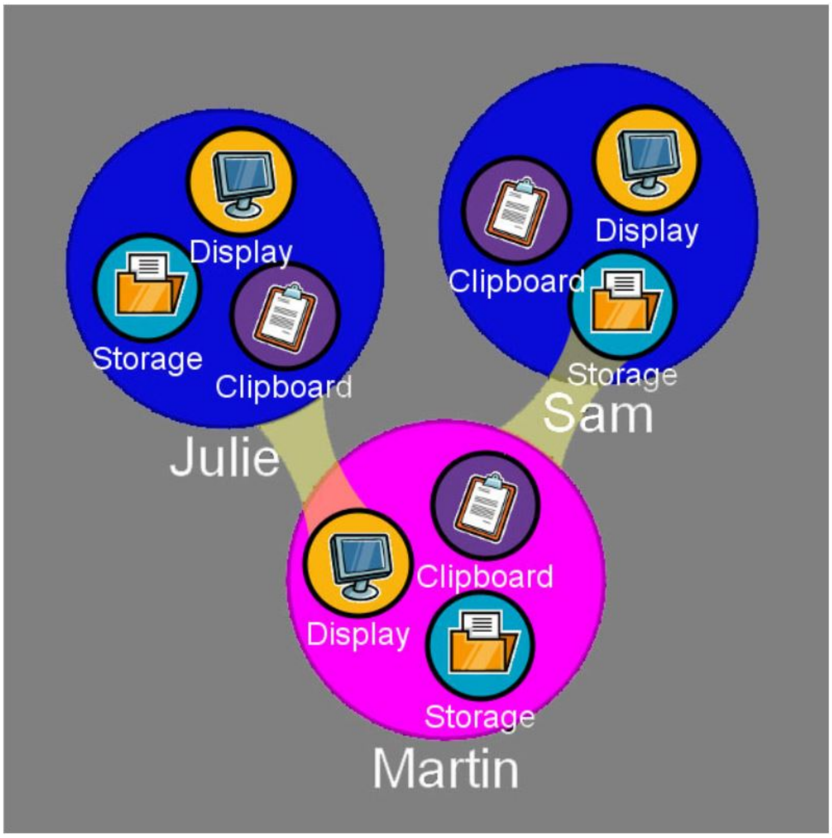


Figure 2.2: Simple jigsaw pieces in Puzzle [26]

The major advantage of this metaphor is its minimalistic nature of visual representation. Only those services and devices are visualised which are available. However, another environmental state is present which displays all unavailable and available devices and services. A nice analogy of this environment state can be made with the display of *manage known Wi-Fi networks* in Microsoft Windows 10. Here one can see all the Wi-Fi networks which the devices had once connected to despite of their availability status.

Jeong et al. [16] presented AVIoT, an interactive framework of visualizing and authoring IoT in indoor environments. Visualisation and scripting languages are two modes which can be used with AVIoT. Visualisation is limited to configuring basic environment. Scripting languages are used for the authoring advanced situations. Predefined models of spatial configuration are used as the authors are considering that most houses have a similar layout. The flexibility to change the layout is provided upto a very minimal extent which expects users to relocate these template models to fit with respect to the real positions (see Figure 2.3). One of the issues with this type of approach is related to generalisation of architectures/layouts of houses across the world. The authors are providing capability to users to alter the 3D templates to a minimal level on the basis of a real 2D indoor plan but even the slightest variation in the template, brings a big change when compared to the actual layout of the house.

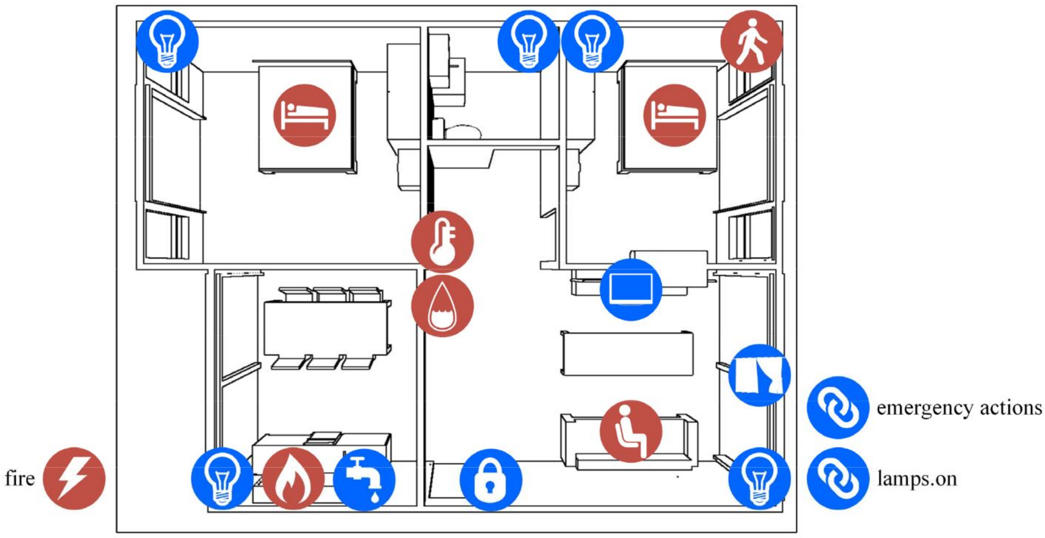


Figure 2.3: 3D space template in AVIoT [16]

The positive aspect of their work is that they have performed user studies to analyse the efficacy of both the modes of authoring, namely scripting and visualisations. In the results, it is shown that visualisation is more efficient for authoring. The completion time of the task using visual authoring is much less compared to the text-based authoring (47 percent savings). It is also mentioned that with visual authoring the ease of learning is more along with enhancement of usability in terms of user friendliness and efficiency [16].

The need to make interoperable IoT devices has been realised by many researchers. Imagining about the freedom of IoT devices, many researchers have started researching about interoperable platforms which support end-user authoring. Heo et al.[14] have worked upon a prototype – IoT-Map, to make this dream come to reality. IoT-Map is a mobile application platform which promotes interoperability between smart devices and mobile things. They have created a platform library which they call IoT-App. The interactions between these devices, which are based on IoT-App, can be customised and built by using an API (for developers) and by using a GUI authoring tool for end users. It is mentioned [16] that when it comes to the platforms, there exists ambiguity in the role of developers and device manufacturers.

To solve this issue of division of roles, the authors have adopted the concept of a model-driven architecture (MDA) [8]. MDA works on the idea of extraction of platform-independent and domain specific model from elements which are platform specific like operating systems, communication protocols or programming languages to promote interoperability and efficacy. The authors are suggesting to use the Electronic Product Code (EPC) standard, specifically EPCglobal's Object Name Service (ONS) [31] at the manufacturer's level. ONS helps in retrieval of information of product using a server which needs to be maintained by manufacturer. For developers, the work suggests easy creation of applications using the IoT-App API. For users to develop their application, they can use IoT-Map's authoring and composition tool which is implemented based on the Node-RED[5], an open-source service composition framework of IBM for IoT devices. Node-RED follows a flow metaphor as shown in Figure 2.4. Here the authors are assuming that most manufacturers will implement the ONS standard. So the end-user will only be able to use those devices which are already based on this standard.

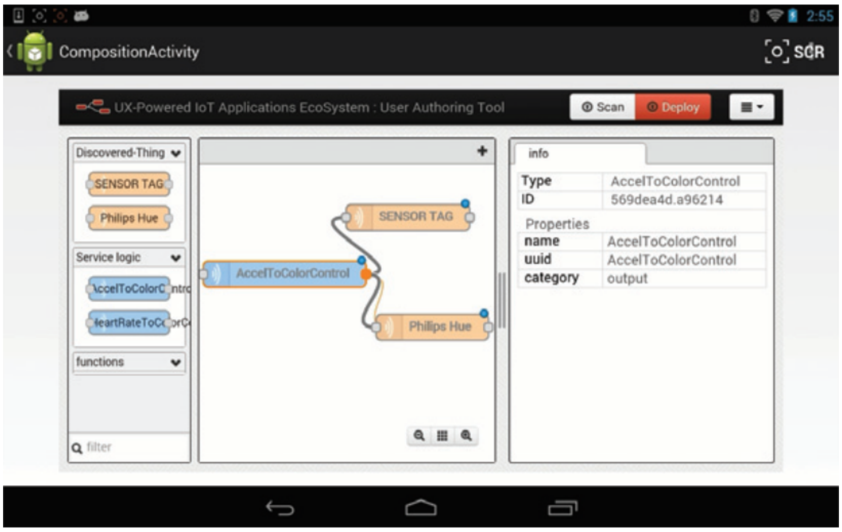


Figure 2.4: IoT-Map – authoring tool

Desolda et al.[7] have performed an extensive study to identify possible visual paradigms which are best suited to express composition rules. It is highlighted that many commercial tools have come across in the market which allows users with no programming experience to play with IoT devices. The limitation of these tools are – they are pre packaged solutions which interacts with vendor specific products only and is cannot be adapted

[5]`https://nodered.org`

to mix-up with different smart devices and services. They are also mentioning about the popularity of task-automation tools [3] which is mainly due to the easy and intuitive paradigms they offer for synchronisation of behaviour of objects and objects and applications [19]. The main motivation for the authors seems to be lack of match of graphical notations for specification of rule with mental model of users [35] despite of popularity of Task automation tools and tools working with simple event condition action rules which make ease for people having no programming background [24]. The authors are also highlighting the popularity of graph-based notations via a study based on web mashup composition paradigm (having high similarity with smart object composition) [9], which are suitable for programmers but cumbersome for lay people to conceptualise as usually lay people do not think about connected services [23, 38]. They have also mentioned about the limited expressive power of ECA rules using current tools and the need to add temporal and spatial conditions in creation of ECA rules [32]. Temporal conditions are an important feature or requirement for home automation [29]. Authors have identified the use of temporal and spatial conditions being offered by some TA tools like Zapier[6], but it is mostly done via workarounds like considering events to take into account the system time and by filtering the data of smart devices. Authors have clearly mentioned that due to these orkarounds the compexity of these tools increases which consequently leads to scare adoption of these by general mass. Commercial tools such as IFTTT, elastic.io, Zapier, ifDuzzit and tolls mentioned during research work [37, 17] are focussing on non technical users but allow creation of only basic rules or minimal alteration over the predefined recipes and tools which allow creation of more complex rules like Node-RED, requires some advanced skills. Authors are trying to find a trade-off to these two extremes mentioned above. The common schema on the basis of which the work defined by authors exists is -

cause(s) => effect(s)

where events triggered by services are the causes and actions performed by other things are effects.

[6]`https://zapier.com`

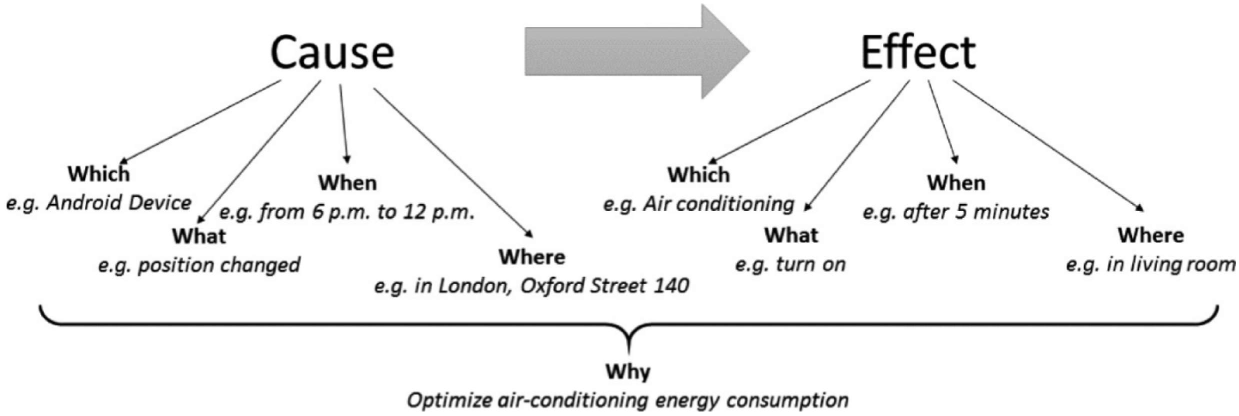


Figure 2.5: Example of cause and effect [7]

The authors in the work are inspired by the *5W* model which they have mentioned is adopted in general problem solving in various domains. However the have altered the model a bit. According to the original model each fact can be described by answering the following questions

1. Who did it?
2. What happened?
3. When did it take place?
4. Where did it take place?
5. Why did it happen?

After alteration it is - *Which* did it? What happened? When did it take place? Where did it take place? Why did it happen? Which specifies service, what specifies event, when and where specify the temporal and spatial conditions. Extensive user studies have been conducted where users are asked to create simple rules based on cause and effect. They have conducted the user studies very nicely but the participant pools includes people who are students of Computer Science.

2.2 Cross-Device Interactions

Research is being conducted to make it easier to develop applications possessing the power of cross-device interactions. Chi and Li [2] have worked on Weave (now Chord[7]), which is a framework to assist developers to create cross-device wearable interactions by scripting. It works by providing APIs based on JavaScript which makes it easier to distribute UI output and combine sensing events and user input across mobile and wearable devices. Weave is now known as Chord and is developed with a focus on developers.

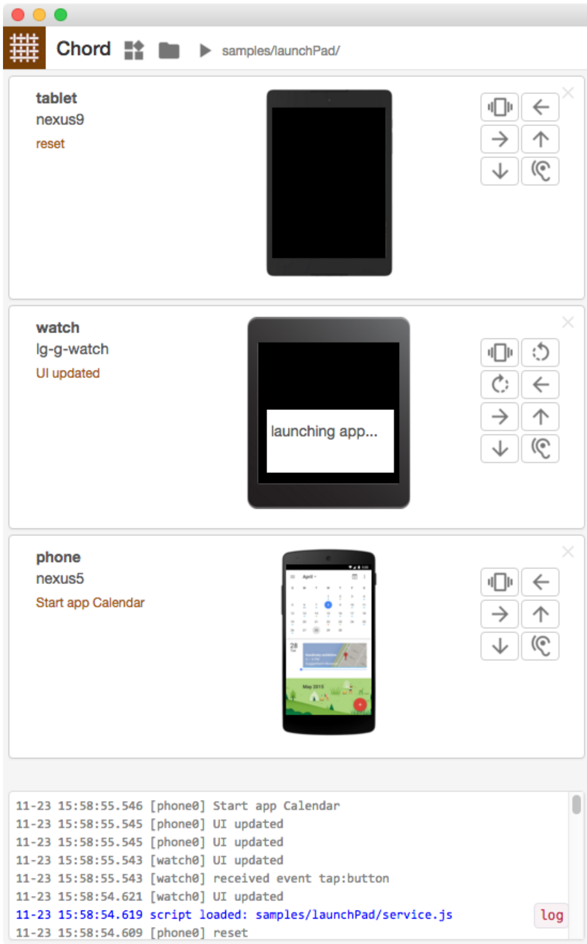


Figure 2.6: Chord – user interface

People have started feeling that rather than making authoring tools focusing on both developers and users (like Weave as shown in Section 2.2), end-user development should be the priority. Thus, Ghiani et al.[10] are focussing on enhancing the end user's experience by presenting a method along with a set of tools which provide end users without having experience with programming to customise the behaviour of context-dependent web appli-

[7] https://github.com/google/chord

cations by using and specifying trigger-action rules. The motivation they had to perform this work is based on the fact that it is difficult and not of much use to hard code context-dependent applications by developers at the time of designing as developers cannot predict all possible situations that application would encounter during its use. They have also highlighted that the pace of development in existing software development cycles is too slow to quickly respond and adapt to the changing needs of the different variety of users. Thus, they are defining an EUD paradigm based on trigger-action rules which they consider can help in softening of boundaries between the end users and professional developers. As mentioned by the authors, this type of solution can be great if it is able to address the challenges for obtaining low threshold/high ceiling environments [22]. Ghiani et al.[10] are making nice comparison with the existing trigger-action rules platforms available like IFTTT [8] which allow users to define basic trigger-action rules like *If I do this, then do that*. As per authors, the major disadvantage of IFTTT despite being an expressive application is that it is very limited when it comes to defining rules as it does not allow users to create more complex structural rules which involve multiple events and actions. This limitation with IFTTT is well researched and explained by Ur et al.[34]. While comparing with IFTTT, the authors have taking into account that users should be able to differentiate between event triggers (happens when a contextual change takes place) and condition triggers (happens when a condition is true).

The authoring tool defined in the work is web based. Users can initiate the creation of a rule by either defining triggers first or the actions. The interface allows users to reuse previously defined rules and use of boolean operators is possible in rule definitions.

[8] `https://ifttt.com`

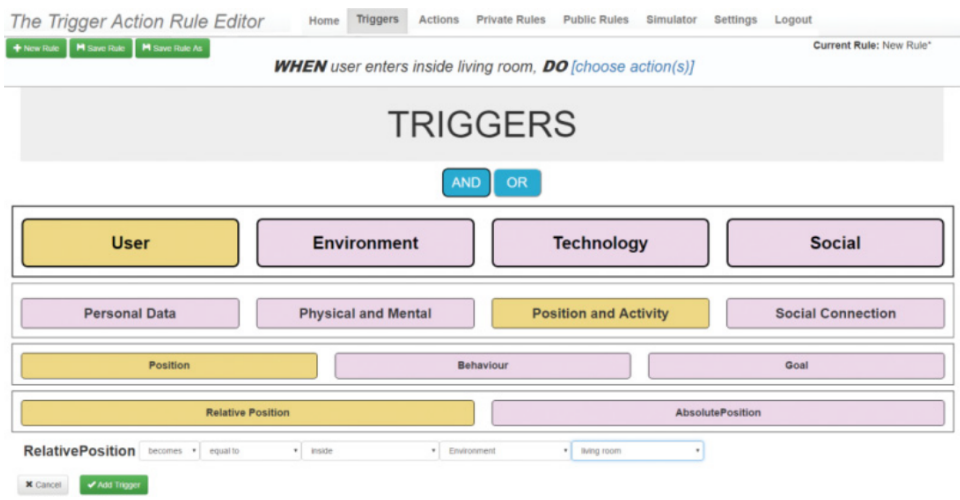


Figure 2.7: The trigger action rule editor

The applications shows the rules in natural language also and allows saving of personal rules as shown in 2.8. In cases of conflicts, priorities are used to perform a particular task. In case of an hardware issue, like non availability of a particular device, the rule's corresponding part to the missing device is highlighted in red colour.

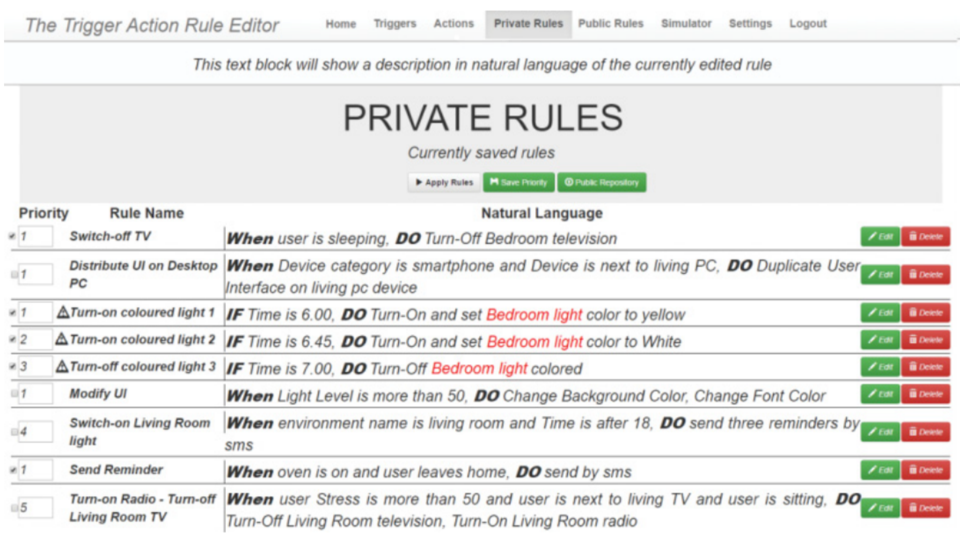


Figure 2.8: The trigger action rule editor

This tool uses a rule-based metaphor. Authors prepared a smart home environment using this tool and performed user studies with 18 participants to analyse the performance in intuitiveness of the tool. From eighteen, twelve participants had experience with programming. The results of user studies have demonstrated that the tool is good for defining simple rules but defining complex rules is still somewhat cumbersome. Several participants in the study were confused between events and conditions which shows that the tools is not the best when it comes to use with general mass.

2.3 Metaphors

"A figure of speech in which a word or phrase literally denoting one kind of object or idea is used in place of another to suggest a likeness or analogy between them." — Merriam-Webster Dictionary
Metaphors have the virtue of an expected behaviour that is understood by all. Therefore metaphorical abstraction makes easier to think about problems by allowing them to be simplified.

The related work discussed above included examples of authoring tools used in the domain of IoT and CDI like AVIoT, Puzzle and others. While developing Puzzle 2.1, an iterative approach is followed which included development of prototype followed by usability testing. As mentioned before, the usability testing is based on less participants thus it cannot validate jigsaw as the best metaphor, although it is being used in scratch, it does not verify its effectiveness for authoring applications focussing IoT and CDI. Tools like Chord might be nice for easier development of cross-device applications, but still requires users to have experience with scripting languages which at the present date is not present in majority of population. Development of AVIoT has been made in a systematic approach. It has clear from the study performed by researchers who have worked on AVIoT that visualisation if more effective than text-based authoring. In AVIoT, to create complex applications support for scripting languages is provided. One thing which we have seen above is that the applications which are easier to use by end users, limits them to some extent. The applications which allow to explore the full potential of user's vision, is complex to understand by the user. Thus, there exists a need to find the most common metaphors which are well known to end-users. Also, researchers are focussing on development of authoring tool for IoT or CDI, but very less people are focussing on them together. There is a need to find the metaphors which end-users can relate to.

3
Methodology

In this chapter we discuss the strategies which were adopted to conduct research towards finding the best metaphor for end-user authoring of Web of Things and cross-device applications.

3.1 Goal

The objective of our research is to investigate the best metaphor(s) for the end user authoring of Web of Things and cross-device application. As discussed in the Chapter 2, the absence of a good metaphor is restricting end users to utilise their complete potential towards end-user authoring applications. Some solutions for users who have programming experience are present, but this group of people (equipped with technical expertise) represents a minority of all end users.

3.2 Users

Figure 3.1: Power to the end user

The focus of this research is towards *end users* to consequently contribute towards end user empowerment.

3.3 Requirements

3.3.1 Functional Requirements

The functional requirement for this research is that the end user shall be able author Web of Things and cross-device applications and be able to enrich their applications with the features they can think of, using an application design structure which is user centred and thus easier for users to understand.

3.3.2 Non-Functional Requirements

The application should have the potential to combine different devices and execute all ideas of the end user.

3.4 Approach Towards the Problem

As the goal of the thesis is to focus on end users, an approach closely related to contextual designing (sub process of UCD) is used.

It was decided to follow a three step approach

1. Conduction of user study experiments

2. Preparing mock-ups

3. Developing a prototype

3.4.1 User Experiments

As seen in Chapter 2, research towards the end-user authoring of applications related to WoT and cross-device applications is mainly performed without actually involving the end users. We decided to perform studies which actively involve end users.

In order to observe the difference between users with and without a technical background, it was decided to have two groups of participants, those having a technical background and those not having technical background.

Initially three use cases were developed which were focussing on IoT devices and cross-device interaction separately (first two use cases) and collectively (third use case). We are going to refer this use case set as *Use Case 1* from now. It consisted of:

1. Use case 1.1: Focussing on IoT devices

2. Use case 1.2: Focussing on cross-device interactions (CDI)

3. Use case 1.3: Focussing on IoT and CDI

Use Case 1

The detailed use cases of set UC-1 are mentioned below.

- Case : 1.1
  Consider Paola, a young HR professional, who has a very tight schedule. For Paola, efficient utilisation of each minute is a necessity. Paola recently shifted to a smart home. She has a lot of smart equipments- smart lights, smart coffee machine, smart heating devices, smart TV, smart radio systems, a nice tablet and smartphone. After moving to the smart home, Paola is trying to make her mornings a bit more efficient. Her usual morning starts with the alarm ringing. Then she opens the curtains and moves to take a shower. After the shower, she takes breakfast while reading her emails on her tablet. Once, she is done, she commutes to work via public transport. She continues reading on her smart phone and usually likes to continue with her morning music playlist.

- Case 1.2
  Consider Josh, a journalist of the local news channel. He is always on the move and captures news footage on his video camera and at times via his smartphone. It is the time of the year when it is maximum cold. He hates to wait 15 minutes after reaching home, which is taken by his home's heater to make the room cozy. After reaching, he plays soothing music and he transfers all the videos and pictures from smartphones and video camera to the computer. He sorts it according to the date and time and then while sitting on the bed, he likes to delete the videos which are not good. He will love to do on the tablet, but this will require extra effort as he will have to move all the data from the computer to the tablet. Josh is a person who appreciates the beauty of the surroundings and his efficiency improves with the surrounding. Thus, he purchased smart lights and smart music speakers but unfortunately has not tried them yet. Try to think of innovative solutions about how can you help him to make his life better.

- Case 1.3
  Alex, a university student wants to make his or her life a bit more organised. She looks for trending music on YouTube and the one's she likes, she adds to her Spotify playlist. She goes to the university with her tablet, takes notes on them and compiles it on her laptop by transferring the contents from tablet to laptop. She has been diagnosed by diabetes soon. She has a sweet tooth, but now she needs to limit her sugar intake. So, she needs to track her blood sugar and for that she purchased a smart machine which keeps a track of her sugar level in real time. Once, she gets back home, she eats food (usually sweet). After that, she transfers her notes from her tablet to the computer in order to compile them nicely. Tonight, Alex has to go to pick her cousin at the airport and she wishes to take her notes in her smartphone to do the sorting and organisation of notes on the move. Think of creative ideas to help Alex.

Pre-Study

Pre-studies, using the above mentioned use cases were performed in an architectural college[1] in a small city in India[2]. A presentation to introduce the concepts of IoT and cross-device Iinteractions was delivered before conducting the study. The study was conducted in groups wherein each group

[1] Buddha College of Architecture
[2] Karnal (29.6857 N, 76.9905 E)

was composed of two persons. Five groups were formed and each group was provided with a different use case.

Description of Participants

All participants were students pursuing a four-year Bachelor of Architecture. Their age varied from 19 to 23 years.

Observations

- It was difficult to understand the concepts of IoT and cross-device interaction for students despite giving multiple examples during the presentation.
- It was difficult to initiate the drawings.
- One group came up with a metaphor in the form of a wheel (For case 1.1) as shown in Figure A.3.

Improvements after Pre-Study

After analysing the observations from the pre-study, it was decided to create a single use including situations related to IoT as well as cross-device interactions. This decision was taken considering the fact that different situations might not be able to provide a true result towards both IoT and CDI. It was also decided that the use case should be interactive (having graphics) and should be provided to the users in printed form.

Another change which was adopted after pre-study was that rather than making both participants think and discuss together on solving the issue, the process would be divided into two phases. The initial phase allows participants to think and brainstorm individually, later in the consolidation phase they will be made to discuss, compare and improve the results together. The detailed information about phase one and two is given in the Chapter 4.2.

As witnessed during the chapter 2, in most of the research being conducted on metaphors for the end-user authoring of IoT or cross-device interaction, the study participants hace a background in Computer Science. As this might lead to a bias, we decided that the our participant pool should include both types of users — having technical background (exposure to courses related to computer science and engineering) as well as users having no technical background.

Use Case

This use case is based on a student named Alex. Different situations in which Alex is interacting with cross-device interactive applications and WoT devices are shown in different. The detailed information present on each slide can be seen in Appendix A.1.2

Fallbacks

In case of participants being stuck at a point, certain fall-backs were created and was decided to be provided to the participants in case of need.

- - *How would you draw interaction between two persons?*
  - *Now how would you draw interaction between a person and a device?*
  - *Imagine that you are doing an interaction with your phone that triggers the TV to go on, how would you draw that?*
  - *Now imagine, that not only the TV goes on, but the light on the ceiling goes off at the same time, how would you draw that?*
  - *You know drew, a part of the scenario, can you complete the rest on your own?*
- Imagine you have to explain this scenario to someone else, how would you draw the functionality/interaction present between the different devices?

After completion of phase 1 and 2 brainstorming with the use cases, individual interview of the participants were conducted. The purpose of this interview was to analyse their (user's) experience with use cases and with the existing IoT tools and cross-device interaction tools. This was achieved by asking the following questions to the participants -

- How did you come up with such a solution?
- Did you have any difficulties during the study? If yes, which ones?
- Do you think you would use an application proposing IoT and cross-device interaction that you can create by using the components that you drew? Why, Why not?

- Do you think you have enough control to custom your interfaces with existing solutions?
- Do you have any comments?

Thereafter participants were asked to fill a post-survey questionnaire which will be based on some general information of users (see figure A.2 in Appendix).

Once done, participants were asked to put their signatures on an acknowledgement and they were provided with Euro 5 cash to thank them.

Evaluation Study

To test this approach demo studies were organised at the WISE Lab of VUB, Pleinlaan 9, Brussels.

Description of Participants

Evaluation study was conducted for two groups of two persons each, thus total number of participants for *demo study 2* were four. The average age of participants is 26. Group 1 was composed up of people having technical background and group 2 was with people having no technical background.

Observations

It was observed that for participants having a non-technical background, it was difficult to start. Participants were confused about what type of interaction needs to be drawn and mostly were just linking devices and not focusing on details. It was also observed that participants were relating things to reality and if they haven't been exposed to IoT or Cross-Device tools then they used to limit themselves to the technology by which they have acquaintance.

Improvements After Evaluation Study

Considering the observations of Demo study 2, it was decided to change the question which users were asked to answer after going through the use case slides. The improved question was -

- *How would you graphically represent the functionality and interactions between different components in this scenario?*
  For example, how would you draw that the interaction with Alex' phone triggers the TV to turn on?

- *How would you show that one output of a device is used as input for another device. For instance,on page 5 (referring to slide) the amount of calories kept by the calorie tracker application on Alex' smart-phone (output) is used as input by the smart-watch to notify Alex about an excess.*

- *Go through the slides one by one and try to describe the interactions present on each slide in a single graphical drawing.*

- *Try to be precise and add as many details as possible*

Another addition which was made to the Use Cases was, at the top of each use case's printed page was mentioned -

Assume the functionality in this scenario exists. Do not limit yourself on existing technology.

3.4.2 Preparing Mockups

Microsoft Visio is used as a tool to support in preperation of wireframes. Wireframes need to be prepared after conduction of user studies and analysis of its result.

3.4.3 Prototype

After finalising the wireframes, a front-end prototype was prepared. As the purpose of prototype is limited to demonstration of a user centred design, so it shall not include server side programming and will be prepared using

- HTML 5
- CSS 3
- Javascript

4 User Studies

In this section we are going to discuss the user studies which have been conducted to analyse the best metaphors.

4.1 Participants

The user study involved 30 participants, 14 females and 16 males, who participated in the groups of two, aged between 14 and 54 years old. As mentioned in Section 3.4.1, the participants were taken from both technical and non-technical background to perform a comparative analysis. The background education of all participants is highlighted in Table A.1 in the Appendix.

4.2 Procedure

The study was conducted by two persons, Satyam Kapoor assisted by his Master's thesis' supervisor Audrey Sanctorum. It consisted of 15 separate sessions for each group. At the start, one of the two experimenters gave a 10 minute long presentation to introduce participants to the concepts of IoT and CDI. The presentation included examples of both IoT (Philips Hue and Amazon echo) and CDI (Spotify and Chromecast). To avoid bias in the experiment, participants were not provided with any examples of metaphors.

After the presentation, participants were explained that they will be provided with a use case along with some questions. They were also suggested to follow the *think-aloud strategy* which involves speaking out their thoughts during the course of the experiment. Each participant was provided with blank paper sheets, a hard copy of the use case, along with pens and pencils. The study was divided into two phases:

- Phase one: Participants were asked to sit separately to start solving the use case. In case of any questions, they were assisted by one of the supervisors. Participants were encouraged and reminded to follow the think-aloud strategy. If participants were having difficulty in initiating, they were assisted by the supervisor who provided them with some fallbacks.

- Phase two: Participants were asked to sit together and discuss each other's work performed during phase one. They were motivated to make a comparison between their drawings and have a discussion about which one is better and why. They were encouraged to make alterations to their drawings in case they could think of better ideas.

Phase one and two were both audio and video recorded.

After the completion of phase two, individual interviews with the participants were conducted. There were five questions asked in the interview out of which three were related to their drawings and their understanding and comfort with the study procedure and proposed tasks. The questions can be found in Appendix A.1.1. At the end of the session, participants filled in a questionnaire composed of 15 questions. Five questions aimed to collect the participants demographic data and their qualification. Nine questions aimed to collect information about their exposure to IoT and CDI applications and devices. One question aimed at collecting feedback on the participants' ease during the coarse of the user study. Later, they were provided with a gift of five euros to thank them for their participation.

4.3 Data Collection

The data used to perform the study analysis was collected by reviewing the following

1. The notes taken by both experimenters during the study

2. The video recorded during the study

3. The drawings which were drawn by the users during the study

4. The answers filled in by the users in the post-survey questionnaire

4.4 Observation and Discussion

4.4.1 Observations from user drawings

All participants' drawings and information can be found on Github.[1]
For simplicity in the analysis, we have mentioned participants who have exposure to programming as belonging to *class one* and those not having exposure to programming as belonging to *class two*. We will use the following format to display group information of participants:
"*a(x,y)*" (where a: participants, x: number of participants belonging to class one and y: number of participants belonging to class two).

User drawings were analysed based on certain characteristics which are discussed below.

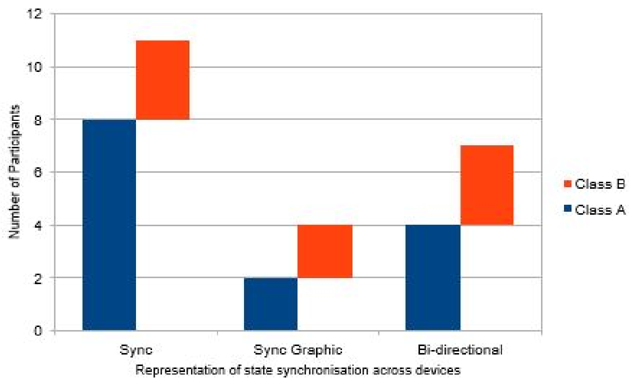
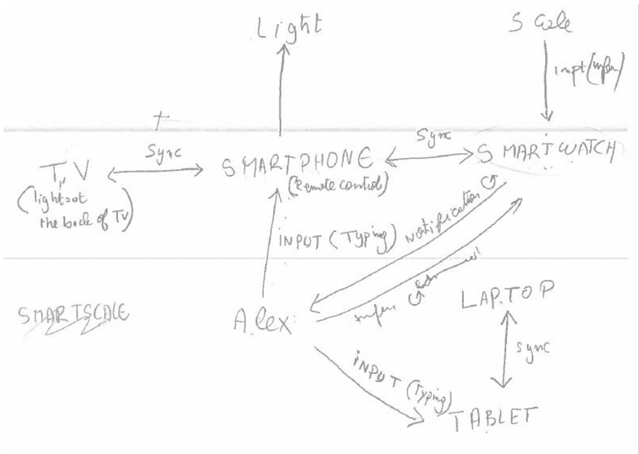


Figure 4.1: Representation of participants based on how they are depicting state synchronisation across devices

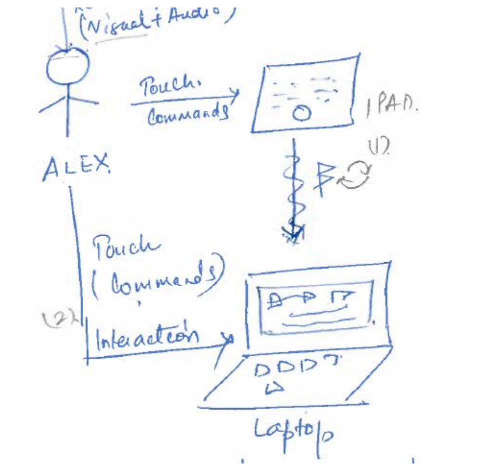
State synchronisation between devices : 11(8,3) participants out of 30 mentioned the word "sync" (shown in Figure 4.2a). 4(2,2) participants out of 30 drew sync symbol (shown as 4.2b) to show synchronisation. 7(4,3) out

[1] `https://github.com/satyamkapoor/master_thesis`

of 30 participants used bidirectional arrows ($\longleftrightarrow$). From the results can be seen that using arrow with word “sync” or using bidirectional arrow to depict sync seems good.



(a) Participants mentioning “sync” to show state synchronisation

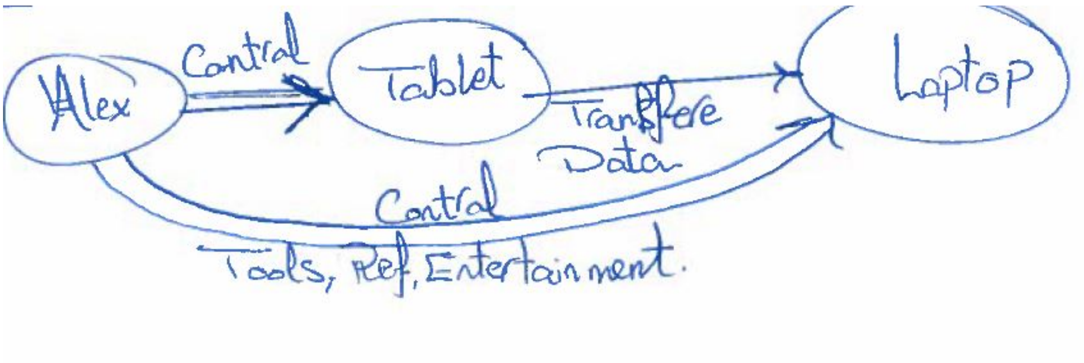


(b) Participant using Sync symbol

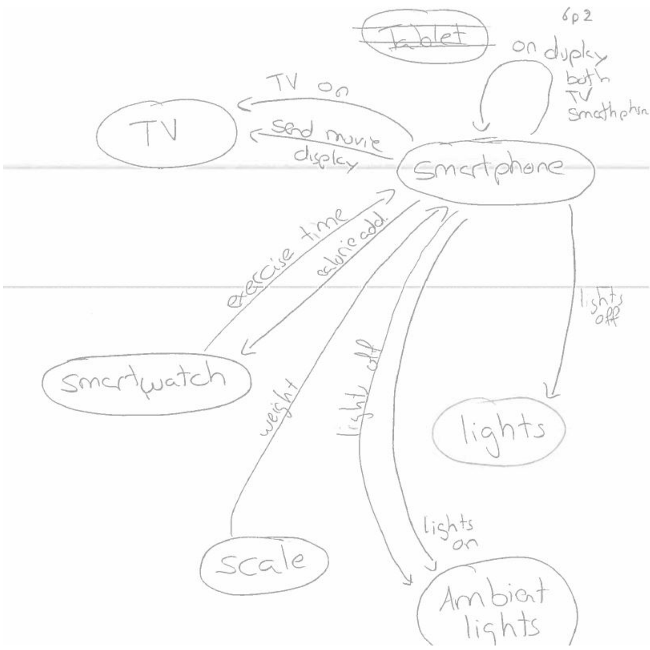
Figure 4.2: State synchronisation between devices shown via a) word “sync” on the top of the arrows and b) drawing symbol of sync

Data transfer from one device to another: 22 participants used arrows to illustrate data transfer from one device to another. Out of these 22, 13(5,8) wrote the data being transferred at the top of the arrow (shown in Figure 4.3a). 6(5,1) participants also mentioned the actions on the top of the arrow along with the information about the transfer of data. 2(0,2) participants used the term “signal” over the arrow (shown in Figure 4.3c).

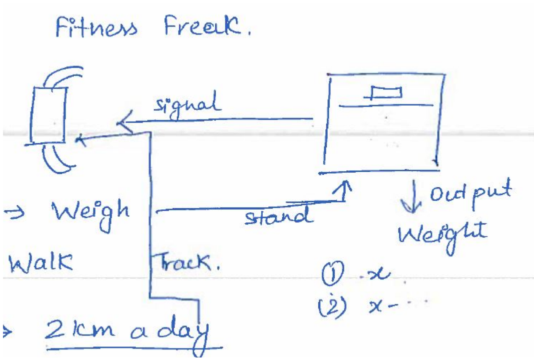
Arrows depicts direction and movement. Thus most people drew an arrow. To make things more clear, 13 participants wrote about the data which is being transferred. The 2 participants who are using the term “signal” belonged to the class two and were thinking that it is via signals that data is being transferred, relating it with Wi-Fi or GSM signals. As a high number of participants are using arrows in their drawings for depicting data being transferred from one device to another, it gives an indication that this can be an important metaphor for expressing the data transfer.



(a) Data transfer shown via arrows



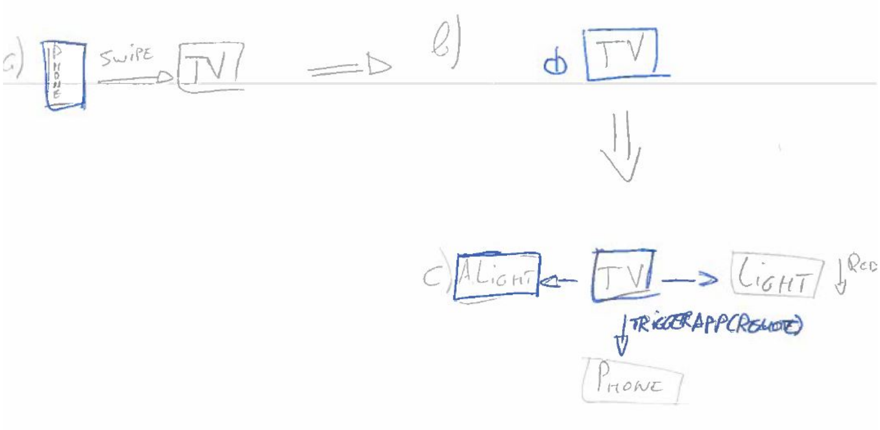
(b) Data transfer shown via arrows and type of data on top of the arrow



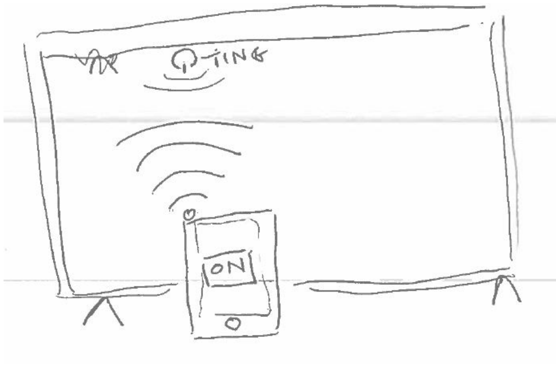
(c) Data transfer shown via arrows with "signal" mentioned on top of the arrow

Figure 4.3: Depiction of data transfer from one device to another by different participants

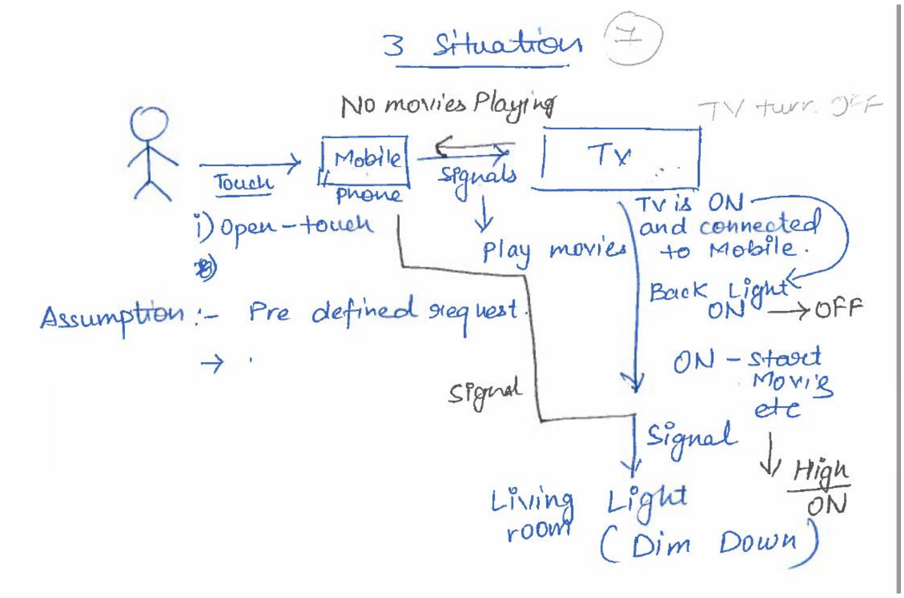
Concurrent actions (e.g.light & TV turning on: 15(7,8) participants grouped the actions together. 8 of 30 used numbers out of which 4 used them over the arrows and the other 4 next to their drawings. Since the majority of them are grouping the actions together, this would suggest to group them as well, for example, using the box metaphor. The box metaphor in this situation will make things easier to understand. Regarding writing numbers on arrows, it can become difficult to interpret since user will have to find all arrows containing the same number to know that they occur simultaneously.



(a) Concurrent actions: shown by grouping concurrent things with one letter



(b) Concurrent actions: Grouped together



(c)

Figure 4.4: Concurrent actions

Sequential actions (e.g. smartphone puts movie on TV, then becomes remote control): 14 participants (5,9) used numbers to deal with this case. Out of these 14, 5 participants used numbers on arrows(shown in Figure 4.5), 8 used numbers next to the drawing and one participant used both on arrows as well as the drawing. 12(7,5) out of the 30 participants, just drew the arrows from left to right. For example, participant X drew first an arrow from the phone to TV and then one from the TV to the lights. Therefore, numbers might make complex sequences more clear but might be unnecessary for simple situation.

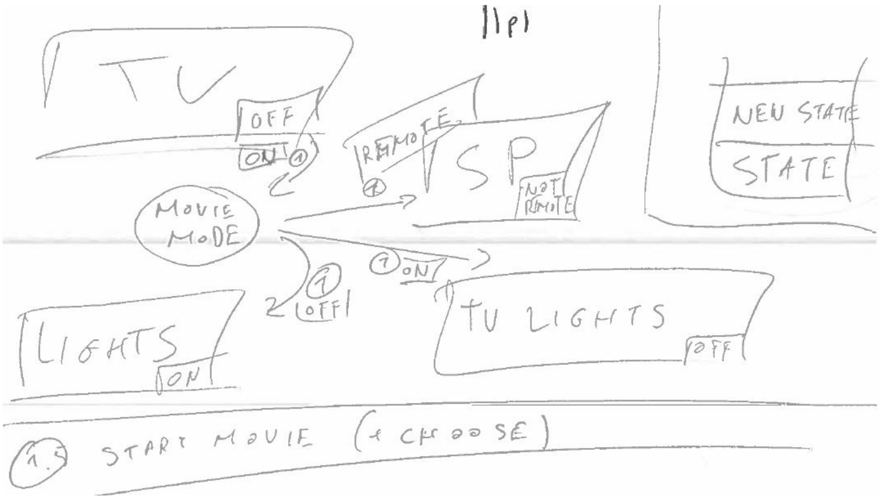
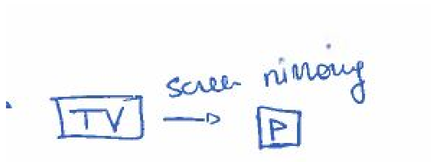
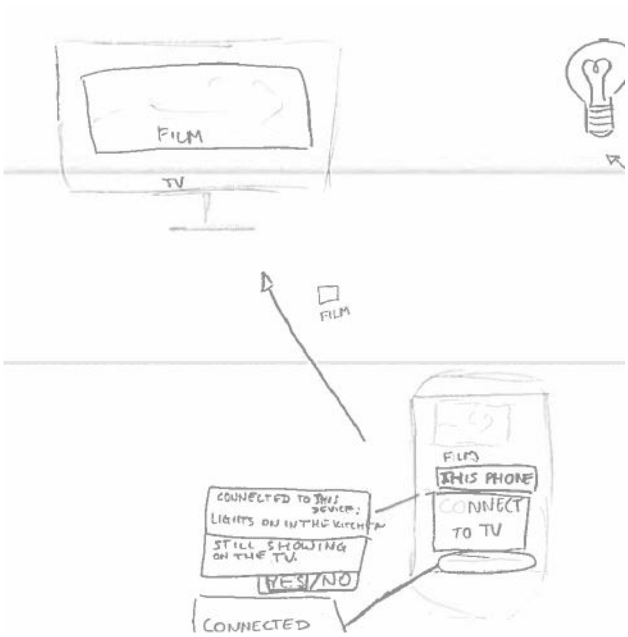


Figure 4.5: Sequential actions: shown by numbers on arrows by participant 11p1

Multiple instances of same data (e.g. movie on TV & smartphone): 13 (3,10) participants out of the 30 depicted same things under both devices. 9 of 30 mentioned "duplicate movie" / "mirroring" over the arrow to depict the same state (shown in Figure 4.6a). 3 of 30 used bidirectional arrow (<–>) show multiple instances of same data.



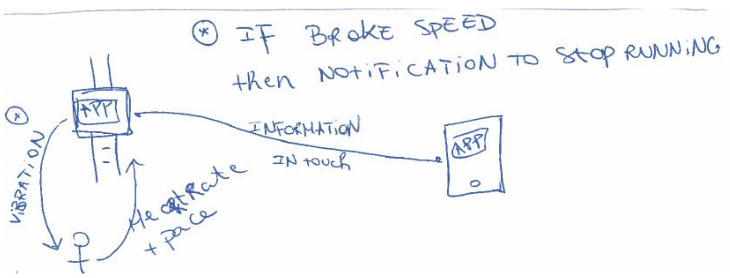
(a) Multiple instances of same data shown by writing "screen mirroring"



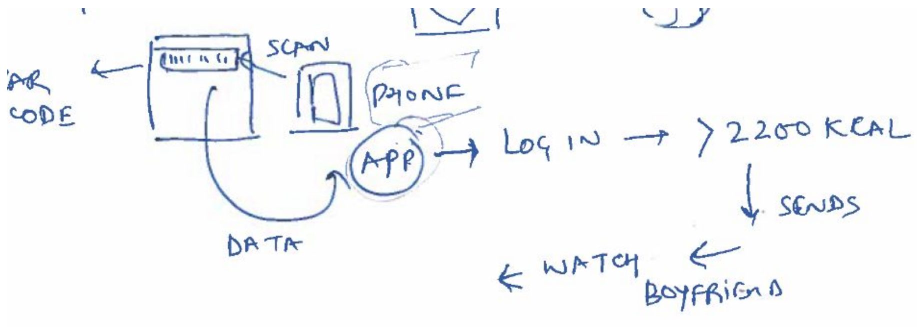
(b) Multiple instances of same data depicted by showing same picture on TV as well as TV

Figure 4.6: Multiple instances of the same data being depicted by a) mentioning screen mirroring b) showing same picture on both devices to depict state synchronisation

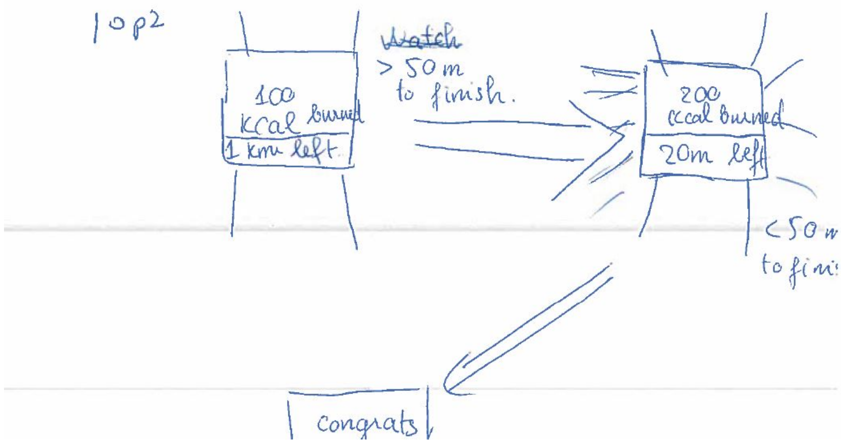
Conditional statements : 13(7,6) participants used the "If" keyword and 3 of these 13 also used "then" keyword(shown in Figure 4.7d). For example, participant 8p1 just quoted ">2200 kcal" as a threshold to send notification to the watch (shown in Figure 4.7b). 9(4,5) of the 30 participants noted condition without any keyword. 5 drew the resulting condition, which in case of an authoring tool will be not feasible due to large number of possibilities. Providing If... Then... structure seems to be good. Also putting conditions over arrow can be nice.



(a) Conditional statements by using 'If-then' structure



(b) Conditional statements shown by using '>' next to arrow

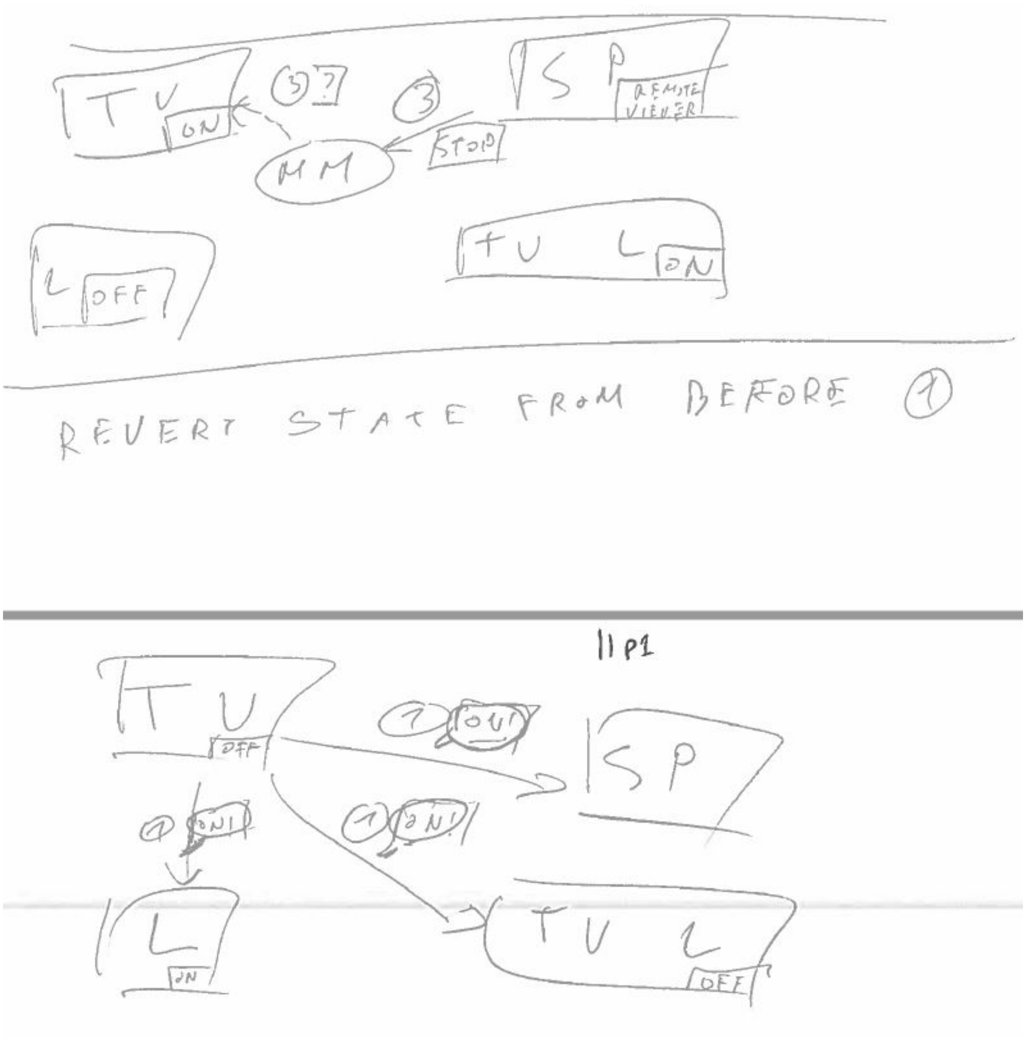


(c) Conditional statements shown by drawing '>' on top of the arrow

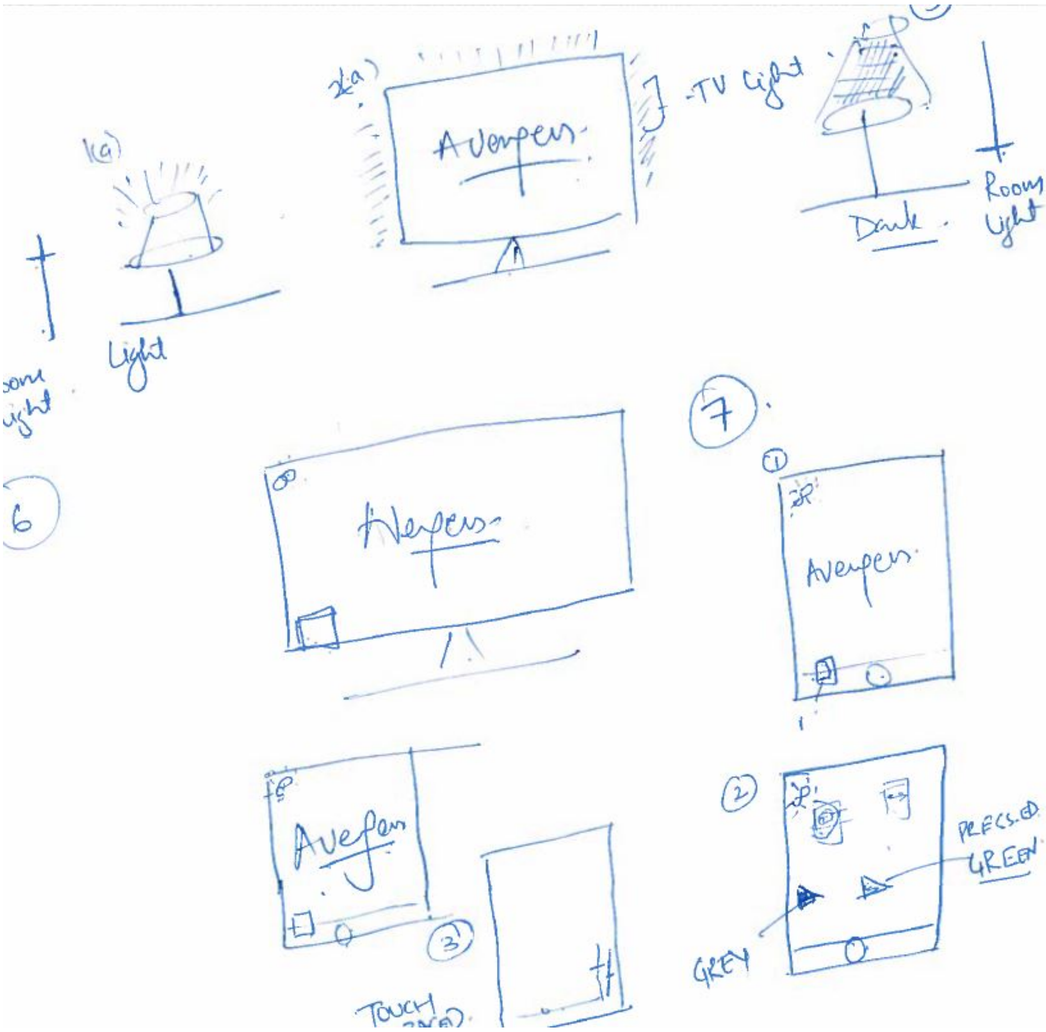
(d) Conditional statements by using both 'if and >'

Figure 4.7: Conditional statements shown using different styles by participants

Revert back to previous state (e.g. smartphone becomes remote controller again after stopping the movie): 17(6,11) participants of the 30 made new drawings out of which 6 also showed the previous state. For example, participants 11p1 and 13p1 have shown both the states and created new drawings (Figure 4.8a and Figure4.8b respectively). 3(2,1) of 30 used same drawings. Thus, it seems nice to provide users these two alternatives of others making new drawing or using the same drawing. 2 of 30 mentioned the *state of device* under the device's name. This also seems interesting as the idea depicts clarity. 2(0,2) of the 30 also used rules based on location, defining that the phone should be a remote controller again. Alex (the actor in user case) comes back to the living room from the kitchen.



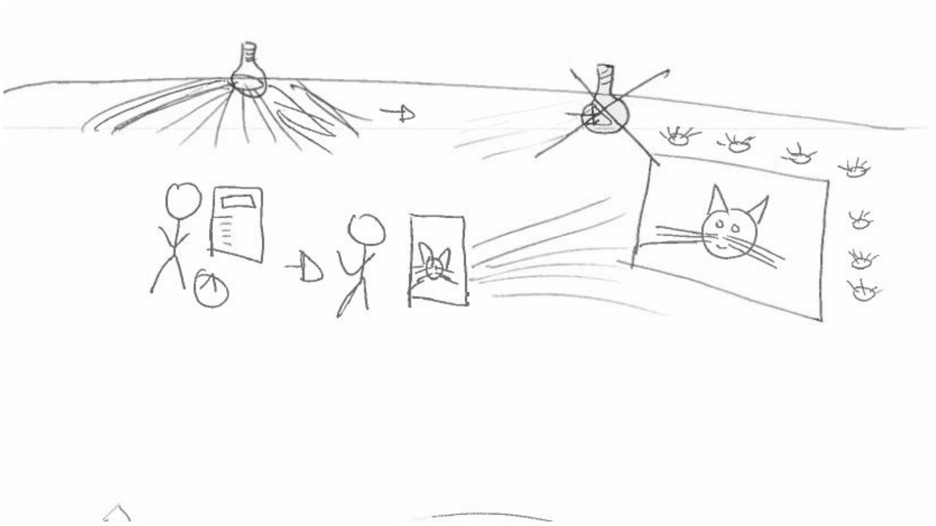
(a) Revert back to previous state: shown by making new drawings and also showing the previous state



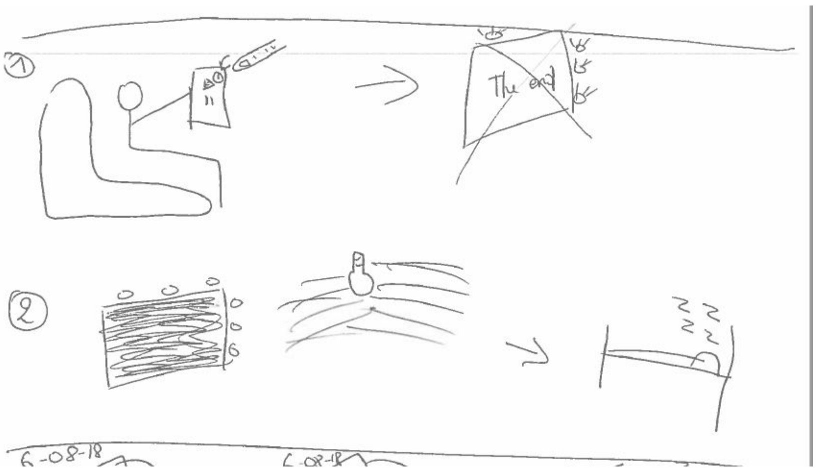
(b) Revert back to previous state shown by making new drawings as well as old state

Figure 4.8: Representation of revert back to previous states

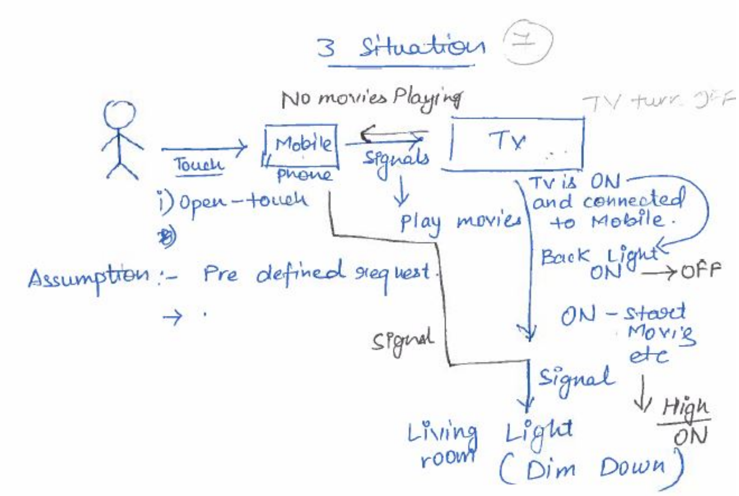
Opposite of a situation that has already been drawn (e.g. TV off & lights on/off): 17(6,11) participants out of the 30 made a new drawing to depict the opposite situations. 7(5,2) participants used a single drawing to depict both situations. One of these 7 participants, used different colours to represent and distinguish between both situations. It is better to provide the users with both the options in the authoring tool despite of the fact that keeping a single drawing can make things messy in situations where many actions/rules are present.



(a) Lights Off with TV On depicted by participant 15p2



(b) Lights On with TV Off depicted by participant15p1



(c) Lights and TV On/Off shown together in one figure by participant 8p2

Figure 4.9: Participants drawing opposite of a situation that has already been drawn

Actions happening on one single device (e.g. smartwatch monitoring pace): 10(6,4) participants out of the 30 are depicting this activity by drawing arrows from one instance of a device to another. 7(3,4) participants out of the 30 drew an arrow from device to the text. 3(3,0) participants out of the 30 are drawing arrows from device towards itself. This options is nice but none amongst class two participants have drawn this. It would be nice to try this with non technical people.

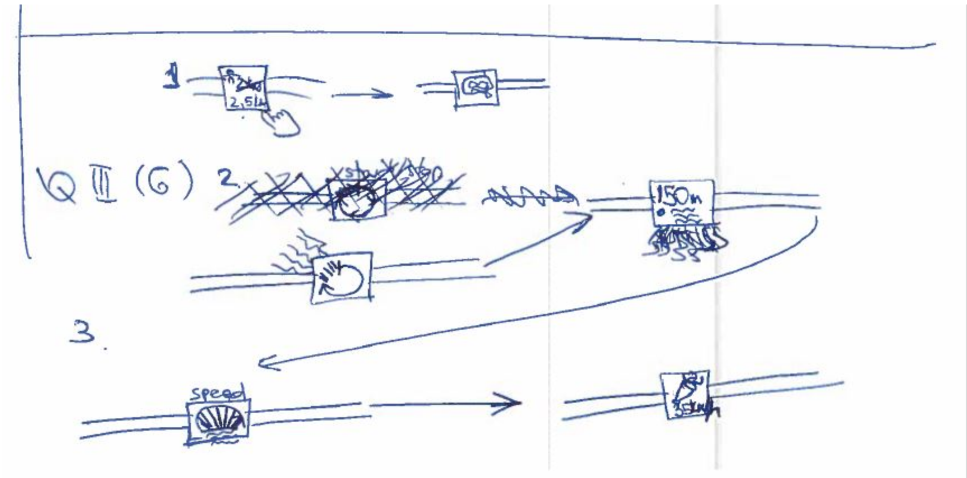
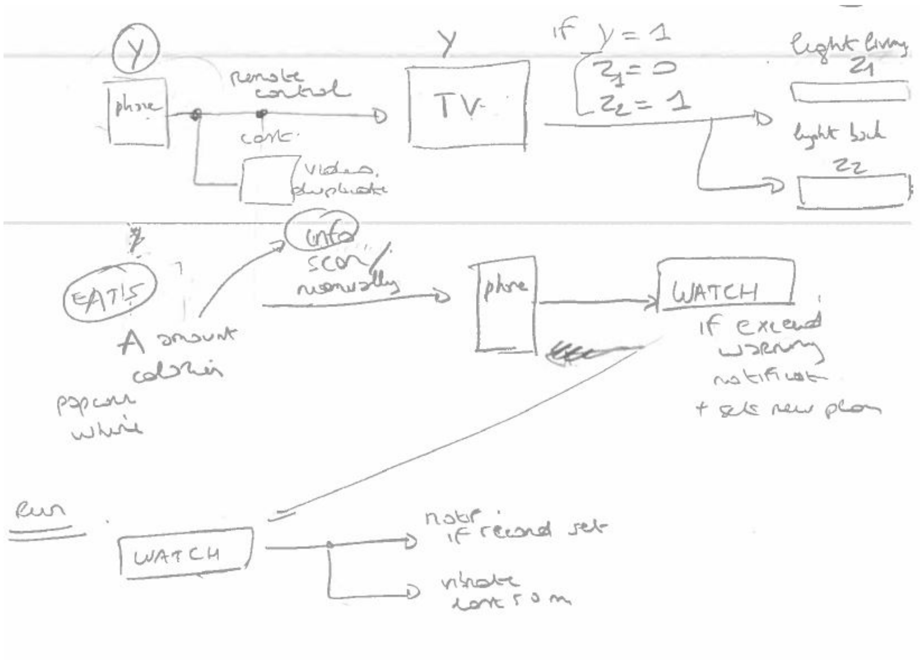
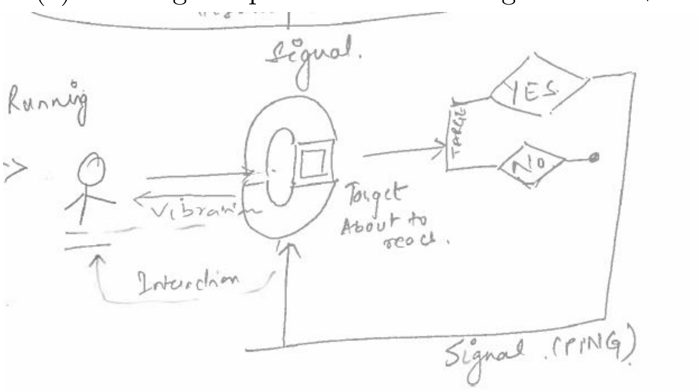


Figure 4.10: Action happening on one single device: Participant 9p1 drew same device multiple times with arrow in between and different interface

Conditions with multiple parameters (e.g. complex conditions like 'if record broken & session ended, then receive notification'): 7 out of 30 participants showed complex conditions. Out of these 7, 1 drew these conditions under each other. 5 of them drew conditions. One of these 7, 1 participant (having id 13p1) used diamonds to depict conditions as shown in Figure 4.11b.
5 participants showed complex actions. Out of these 5, 1 used '+'(shown in Figure 4.11a), another one used '&' and 3 wrote it on different lines however writing conditions under each other can be confusing. Using a diamond can be difficult on small screen devices as it will cover more space. However it can be tried. We can utilise logical operators for depicting this.



(a) Showing complex conditions using 'If' and '+'



(b) Showing complex conditions using diamonds

Figure 4.11: Complex conditions being shown by using 'If' or symbol '+'

Representation of person in the drawing (e.g. Alex or her boyfriend): 22 participants have drawn or mentioned Alex, the subject of our experiment. 16 of these have drawn Alex using similar graphic as shown in Figure 4.12. Going with the results, it is a good idea to demonstrate persons via a symbol or a graphic. This can also be used to define multiple users in the environment.

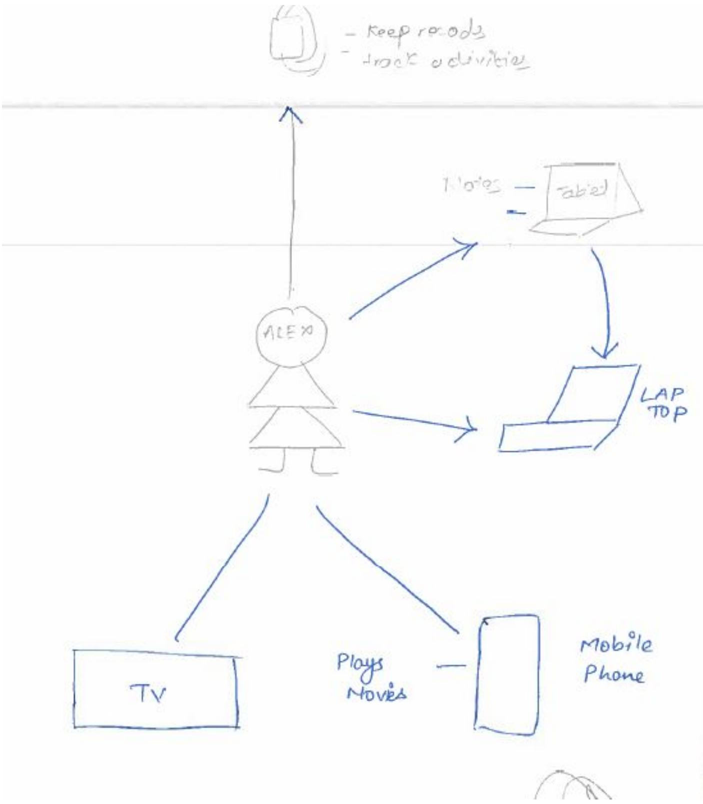


Figure 4.12: Representation of the person: Alex

Presence of location : 8(3,5) participants of 30 have written location. 6(3,3) location-awareness. Out of these 6, 1 wrote 'close' and another one drew the house plan. The remaining 4 have mentioned the location but have not drawn it. Possibility to add location should be present even if it does not matter. It will make it easier for people to relate their programs according to different locations.

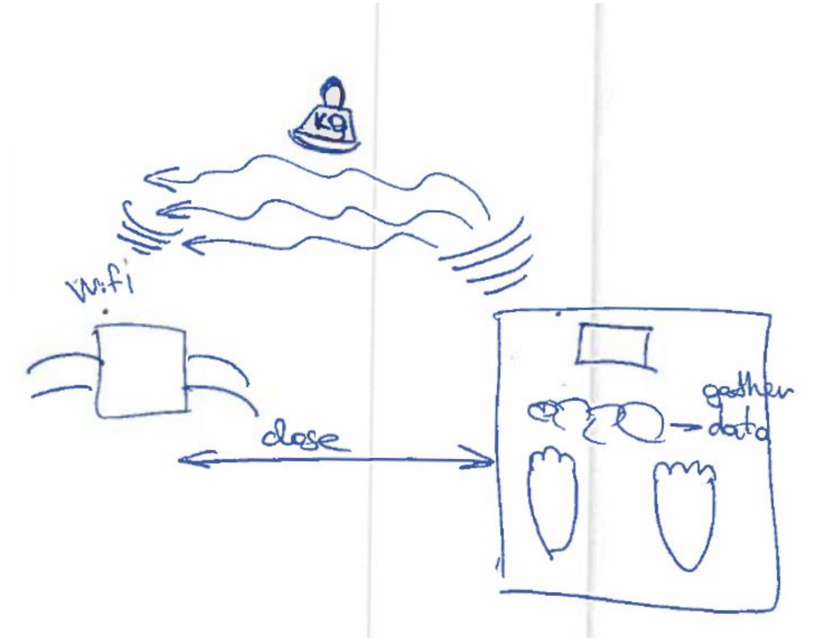


Figure 4.13: Mentioned “close” on the arrow between smartwatch and smartscale indicating that they sync when in close proximity

Presence of action in the drawing (e.g. running or eating): 15 participants wrote actions on the arrows. 3 wrote actions next to their drawing. 5 showed actions graphically. 7 did not mention actions at all.

Representation of device : 10(4,6) participants of the 30 wrote device’s names in squared boxes. 18(7,11) represented devices by their graphical representation. Both of these options can be provided and then evaluated on the basis of another user study.

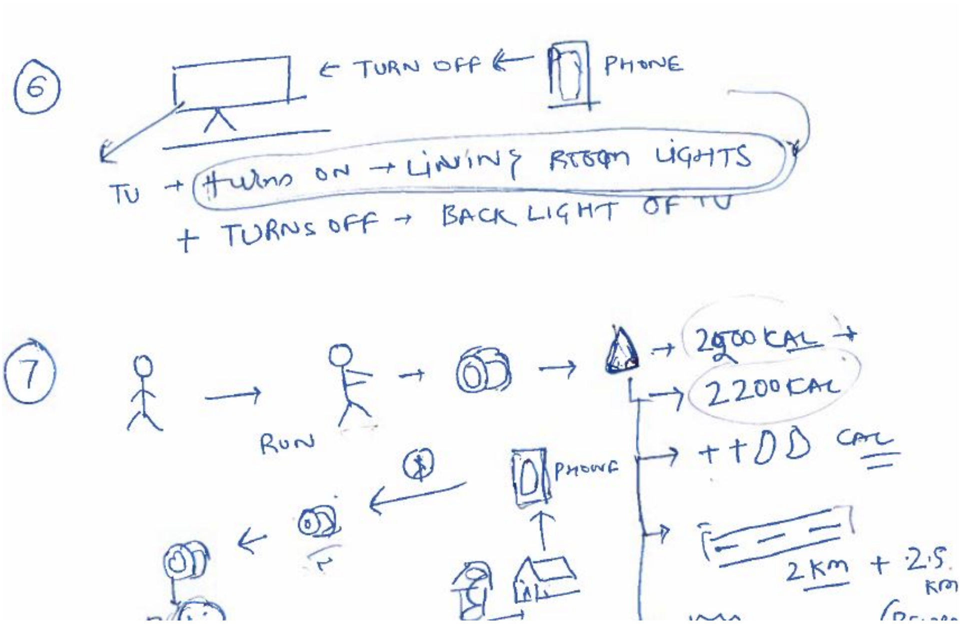


Figure 4.14: Devices represented by graphics

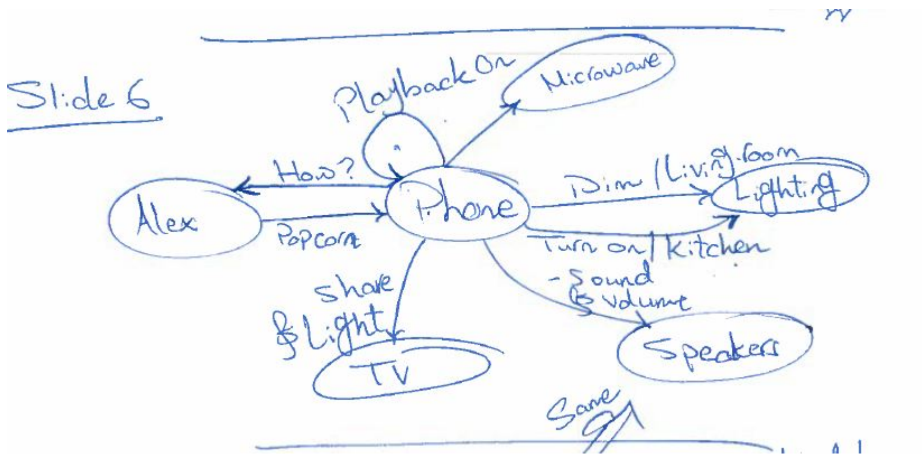


Figure 4.15: Devices mentioned in a circle

Metaphor(s) participants used to show connection between two devices: 23 out of the 30 used arrows to represent a connection across two devices. 6 of these 23 used special kinds of arrows. One amongst these 6 used dotted arrows to represent devices connected through the Internet. Some are using radio waves alike drawings to show this connection. We are going with the arrows metaphor following the majority.

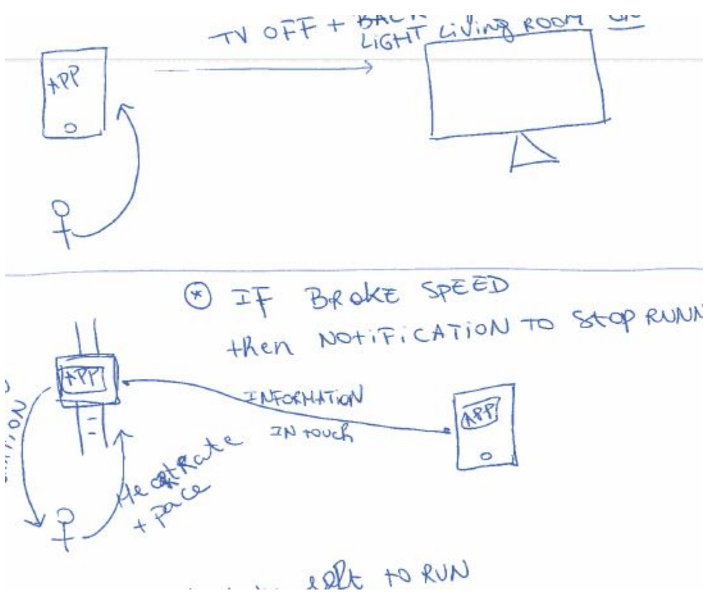


Figure 4.16: Metaphor arrow being used to depict connections between two devices

Presence of specific symbols in drawings like that of Bluetooth or Wi-Fi : 22 participants have used symbols in their drawings. 8(5,3) users have not used any type of specific symbols. This shows that maximal symbols needs to be provided to users. For example, use of Wi-Fi symbol when transferring via Wi-Fi or Bluetooth symbol in similar cases.

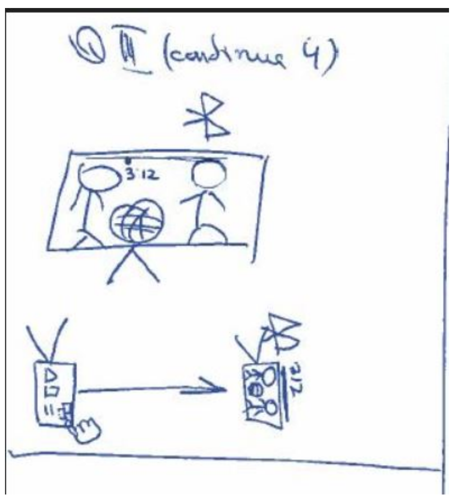


Figure 4.17: Participant using the symbol of Bluetooth

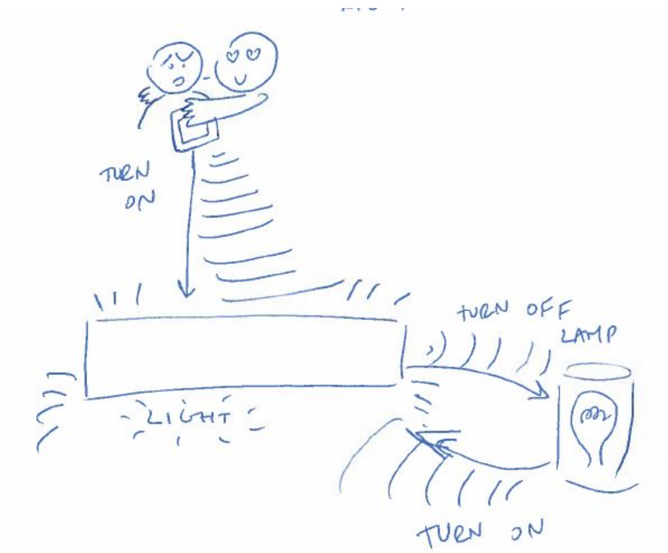
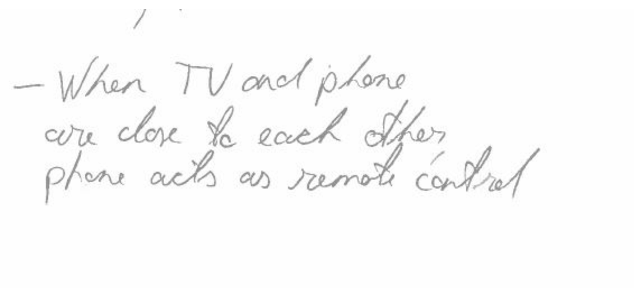


Figure 4.18: Participant using radio waves alike graphics similar to the symbol of Wi-Fi

Presence of specific keywords in drawings like AND, IF, or NOR: 13 participants have used “IF”. 3 have used “THEN”. 1 has used “CHECK”. Another one has used “WHEN”. Some other participants have also used “&”, “=”, “>”, “+” etc. This shows that keywords help users and should be provided. However confusion should be avoided for the use of the keywords “if” and “when” since users are using them to depict the same conditions.



(a) Participant using “WHEN” keyword

Use of specific type of diagram on the basis of background of participants: 5 participants drew diagrams related to their background in Computer Science. The different types of diagrams they drew were, sequence diagrams, activity diagram and use of stacks in the diagram. One of the participants drew flow charts because of their profession.

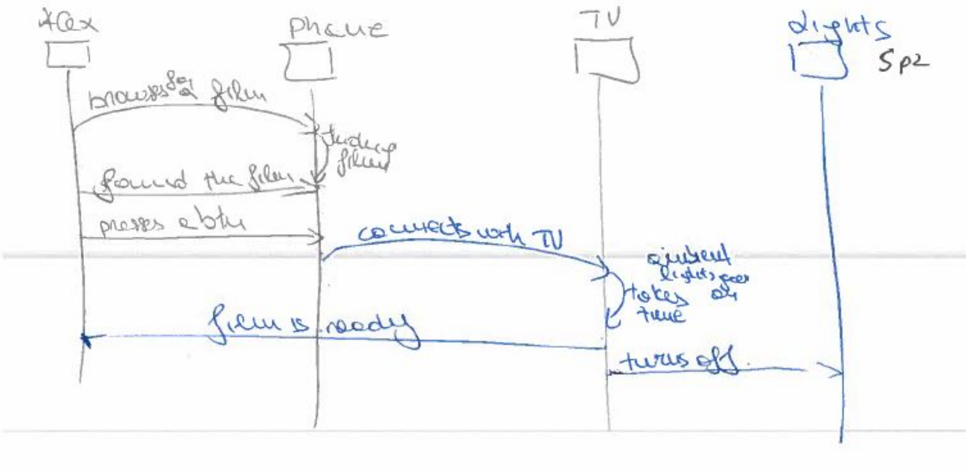


Figure 4.20: Participant using diagram because of their background in Computer Science

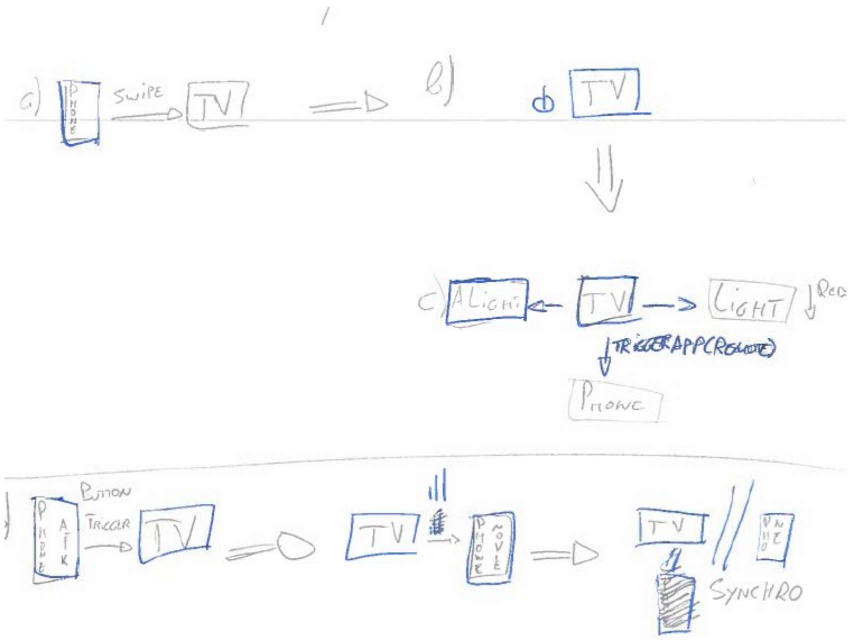


Figure 4.21: Participant using a flowchart since they are using this in their job

representation of interactions with the interface (e.g. touch, gesture or voice): 15(5,10) participants of the 30 specified interactions such as 'touch', 'press' and 'swipe'. 11 participants showed interaction between the subject

Alex and devices present.

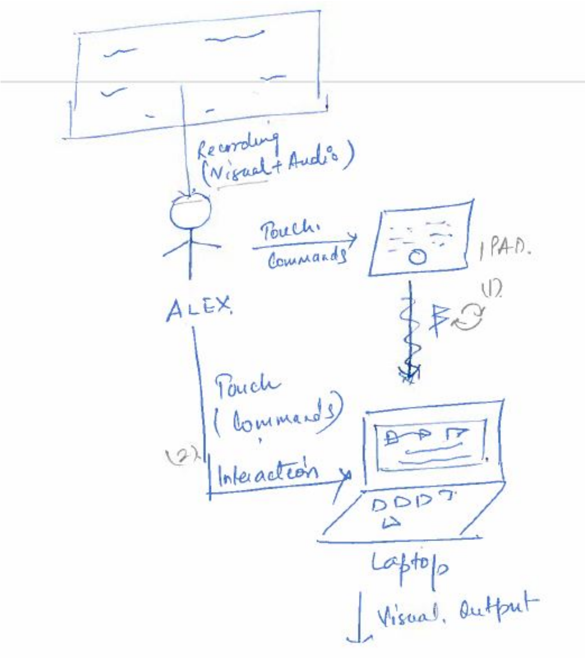


Figure 4.22: Participant mentioning *Touch-based* interaction in the drawing

4.4.2 Observations from user interviews

One of the questions we asked from our participants showed if people feel the need to customise thing at the moment or no? The question was: Do you think you have enough control to custom your interfaces with existing solutions?

We recieved different types of responses. A few of them are discussed here. Some users feel that they are satisfied. "*Umm... to be honest, I never had a feeling like I need to customise more. I just need things to be working.*" –10p2

"*With everything we have now, we can do what we can think. Like the company Dyson*[2]*. I think he is (referring to Dyson) the best.*" –10p1

"*For the moment I use the solutions which are present and I never customized.*" –5p2

[2] `https://www.dyson.be`

Some participants felt that there is incompatibility across IoT and CDI devices. "*No, I feel the problem write now is that there is not enough compatibility. Like one device is just compatible with the device belonging to the same brands*" –4p1

A participant felt that they need to explore more and their knowledge in this field is limited. "*I think I have to explore more advanced things. There could be more things but I never felt like a need. It was always okay.*" –8p1

Another participant felt that need of custom control. "*I have felt many times that I should have more control. For example, I think we do not have enough watch interfaces (referring to Apple watch). I have like this Mickey mouse I can customise with my picture but I want to see something else.*" –9p1

4.4.3 Observations from Questionnaire

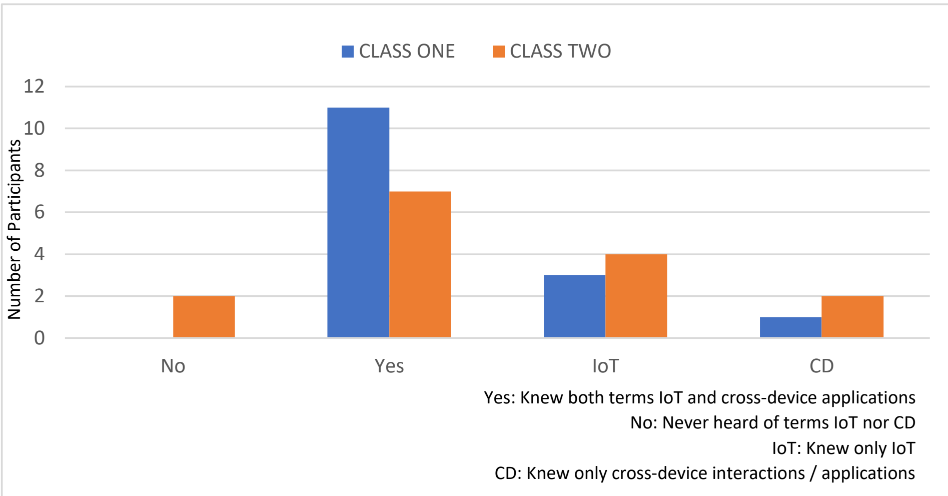


Figure 4.23: Exposure to terms (just terms) IoT and cross-device applications(CD)

Figure 4.23 depicts the popularity of IoT in both class of participants. According to the figure, it is clear that more than 50% of participants knew the term IoT and cross-device interactions. 8 of the participants knew only IoT and not about CDI. 3 knew the term cross-device interactions but not IoT. 2 participants had never hear about IoT or CDI. These two people belong to the class two. The results have show that IoT and cross-device applications are famous and not just the terms used in literature.

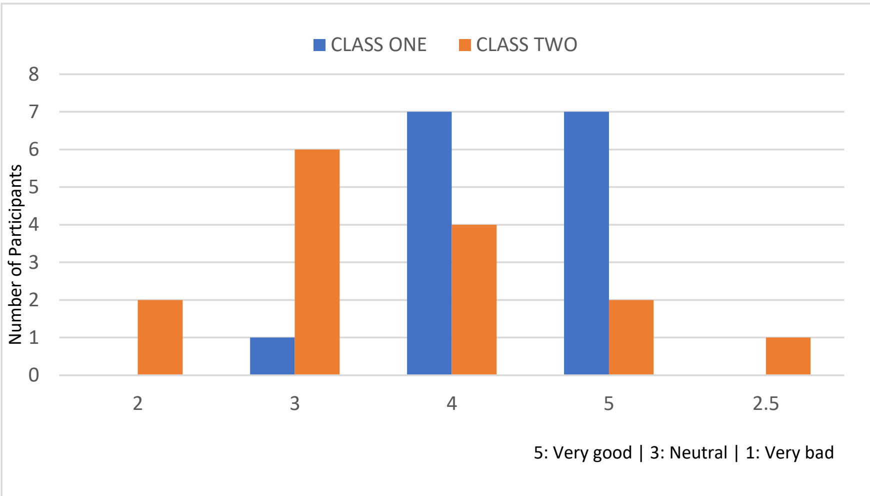


Figure 4.24: Participants comfort in using technology (5 very good — 1 very bad)

In the questionnaire, participants were asked to rate themselves on the basis of how good they are in using technology. The results obtained have been plotted on graph shown in Figure 4.24 From the results it can be seen that majority of people belonging to class one marked them with a 4 and majority of people belonging to class two have marked them with 3 expressing that they are neutral in using technology.

Figure 4.25: Familiarity with the IoT

When asked about participants familiarity with IoT, majority of people were found familiar with. it. 2 participants wrote a '/'. The results can be visualised in Figure 4.25.

Figure 4.26: Count of IoT devices at home

When inquired about the IoT devices participants had at home, it was found that the majority answer was smartphone and tablet for class one and just smartphone for class two participants (see Figure 4.26).

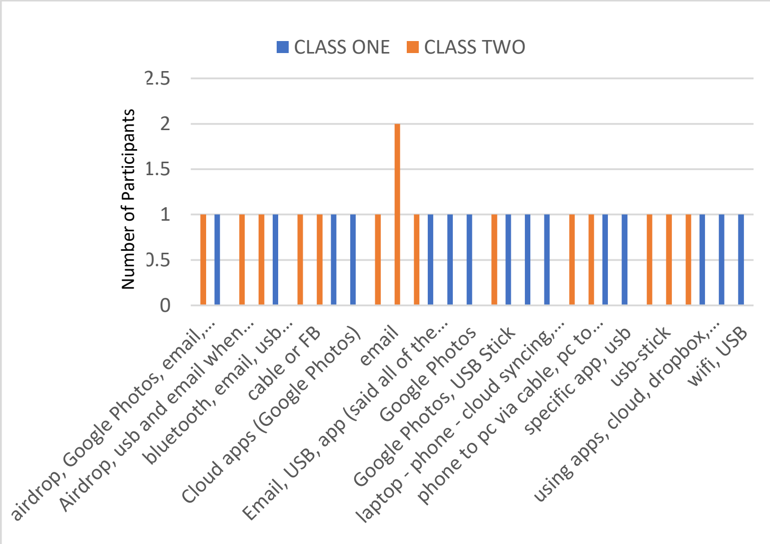


Figure 4.27: Familiarity with the IoT

Participants were asked about how they usually transfer a picture from their phone to computer or other devices. The answers received are plotted at Figure 4.27. It is seen that two participants belonging to class two use only emails for the transfer. Other user different modes of transfers.

5
Wireframes

Following the best practices of UI development, mock-ups for the prototype of end-user authoring tool were prepared.

Towards the left of the screen (see Figure 5.2) , a sidebar is placed which includes the following.

1. Workspace : Allows to open/swap environments. Name of the environment can be set. During user studies, one of the participants showed switching between state of phone and remote by pressing a box at the right corner of the screen. This will be achieved by using this workspace feature.

2. Devices : shows all devices which are available along with their symbols. Users can drag the devuces and drop it to the canvas. Users also can add a new device.

3. Tools : Tools includes different types of arrows. For sync, a double-sided arrow is used and for data transfer a single sided arrow is decided to be used since majority of people we using single sided arrow to shoe data transfer.

4. Users : It allows to add different users. E.g. Alex and his boyfriend. The application include rules based om users.

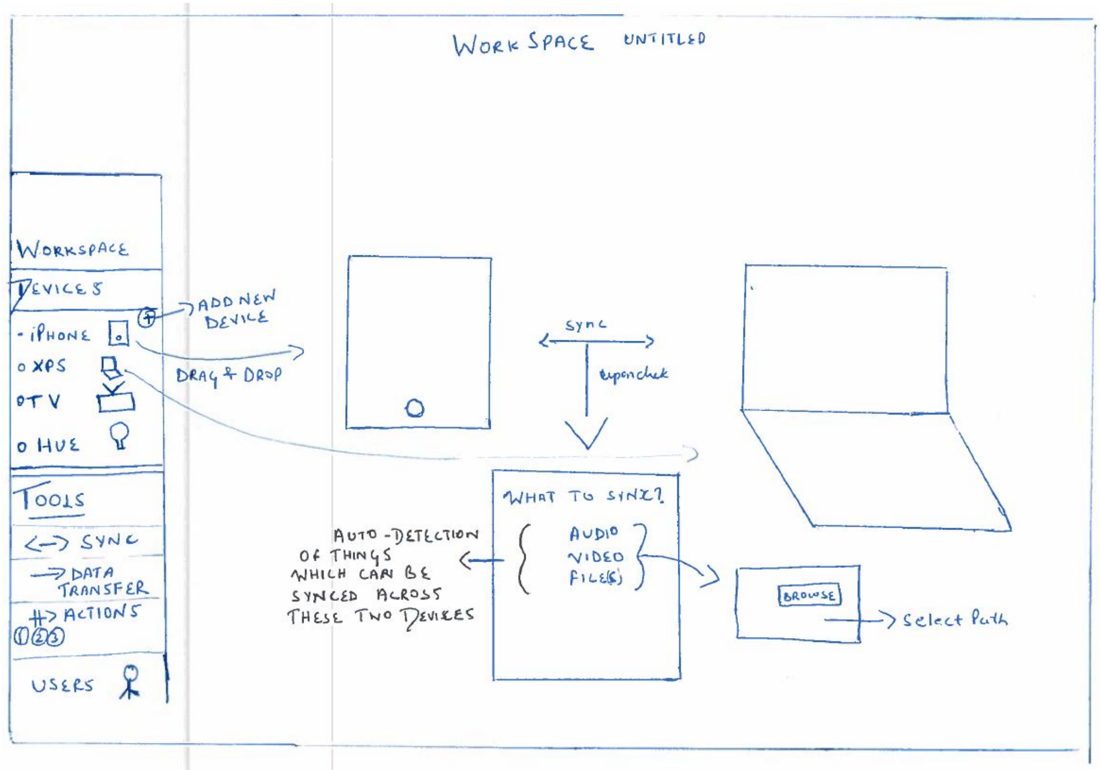


Figure 5.1: Workspace

Users can drag and drop elements from this left side bar to canvas. Once done, users can drag double sided arrow from tools and drop in between two devices. E.g. between Phone and Laptop to show the state of synchronisation, as shown in Figure 5.1. As soon as you drop the double-sided arrow, which is representing "sync" state, a modal is popped up which further allows users to select the type of data that is expected to be synced across these devices. If user selects to add a new device, they will be prompted to select the communication mode via which the device should be synced–Bluetooth or Wi-Fi. While adding a new device, user has the option to select a symbol for the device and choose the type of the device as shown in Figure 5.2. This has been kept considering the observations from the user studies where majority of users were showing devices by graphic icons.

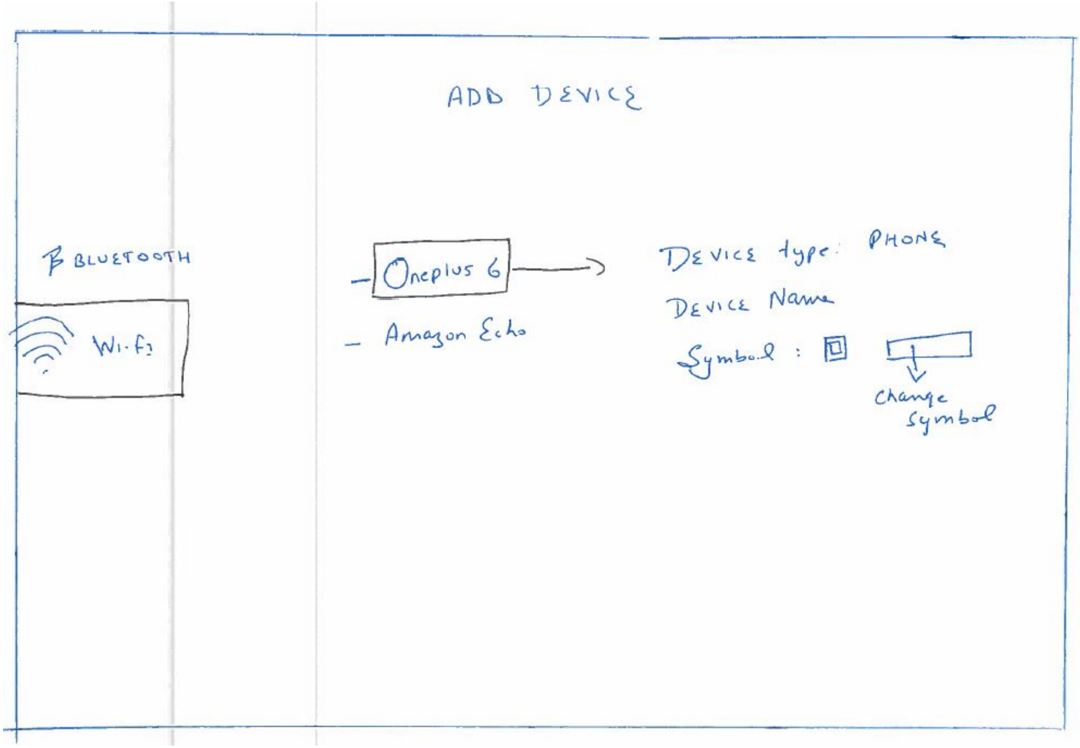


Figure 5.2: Add a new device

In the case when user selects a single-sided arrow and drops it between two devices, a modal will pop-up which allows users to add condition action rules (shows in Figure 5.3).

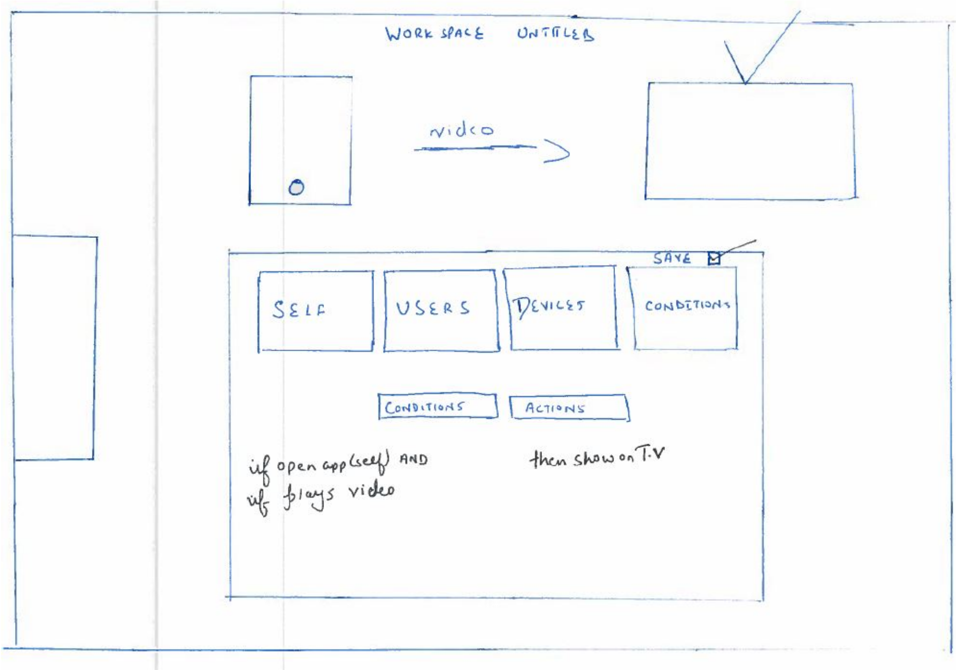


Figure 5.3: Data Transfer : Conditions and actions

The conditions as well as actions can include informations from four domains, namely SELF, which includes all the capabilities of the device which is the originator of data transfer, USER, which will include information about users, Devices, which will include information from all the devices which are connected at the moment, and conditions which are the pre-set conditionals. For e.g. in Figure 5.3 condition—If open app (let us say YouTube), then added the AND condition, then another condition—If plays video, then condition can be defined like then show the video on TV. On the right corner, a check box is present written 'SAVE'. If checked, it will save all the rules defined in this windows as a conditional. This design approach of adding four domain boxes is inspired by the work of Ghiani et al. [10] Conditionals are saved group or channels. Conditionals can be used in case of concurrent or sequential actions. It is also possible to define the order of execution of conditionals.

Conditions can be used while developing rules for event condition action.

When viewed the connections, symbolic representation of the medium exists along with numbers to show sequential or conditional events if any.

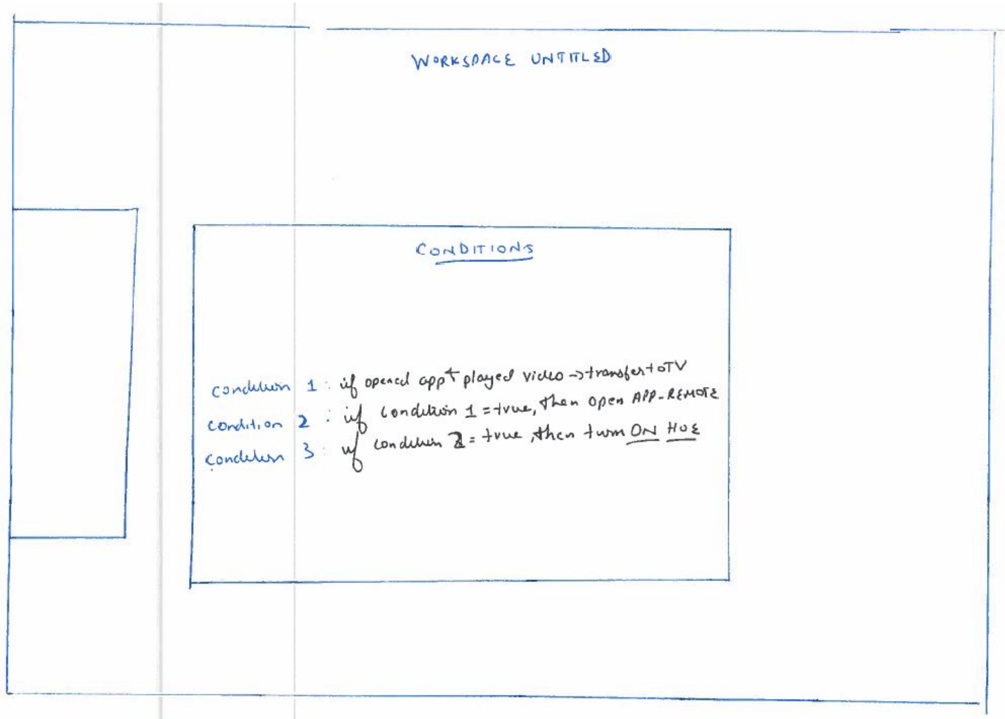


Figure 5.4: Conditions Window

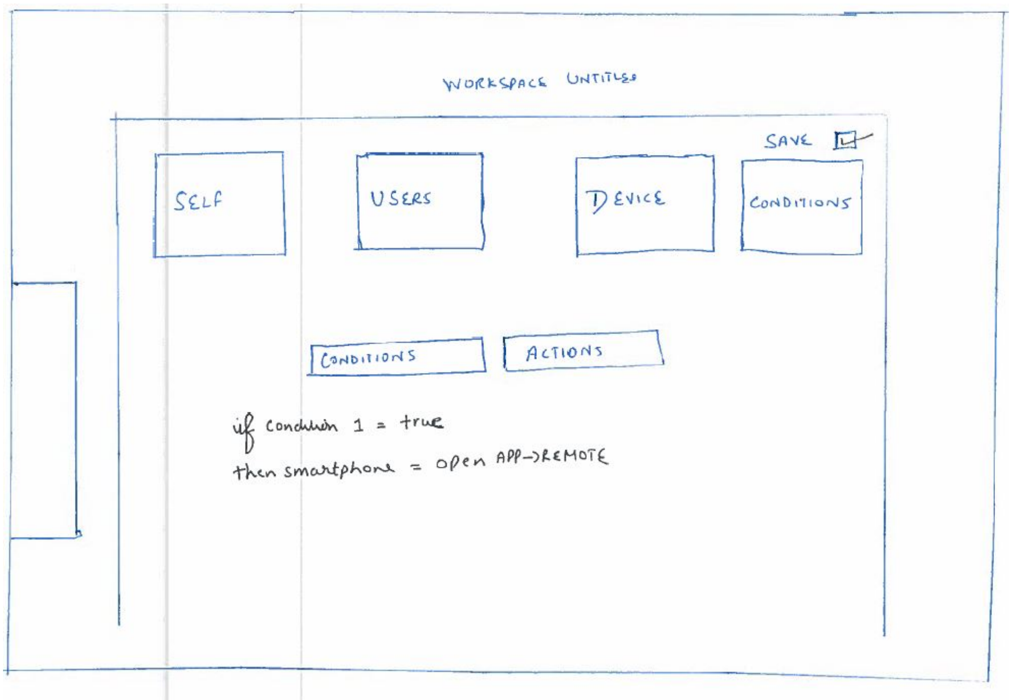


Figure 5.5: condition action rule using saved condition

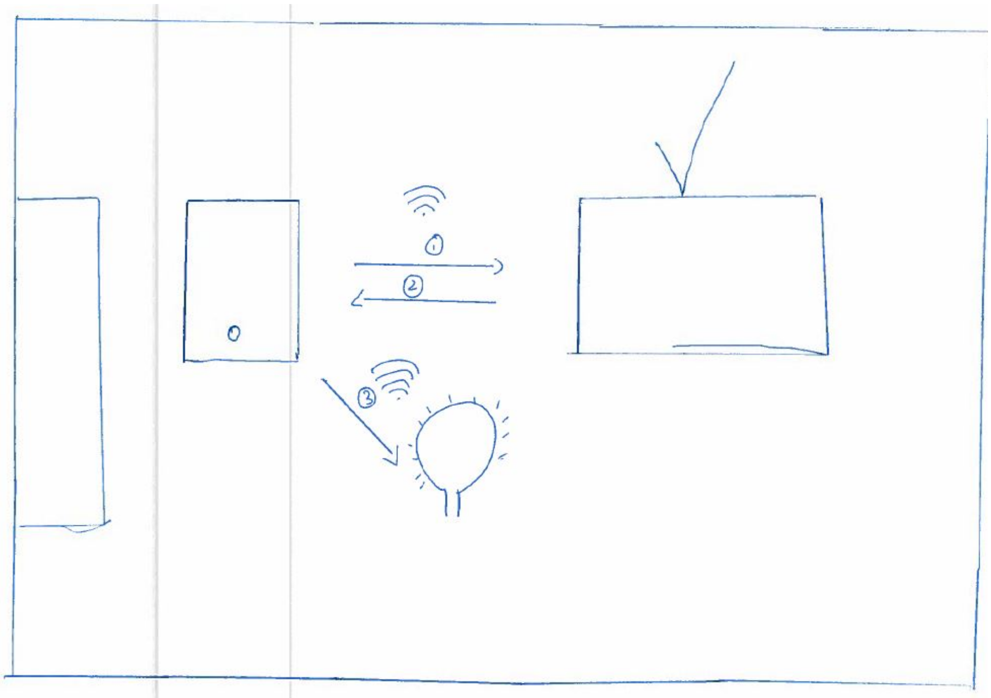


Figure 5.6: Workspace view after creation of connections

6

Prototypes

In this Chapter, details about the prototype end-user authoring tools have been provided.

We have developed a prototype end-user authoring tool on the basis of the mock-ups prepared and shown in Chapter 5. The prototype tools is based on web technologies: HTML5, CSS and JavaScript. The structure has been tried to keep similar to mock-ups developed in previous chapter. This tool allows addition of a new devices, creation of condition action rules across available devices and saving the rules in the form of saved-conditions. Moreover users can define their own workspaces and set sequential actions.

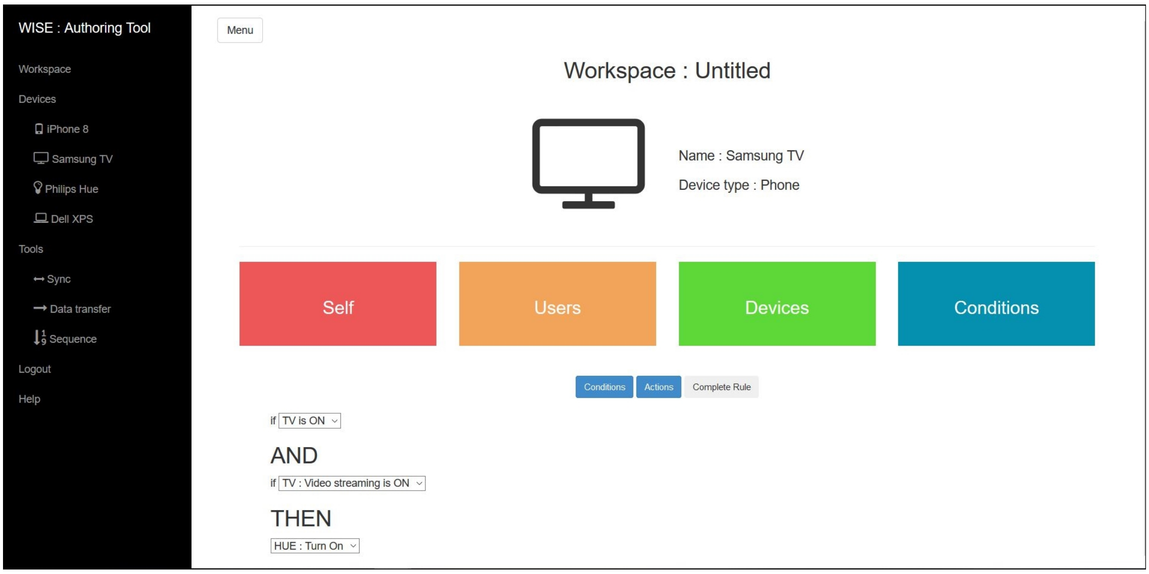


Figure 6.1: Prototype: Add a new device

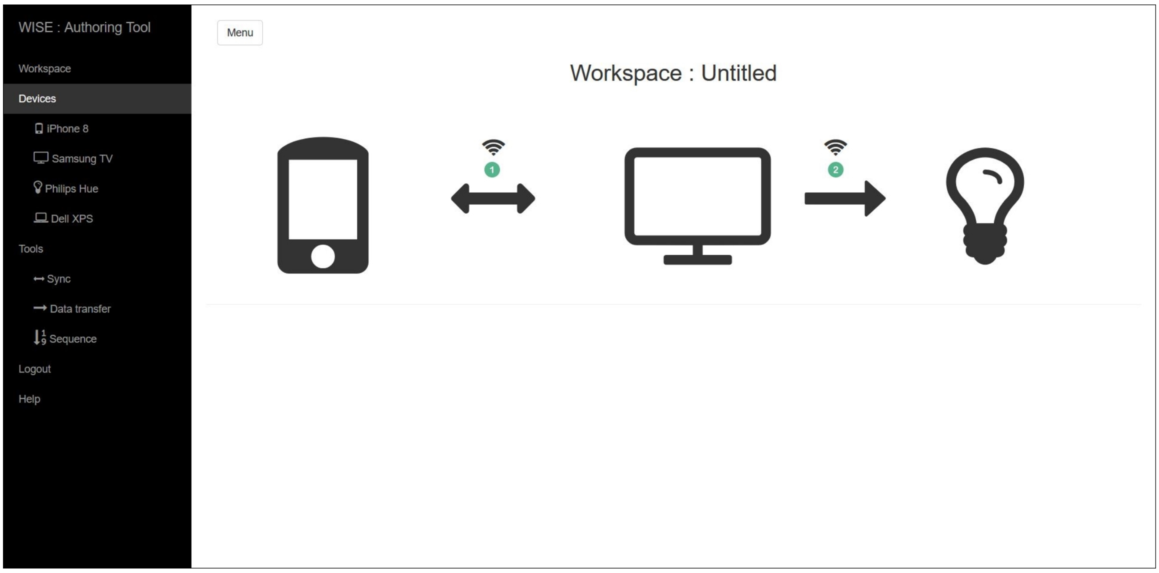


Figure 6.2: Prototype: Workspace view with defined rules.

7

Future Work and Conclusion

7.1 Discussion

As seen in Chapter 2, one of the main issue with authoring tools being developed today for IoT and cross-device applications is the lack of involvement of end users. Thus, we designed our methodology focussing on involving the end users. Therefore, a three-step approach has been applied which includes 1) Conduction of user study experiments, 2) Preparing mock-ups and 3) Developing a prototype. The main part was conducting the user experiments.

Based on background research, it was decided to go for scenario-based approach for conducting the user study experiments. Use cases focussing on IoT and cross-device interaction technologies were created and improved based on the pre-study experiments. The observations from the users' drawings gave insights about metaphors that are most relevant for end users, for example, using graphical icons to represent the devices, arrows to depict data transfer from one device to another and numbers on top of arrows to depict concurrent and sequential situations. Each user experiment involved an interview and a questionnaire, which provided information about the familiarity of people with technologies (in general and specific to IoT and CDI) along with their satisfaction level with current products and the usual mode of transfer they use across devices. To witness the impact of educational background, the participant pool included two groups of people: people having exposure to computer programming and people having no exposure of programming.

Based on the results of the user study an analysis has been made depending on different criteria that are explained in detail in Section 4.4. Post analysis of the results of the user studies, mock-ups for the authoring tool are prepared. The background study conducted has helped in defining some design issues in the development of the authoring tool.

7.2 Future Work

Analysing the results of the user studies, it is identified that more than one type of metaphors can be efficient for certain situations. For example, to show conditional statements, the *if-then* structure as well as writing conditions on top of arrows are identified as effective. At present, the prototype authoring tool we have developed is using *if-then* structure for conditional statements. In the future, multiple versions of prototype authoring tools can be developed, focussing on different metaphors as identified in this thesis. Later, user studies can be performed on these different prototypes to find the most suitable metaphor for that particular situation. Also, the prototype developed in this thesis is very basic and a user evaluation study needs to be conducted to validate its efficiency.

7.3 Conclusion

In this thesis, we have performed user studies to find the best metaphors for end-user authoring of WoT and cross-device applications. A lot of research has been done in finding metaphors for IoT or cross-device applications but to the best of our knowledge, none of the existing research studies have focussed on both IoT and cross-device applications. The observations from user studies have helped us to identify the best metaphors for end-user authoring in IoT and cross-device applications. The participant pool (comprising of both types of users: technical and non-technical) has helped us in analysing the metaphors that are suitable for both types of users. Further, we have developed mock-ups for the prototype authoring tool. Last but not the least, a prototype for end-user authoring of IoT and cross-device applications has been developed.

A

Appendix

A.1 User studies : Support material

A.1.1 Questions for Interview

1. How did you come up with such drawing?

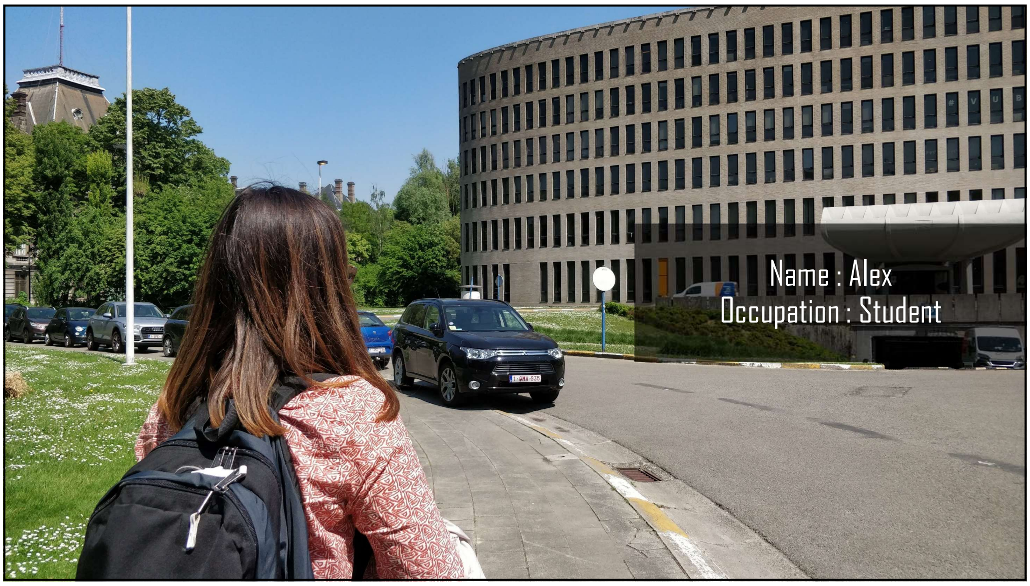
2. Did you have any difficulties during the study? If yes, which ones?

3. Do you think you would use an application proposing IoT and cross-device interaction that you can create by using the components that you drew? Why, why not?

4. Do you think you have enough control to custom your interfaces with existing solutions? Why, why not?

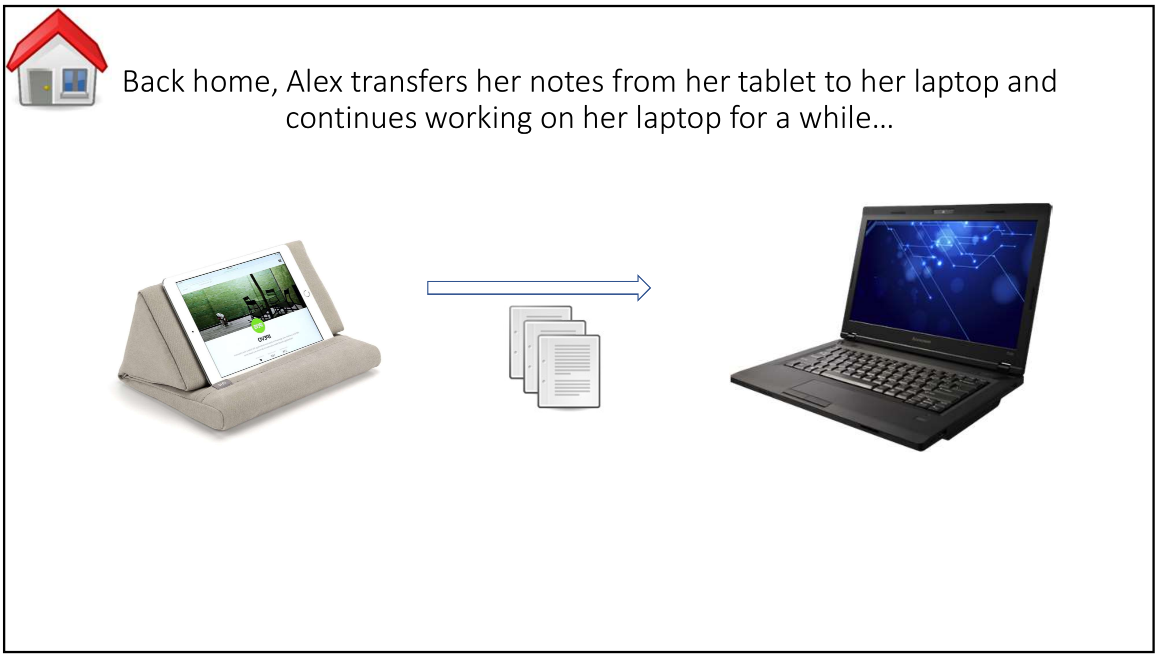
5. Do you have any comments?

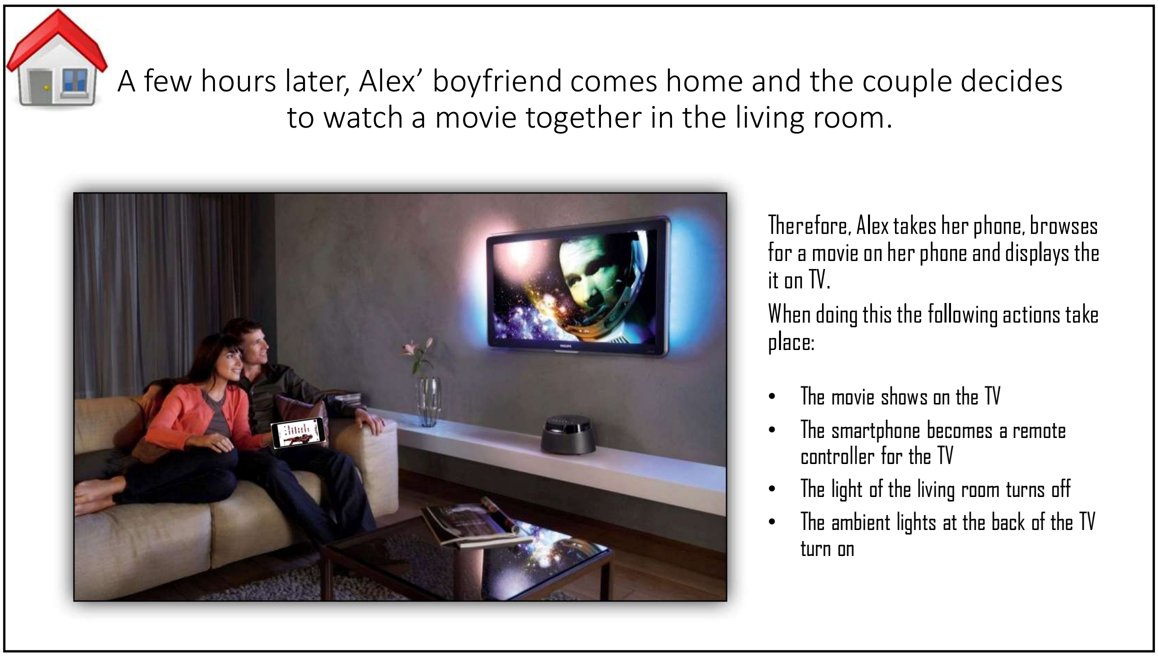
A.1.2 Use-Cases

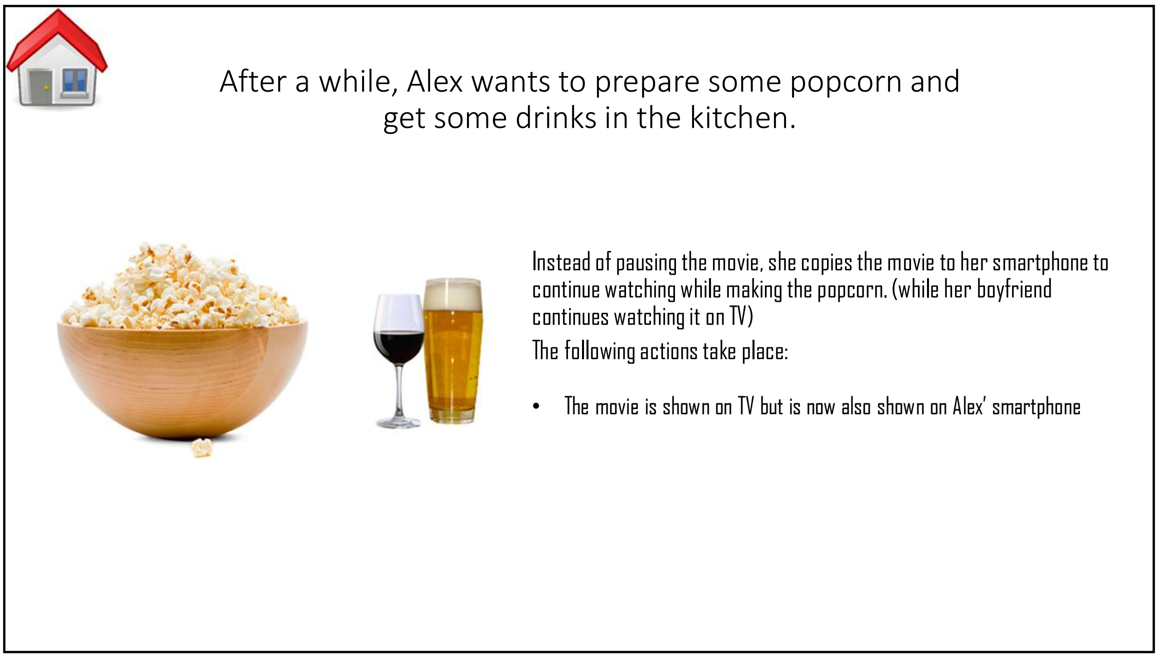


Alex has a smartwatch and a smart scale to keep track of her physical activities and weight


During Classes at the University, Alex takes notes on her tablet


Back home, Alex transfers her notes from her tablet to her laptop and continues working on her laptop for a while…


A few hours later, Alex' boyfriend comes home and the couple decides to watch a movie together in the living room.
Therefore, Alex takes her phone, browses for a movie on her phone and displays the it on TV.
When doing this the following actions take place:
• The movie shows on the TV
• The smartphone becomes a remote controller for the TV
• The light of the living room turns off
• The ambient lights at the back of the TV turn on


After a while, Alex wants to prepare some popcorn and get some drinks in the kitchen.
Instead of pausing the movie, she copies the movie to her smartphone to continue watching while making the popcorn. (while her boyfriend continues watching it on TV)
The following actions take place:
• The movie is shown on TV but is now also shown on Alex' smartphone

While preparing the popcorn and drinks, Alex adds the calories of the popcorn and her drink in her calorie tracker application on her phone.

The following actions take place:

- The calories are updated in the calorie tracker application
- The data from the calorie tracker application synchronises with her fitness application on her smartwatch
- Since she exceeded the 2 200kcal today, Alex receives a notification on her smartwatch warning her about this excess

When Alex comes back from the kitchen, she stops the movie on her phone and continues watching it on TV.

The following actions take place:

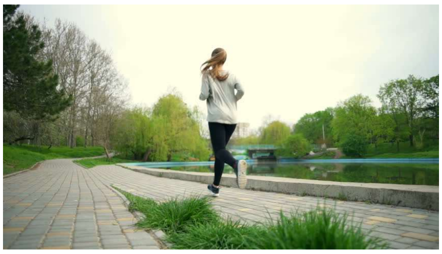
- The movie is no longer shown on Alex' smartphone
- Alex' smartphone becomes a remote controller for the TV again

After the movie finished, they turn off the TV and go to bed.

When turning off the TV, the following actions take place:

- The TV turns off
- The ambient lights at the back of the TV turn off
- The light of the living room turns on

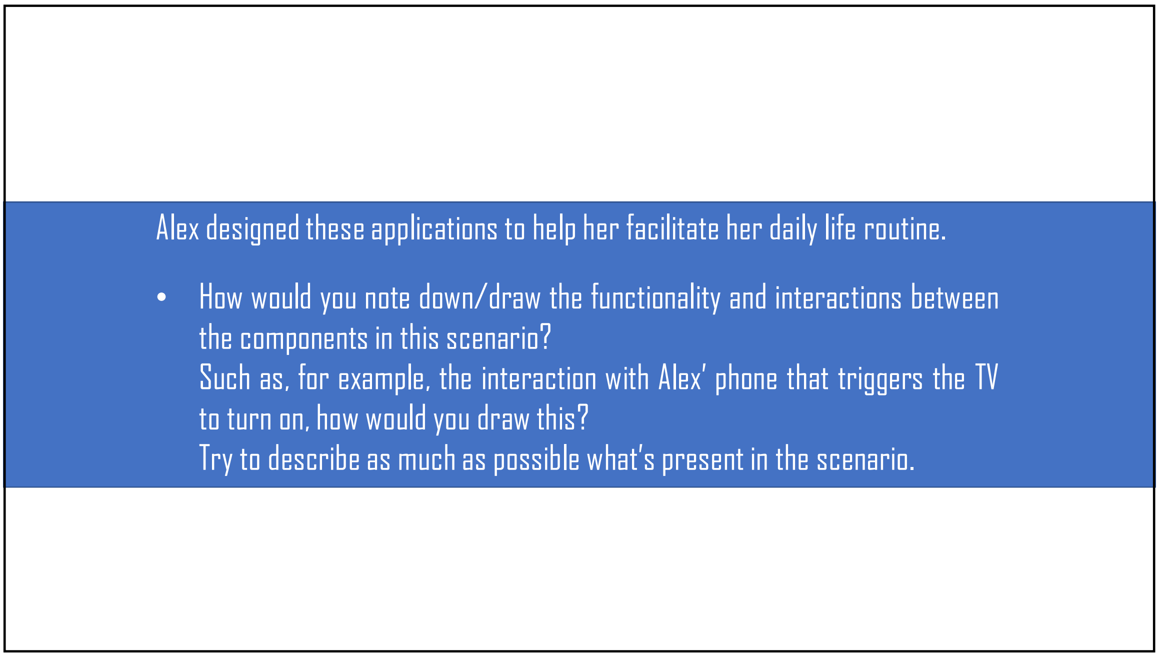
The next morning, Alex goes running in a park nearby.



While running, her heartrate and pace is monitored by her smartwatch. Her smartwatch defined a running track depending on the calories she needs to burn.

The following actions take place:

- Since Alex went over her daily calorie intake yesterday evening, the running track defined by the smartwatch is longer than usual
- When Alex has 50 meters left to run, the smartwatch sends a vibration to motivate her to sprint the last few meters
- If she broke her speed record, she receives a notification at the end of the running session


Alex designed these applications to help her facilitate her daily life routine.
• How would you note down/draw the functionality and interactions between the components in this scenario?
Such as, for example, the interaction with Alex' phone that triggers the TV to turn on, how would you draw this?
Try to describe as much as possible what's present in the scenario.

A.1.3 Questionnaire

Post survey Questionnaire

Age: O Under 18 years
O 19-25 years
O 26-40 years
O 41-55 years
O Over 55 years

Gender: ________________

Education: _______________________

Highest educational degree obtained or pursuing: ____

Position: ____

Did you ever hear about the term "Internet of Things" (IoT)? ___________________________________

If yes, are you familiar with IoT technology? ____

If yes, do you have any IoT devices at home (if so, which ones)?___________________________

How good are you in using technology?

Very bad (1)	(2)	Neutral (3)	(4)	Very good (5)

Did you ever hear about the term "cross-device interaction"? ___________________________________

If yes, how often do you perform cross-device interaction? ______________________________

If yes, how are you performing cross-device interaction? ________________________________

How do you usually transfer a picture from your phone to your computer or other devices? (e.g. email, USB stick, specific application, etc.)

____

Do you own some smart devices (e.g. smartphone, tablet, smartwatch, etc.)? If yes, which one(s): ____

How comfortable or easy was this survey for you?

Very difficult (1)	Quite difficult (2)	Neutral (3)	Easy (4)	Very easy (5)

THANKS FOR YOUR PARTICIPATION!

Figure A.2: Post survey Questionnaire

A.2 Results of Pre-study

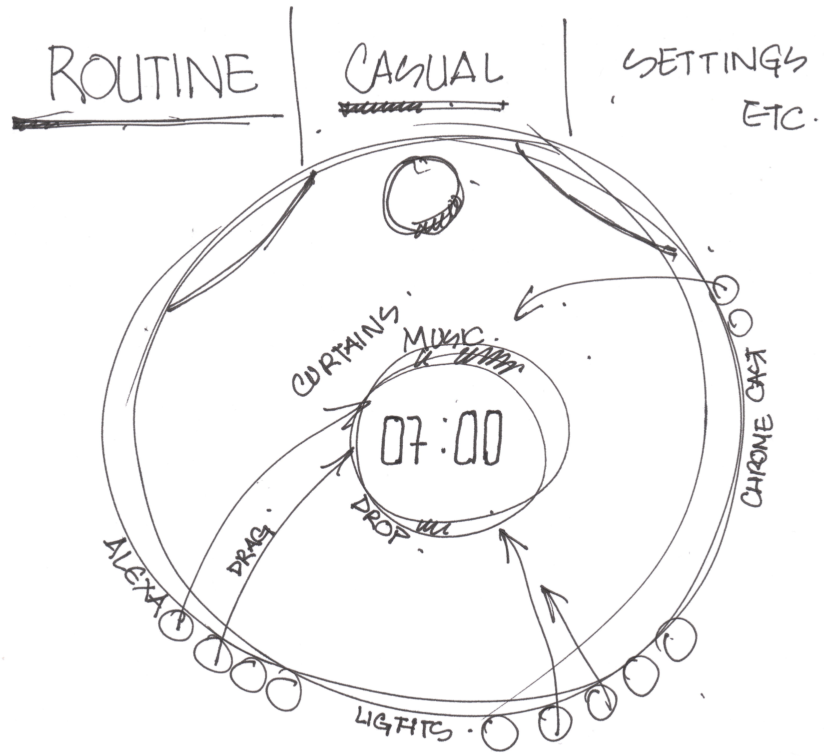


Figure A.3: Wheel Metaphor : Demo study 1

A.3 Background Education

Table A.1: Background Education of Participants

ID	Education or Profession
1p1	Master Business
1p1	Master Business
2p1	Master Applied Computer Science
2p2	Bachelor of Science: Engineering
3p1	Bachelor Economics
3p2	Master Telecom and Master Management
4p1	Master Applied Computer Science
4p2	Master Applied Computer Science
5p1	Secundary School
5p2	Bachelor in Informatics
6p1	Master Applied Computer Science
6p2	Master Electomechanical Engineering
7p1	Master Applied Computer Science
7p2	Master Photonics Engineering
8p1	Bachelor Computer Science, now IT Analyst
8p2	Master Digital Communication
9p1	Bachelor Marketing, now Marketing Manager
9p2	Master in Management
10p1	Architect (masters)
10p2	PhD in Computer Science
11p1	PhD in Computer Science (AI)
11p2	PhD Cognitive Sciences
12p1	Master in Psychology
12p2	Master in Geschiedenis, did 1Y of Handels IR
13p1	Master in Environmental Science, now doing PhD in Air Quality
13p2	Master in Environmental Studies, now PhD in Air pollution
14p1	Master in Computer Science, now doing PhD in AI
14p2	Master in Computer Science, now doing PhD in AI
15p1	Maternal Teacher, High school
15p2	Employee Secretariat High school

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