Concepts of Multi-artifact Systems in Artifact Ecologies

Henrik Sørensen and Jesper Kjeldskov
Research Centre for Socio-Interactive Design
Department of Computer Science
Aalborg University, Denmark
{hesor, jesper}@cs.aau.dk

***Abstract*— The artifact ecologies emerging from the increasing number of interactive digital artifacts, capable of communicating with each other, have created a situation where software applications no longer need to be limited by the physical boundaries of a single artifact. In order to take advantage of the full potential of this situation, we first need to establish a common understanding of the interaction that crosses physical artifact boundaries. Eventually, this will help us understand and design multi-artifact systems that are more than the sum of its individual parts. In this paper, we analyze two multi-artifact systems from our prior work within the domain of music consumption and identify four concepts of multi-artifact interaction: Plasticity, migration, complementarity, and multi-user. We discuss the concepts in order to relate them to an artifact ecology thinking and identify implications for future work.**

Keywords- artifact ecology; multi-artifact; music system

I. Introduction

The establishment of a wireless network infrastructure surrounding us has introduced easier connectivity between different digital devices. In addition, to enable data sharing and synchronization it provides great potential for interactions transcending the physical boundaries of individual devices. Jung et al. [8] describe this network of devices as a personal ecology of interactive artifacts and defines it as *"a set of all physical artifacts with some level of interactivity enabled by digital technology that a person owns, has access to, and uses"*. Taking advantage of the potential offered by such artifact ecologies is however challenging. Our focus lies in the concepts of the interaction between humans and artifacts. It is however clear that interaction designs spanning multiple artifacts is highly dependent on a comprehensive and flexible technical infrastructure for artifact discovery, connection, and communication. We therefore work under the assumption that this is or will be available to some extent.

Interaction designers have become quite good at designing desktop applications and are in a post-desktop era progressively getting better at designing mobile artifacts as well. It is however, our belief that good interaction design for artifact ecologies consists of more than the aggregation of good designs for each individual artifact. Previous work has already moved towards an understanding of the composition [8] and dynamics [4] of the ecologies as a whole. What we find is however that there is a gap between the work on understanding interactions with single artifacts and understanding our personal artifact ecologies. Understanding multi-artifact systems that combine specific artifacts from our personal artifact ecologies creates an additional layer of complexity that requires us to think of the system in a holistic way on an abstraction layer above the single artifact but below the entire artifact ecology.

The overall goal is to move towards multi-artifact interaction designs that deliberately exploit the synergetic effects of artifact combinations. Our contribution in this paper is a step towards an understanding that eventually can lead to this goal. The specific contribution is to identify and discuss concepts of multi-artifact systems that we find to be of particular significance to an artifact ecology context. We base our analysis around multi-artifact systems from our previous work in the music domain.

First, we present related work on artifact ecologies and music consumption in Human-Computer Interaction (HCI). We then clarify our understanding and delimitation of the multi-artifact system concept followed by a description of the two music systems from our prior work. Finally, we analyze the systems in order to identify and discuss characteristic concepts of multi-artifact systems before we conclude with implications for future work.

II. Related Work

This section relates our work to previous research in artifact ecologies and music consumption.

A. Artifact Ecologies

In a study of the social role of products, Forlizzi [6] introduced a product ecology framework used to describe the dynamic aspects of use. The framework puts the product in the middle, meaning that each individual product has its own ecology in which components are interconnected. For example, a product often has certain relations to other products that together act as a system. The components included in the framework, besides other products, are people, activities, place, and the routines and cultural context. Forlizzi's product ecology framework provides means to reason about the single product and its social impact across users.

Artifact ecologies represent a different approach of putting an ecological thinking into play in relation to the

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products surrounding us. In the framework of Jung et al. [8], they put the user in the center and define a personal ecology of interactive artifacts that a person owns, has access to, and uses. This means that an ecology is defined from the perspective of a person instead of a product/artifact. In their work, they conducted two types of exploratory studies with the common goal of understanding the relationships within artifact ecologies. Their study works under the assumption that the experience with an artifact can only be fully understood when it is considered in relation to an artifact ecology. We find the personal perspective very useful in understanding interactions that involve several artifacts. However, the limitations of the framework are that it does not take into account what happens when different personal ecologies intersect in multi-user interactions.

Jung et al. [8] argues that artifact ecologies are dynamically evolving. Bødker and Klokmose [4] follow up on that idea and emphasize the importance of not only understanding a current composition of artifacts in our surroundings but also how relationships among them change over time. Using Activity Theory as their theoretical framing and the Human-Artifact Model [3] as an analytical tool, they identify three states of an artifact ecology: The *unsatisfactory*, the *excited*, and the *stable* state. The artifact ecology of a person will change state over time and at some point reach the unsatisfactory state once again. Changes to the ecology can then put it into an excited state and the cycle repeats itself. One challenge they encountered in their analysis was to describe what the artifacts of artifact ecologies is. While Jung et al. [8] describes artifacts as physical objects, Bødker and Klokmose [4] found from their study that this did not tell the whole story and that something more may be needed to systematically address the software as well.

B. *Music Consumption*

Music has always been an interesting topic due to its universal appeal. Holmquist talks about the field of ubiquitous music and how it has been formed by a digitization of music, portable music players and heightened bandwidth [7]. Although the article is from 2005, the notion of ubiquitous music has only become more relevant due to the emergence of Internet streaming services and affordable multi-room music systems. Liikkanen [10] however points out that music consumption, as a defined research area in HCI is extinct. He argues that research on music consumption through interactive devices continues but is marginal. There are however still interesting projects emerging in the HCI community. An example that operates in the area of multi-artifact interactions is Mo by Lenz et al. [9]. Mo is a music player with an integrated speaker that focuses on a shared music experience. Mo can be brought into a social setting and by placing it next to other Mo players, it creates a connected music system.

III. MULTI-ARTIFACT SYSTEMS

Before we start conceptualizing multi-artifact systems in artifact ecologies, it is important for us to clarify what we mean by the term in the first place and how we delimit it to reflect our scope. By multi-artifact systems, we refer to interactive systems, which are part of an artifact ecology, and involves more than a single physical artifact. Different terms have previously been used to describe similar concepts. Rekimoto has for instance described it as multiple-computer user interfaces with a focus on graphical user interfaces [11]. Terrenghi et al. [12] have furthermore created a taxonomy for what they refer to as multi-person-display ecosystems. As much as we appreciate the desirable features of the visual aspect, we also want to acknowledge other modalities of input and output, especially since our point of departure is in the music domain. Multi-device interface is another term often used. It however ambiguously describe also interfaces accessible across different platforms, which is not part of our scope. Because we want to continue the ongoing work on artifact ecologies, it makes sense to refer to the sub-sets of artifacts as multi-artifact systems. According to the systems' view, the essential properties of an organism, or a system, is the properties of the whole that none of the parts has alone [5]. This view fits perfectly well with our intention of addressing systems with interaction designs that provide more than cross-platform interfaces.

A. *Delimitation*

We acknowledge Bødker and Klokmose's [4] notion of the artifact term encompassing more than the physical interactive artifact. Our interest lies in the interaction designs, which transcends the boundaries of a physical artifact, thus we use multi-artifact systems as a term to describe sub-systems of artifact ecologies consisting of a specific composition of hardware *and* software artifacts used throughout a particular activity. This could technically involve the interaction with a desktop-PC communicating with a web server through a browser, but our focus is more specifically on systems where either the user provides direct input to the artifacts or the artifacts provide direct output to the user. The server part of the example fulfils neither role. Another example is video conferencing that involves several artifacts, however only one from each user's personal ecology, hence it is not a multi-device system either. A system that merges two persons' smartphones into a common interface when put together is however an example of a multi-artifact system from our perspective, as it would become a multi-artifact system in each user's ecology. The last example shows the inclusion of systems that exist in the intersection between different personal artifact ecologies, where multiple persons interact with some or all of the same artifacts.

B. Time and Space

Although the browser and video conferencing examples provide some limitation to our scope it is not to be understood as if the artifacts in the multi-device systems are required to be co-located or even that the interaction with each artifact has to happen simultaneously. We still consider systems that distribute interaction across time and space. It will however have to be as a part of the same activity from the personal point-of-view. An important point is also still that the system should provide more than an interface accessible from different artifacts. An example is the Google Chrome browser. Having a version for Windows, Android and iOS is still a single-device interaction, but when it starts remembering open tabs, bookmarks, search preferences etc. across artifacts it becomes a multi-artifact system.

The following two sections provide descriptions of the two multi-artifact music systems from prior work, on which we base our conceptualization.

IV. AIRPLAYER

AirPlayer is a multi-room music system that adapts to the location of the user with the purpose of allowing for an implicit interaction. It builds on top of Apple's AirPlay, hence the name, making it capable of streaming music from a central digital music collection to speakers placed in different locations around the home. Each speaker connects wirelessly to a central music player application through an Airport Express that also works as a Wi-Fi access point. The use of a Wi-Fi network furthermore makes it possible for the user to control the music independently in specific locations from a smartphone application. AirPlayer handles separate locations through the notion of *zones.* A zone is per default a representation of the room in which a particular Airport Express is placed. The user can however combine zones to play and control the music in several locations simultaneously. The zone name is visible in the bottom of the main screen (see Fig. 1). By sliding horizontally, the user can cycle through the different zones to see the current song playing, change the volume etc.

Similar features are already present in Apple's existing product family, through iTunes, as well as in other multi-room music systems. What is significant to AirPlayer is the addition of the proxemic interaction features that allows the system to adapt to spatial relations between the user and particular speakers placed in different rooms. The proxemic interaction manifests itself in AirPlayer as two features called *location* and *movement*, which the user enables through the smartphone application. A simple implementation of an indoor positioning system. The smartphone application continuously measures Received Signal Strength Indicator (RSSI) values from the Airport Express Wi-Fi access points and uses them to estimate in which zone the user is located.

A. Location

When the location feature is enabled, the smartphone application continuously adapts to represent the music currently playing in the zone where the user is located. As illustrated in Fig. 1, this means that the user interface presents information about the song playing and furthermore automatically controls the music in this particular location. The change happens in a seamless and subtle way, when the user changes location, without the need for further explicit user interaction. Whenever the system detects a change in location, it simply adapts the smartphone application to represent the current zone. The interaction from the user point-of-view is similar to having a universal remote control for independent music players in each room.

B. Movement

When the movement feature is enabled, the music follows the user around the home as illustrated in Fig. 2. By tracking the smartphone, the system is able to anticipate which zone the user is entering, continue the music in the new zone, and stop the music in the old one. What actually happens is that AirPlayer streams the music to all zones simultaneously and simply adjusts the volume in accordance to the location of the user. The movement and location feature can be enabled/disabled independently but are not

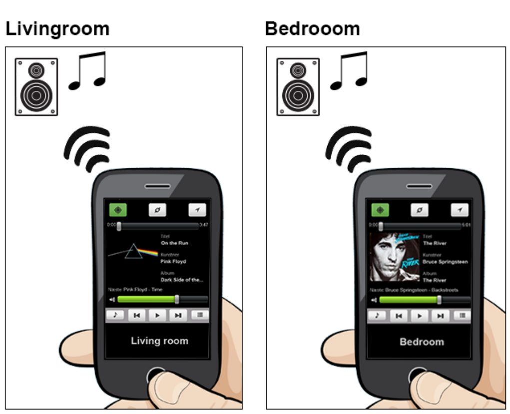

Figure 1. The location feature adapts the user interface and control to the location of the user.

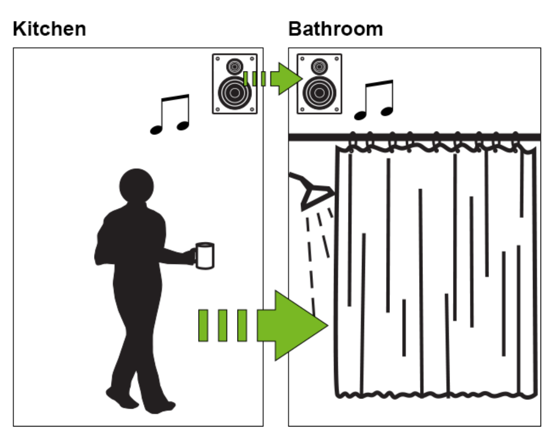

Figure 2. Music follows the user across locations.

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strictly independent. Whenever the movement feature is enabled, so is the location feature as the same music is always playing where the user is located. The location feature enables a state where the smartphone user interface adapts to the location of the user and the music content stays. Inversely the movement feature enables a state where the user interface stays the same and the music content adapts to the location of the user.

V. MEET

The second system, called Music Experienced Everywhere Together (MEET), is a multi-device, multi-user music system used, to explore the interaction space of distributed interactions with co-located artifacts. The concept of MEET is to allow co-located users to share their music at social events, in order to nominate and vote for songs using their smartphones, thereby influencing the music in a collaborative manner. The interaction design consists of the following entities.

A. *Smartphone Application*

This smartphone application is the primary input artifact for the music player. Besides the music sharing control, it features a nominate functionality, where users can browse the collection of music shared by users and nominate songs they would like to hear. Another part of the interface present the list of nominations, giving the option to give a positive or negative vote for each nomination. Each vote will simply add or subtract one point from the total score. An important aspect is to utilize the users' own smartphones, thereby making it a personal token representing the specific owner's choices at any time.

B. *Tablet Application*

The tablet application is a simplified version of the smartphone application that only works for nominating and voting. It first serves the purpose of a public input artifact used by people without a compatible smartphone and secondly to create a physical interaction point for the music system in general. Because the tablet is an artifact shared among several users, we modified the vote feature to include a 10-second countdown after a vote, where the application locks itself. We added this mechanism to prevent a person from voting repeatedly for the same song.

C. *Situated Display*

The situated display shows the primary visual output of the music player to the users. The interface is suitable for a large flat screen TV or projector and should be placed with visibility in mind. The situated display represents nominations as album covers. The current score is represented by size, meaning that the largest nominations are more likely to be played next. This score does not map to the smartphone application, thus the situated display is the only place where the status is visible. Fig. 3 shows the voting interface of the different artifacts.

The music system is running in one place and distributes interaction to other artifacts. Specific artifacts consist of a device with a part of the distributed interface each with their own output screen and each serving a specific purpose.

VI. CONCEPTS

In this section, we use the two presented systems to identify concepts that we find meaningful in the context of multi-artifact systems. The concepts are not necessarily novel in themselves, but the contribution lies in the use of them as concepts that describe interaction across artifacts.

A. *Plasticity*

In AirPlayer, the location feature enables the smartphone application to adapt to the location of the user, providing control of the music in this particular location as well as information about the music playing. Balme et al. refers to this kind of adaptability as ***plasticity*** [1]. More precisely, they define plasticity applied to HCI as *"...the capacity of an interactive system to adapt to changes of the interactive space while preserving usability"*.

Plasticity is not only meaningful in multi-artifact systems but for single artifacts as well. A smartphone application could for instance adapt to the location of the user independently of other artifacts, or a public display could adapt to the time of day or number of people in front of it. In AirPlayer, it is the spatial relations between the smartphone and speakers placed around the home that determines what is presented to the user, which is why we argue that plasticity also has its place as a concept of multi-artifact systems.

MEET does not have any plasticity integrated in the interaction design. Each artifact has a certain form that plays a specific role in the system. An idea of introducing it into the smartphone application could however be to provide

Figure 3. The different artifacts of MEET and their respective GUIs for the voting functionality.

more feedback on the status of the voting, if the user is not able to see the situated display.

Another interesting challenge of artifact ecologies is the increase in general-purpose artifacts capable of executing different sort of applications Our phone is no longer just for making phone calls, our TV is no longer just for watching TV, and the newest addition to our ecologies is seemingly smart watches that does much more than showing the time. As our collection of general-purpose artifacts expand arguably so does the number of multi-artifact systems and the complexity of them. In AirPlayer, the smartphone application adapts to contextual information within the user's current activity. Artifacts able to adapt to fit a certain activity and composition of artifacts could be an interesting aspect of plasticity.

B. Migration

The movement feature of AirPlayer makes music follow the user around the home by moving the music output from one artifact to another. This behavior is very much in line with the work on *migratory user interfaces*, which Berti et al. describes as *"…interfaces that can transfer among different devices, and thus allow the users to continue their tasks…"* [2]. The essential issue here is the continuity in the interaction. The interesting thing about the movement feature of AirPlayer is not that it plays the same music from a central source. The interesting thing is the ability to do so continuously across locations as the user moves around. In the AirPlayer example, it is only the content (the music) that migrates and always between exactly two artifacts. Berti et al. however also defines different levels of migration:

- Total migration: The entire interface migrates from one artifact to another.
- Partial migration: Only a part migrates to the target artifact.
- Distributing migration: The interface migrates to multiple target artifacts.
- Aggregating migration: The interface migrates from multiple artifacts into one.

Migration and plasticity are somehow related concepts that both encourage more flexible and adaptable relations in our artifact ecologies. There is no implementation of interface migration in MEET but is in a similar way as plasticity a concept that could be integrated.

C. Complementarity

In MEET, the system distributes interaction across different artifacts. The different artifacts can be described as being *complementary* to each other, as each of them provides features that improve the overall system. The music player is useless if no one has connected a smartphone, shared some music and nominated at least one song. The smartphone application similarly does nothing on its own. Distributing functionality is of course a conscious design choice that is not strictly necessary to play music at a party. Doing so however takes advantage of available interaction resources to create a different kind of experience. What field studies of MEET have shown is also that such systems can provide an opportunity for a different social interaction and utilization of the environment, than a traditional music system. The benefits however come with the cost of an additional level of complexity, both technically and in the interaction design that we needs to address.

The complementarity between the smartphone/tablet and situated display in MEET is similar to the notion of *coupled displays* [12] and a lot can be learned from the work on that topic. It is however important also to consider other modalities of input and output of multi-artifact systems as artifacts may be able to utilize these to complement each other in different ways in different contexts.

AirPlayer similarly has an element of complementarity in its interaction design although more subtle than in MEET. The smartphone application provides the input and output to a music system distributed throughout the home that provides the music output. Although the smartphone application is able to control various music outputs independently, the complementarity in AirPlayer is basically a remote control metaphor. In a way this is also the case in MEET although both examples illustrate that complementary artifacts can be more powerful than a direct mapping of a traditional remote control.

It seems reasonable to talk about dependency of the relationships between complementary artifacts. In MEET there is a very strong dependency between the smartphone application, the music player, and the situated display as none of them can work independent of the other. The tablet can however be removed without losing crucial functionality but does nothing on its own. In AirPlayer there is also a strong dependency between artifacts as no control of the music is implemented outside the smartphone application. The point is that it can be useful to consider the dependencies of complementary artifacts. Not only in the scope of the multi-artifact system but also in relation to the artifact ecologies involved. In AirPlayer all the artifacts belongs to the ecology of a single person as only one smartphone application is allowed at any time. MEET on the other hand is by design dependent on artifacts from several personal artifact ecologies.

D. Multi-user

The last concept is different from the others, as it addresses the users instead of the artifacts. Whether a system is designed for single or multi-user interaction is not surprisingly an important factor. What it means to include multiple users in terms of artifact ecologies is that the multi-artifact system spans more than one personal artifact ecology and that all involved users' ecologies intersect. MEET is for instance designed specifically for a social context with several simultaneous users. Each user has an artifact ecology, which their smartphone is a part of. When they arrive and connect their smartphone to the player the situated display and music player becomes part of each user's artifact ecology as well. Even though each smartphone at this point is part of the same multi-artifact system, they are not part of any other user's artifact ecology.

The new possibilities for designing multi-user interactions is one strength of multi-artifact systems. MEET for example, has no inherent upper limit on the number of simultaneous users by design. The possibilities do however come with a price. Just as multi-artifact systems adds an extra layer of complexity to single-artifact interaction, so does multi-user interaction. The idea of the movement feature in AirPlayer is an example where whenever there is only one person present there is no problem. Difficulties however arise if more people want to use the feature simultaneously. What happens if two persons, with different music following them, enter the same room? Rules could of course be made to cope with this problem, and as it may seem trivial to always take the number of intended users into account, it is important to do more to understand the multi-user dynamics in artifact ecologies.

E. Summary

We have analyzed the two multi-artifact music systems, MEET and AirPlayer and have identified four concepts of multi-artifact interaction: *Plasticity*, *migration*, *complementarity, and multi-user*. Fig. 4 shows an overview of where the concepts were identified in the two systems.

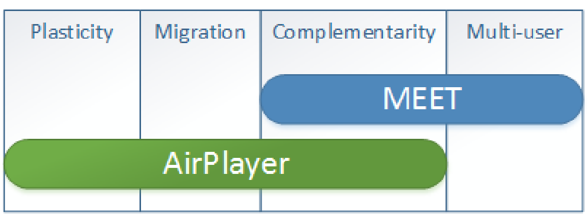

Figure 4. Utilization of discussed concepts in the two systems.

We do want to stress that the concepts should not be seen as individual solutions. There lies great opportunity in combining the concepts as was also evident in our analysis. Partial, distributing, and aggregating migration can furthermore be used to switch between complementary artifact compositions.

VII. CONCLUSION AND FUTURE WORK

The work in understanding artifact ecologies becomes important as they evolve and the relationships among artifacts become more complex. Previous work has focused on the composition and dynamics of artifact ecologies on a very high abstraction level. What we have done is to start an articulation of the sub-systems of artifact ecologies on a level in between the interaction with single artifacts and the understanding of the ecologies in their entirety. The four identified concepts of multi-artifact systems, i.e., *plasticity*, *migration*, *complementarity*, *and multi-user* can help obtain a more fine-grained understanding of artifact ecologies. One future step that we are already looking into is to create a clearer picture of the three layers of artifact ecologies possibly through a reference framework. An obvious next step would furthermore be to get a deeper understanding of the identified concepts with the ultimate goal of creating design guidelines for multi-artifact systems that do not only work well in isolation, but fits into an artifact ecology.

REFERENCES

[1] L. Balme, A. Demeure, N. Barralon, J. Coutaz, and G. Calvary, "CAMELEON-RT: a Software Architecture Reference Model for Distributed, Migratable, and Plastic User Interfaces," Proc. Second European Symp. Ambient Intelligence (EUSAI 2004), Springer, 2004, pp. 291-302, doi:10.1007/978-3-540-30473-9_28.

[2] S. Berti, F. Paternò, and C. Santoro, "A Taxonomy for Migratory User Interfaces," Proc. 12th Int. Workshop on Interactive Systems. Design, Specification, and Verification (DSVIS 2005), Springer, 2005, pp. 149-160, doi: 10.1007/11752707_13.

[3] S. Bødker and C. Klokmose, "The Human-Artifact Model: An Activity Theoretical Approach to Artifact Ecologies," Human-Computer Interaction, vol. 26, no. 4, 2011, pp. 315-371, doi: 10.1080/07370024.2011.626709.

[4] S. Bødker and C. Klokmose, "Dynamics in artifact ecologies," Proc. Nordic Conference on Human-Computer Interaction: Making Sense Through Design (NordiCHI '12), ACM Press, 2012, pp. 448-457, doi:10.1145/2399016.2399085.

[5] F. Capra, "The Web of Life," Anchor Books, New York, 1996.

[6] J. Forlizzi, "How Robotic Products Become Social Products: An Ethnographic Study of Cleaning in the Home," Proc. ACM/IEEE International Conference on Human-robot Interaction (HRI '07), ACM Press, 2007, pp. 129-136, doi:10.1145/1228716.1228734.

[7] L.E. Holmquist, "Ubiquitous Music," Interactions – Ambient intelligence: exploring our living environment, vol. 12, no. 4, July + August 2005, pp. 71-ff, doi: 10.1145/1070960.1071002.

[8] H. Jung, E. Stolterman, W. Ryan, T. Thompson, and M. Siegel, "Toward a Framework for Ecologies of Artifacts : How Are Digital Artifacts Interconnected within a Personal Life ?," Proc. Nordic Conference on Human-Computer Interaction: Building Bridges (NordiCHI '08), ACM Press, 2008, pp. 201-210, doi: 10.1145/1463160.1463182.

[9] E. Lenz, S. Diefenbach, M. Hassenzahl, and S. Lienhard, "Mo. Shared music, shared moment," Proc. Nordic Conference on Human-Computer Interaction: Making Sense Through Design (NordiCHI '12), ACM Press, 2012, pp. 736-741, doi: 10.1145/2399016.2399129.

[10] L. Liikkanen, C. Amos, S.J. Cunningham, J.S. Downie, and D. McDonald, "Music interaction research in HCI: let's get the band back together," CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12), ACM Press, 2012, pp. 1119-1122, doi: 10.1145/2212776.2212401.

[11] J. Rekimoto, "Multiple-computer user interfaces: "beyond the desktop" direct manipulation environments," Proc. CHI '00 Extended Abstracts on Human Factors in Computing Systems (CHI EA '00), ACM Press, 2000, pp. 6-7, doi: 10.1145/633292.633297.

[12] L. Terrenghi, A. Quigley, and A. Dix, "A taxonomy for and analysis of multi-person-display ecosystems," Personal and Ubiquitous Computing, vol. 13, no. 8, November 2009, pp. 583-598, doi: 10.1007/s00779-009-0244-5.

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