Proxemic Interactions with Multi-artifact Systems

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***Abstract*— The artifact ecologies emerging from an increasing number of interactive digital artifacts, capable of communicating with each other wirelessly, have created an interaction space where software applications are no longer limited by the physical boundaries of a single device. With the new opportunities follows an added complexity that interaction designers need to address. Previous work have shown the potential of proxemic interactions as one way of dealing with design challenges of ubicomp systems. However, the work focused on interactions involving multiple digital artifacts is limited. 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 interactions: Plasticity, migration, complementarity, and multi-user. These concepts forms the basis for a discussion on the potential use of proxemic interactions in the design of multi-artifact systems.**

Keywords- artifact ecology, multi-artifact systems, proxemic interactions, music systems.

I. INTRODUCTION

The establishment of a wireless network infrastructure surrounding us introduces an 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 [1]. Jung et al. [2] 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 artifact ecologies without introducing additional complexity to the user is however a challenge.

Interaction designers have become quite good at designing desktop applications and are in a post-desktop era progressively getting better at designing mobile applications as well. However, it is 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 [2] and dynamics [3] of the ecologies as a whole. What we find is that there is a gap between the work on understanding interactions with single artifacts and understanding personal artifact ecologies on a high abstraction level. There seems to be a challenge in understanding the interaction with multi-artifact systems that combine artifacts from personal artifact ecologies. This creates an additional layer of complexity that requires us to think of these sub-systems in a holistic way on an abstraction layer above the single artifact but below the entire artifact ecology.

The idea of proxemic interactions is to take advantage of the significance of spatial organization to the way we interact with people and digital artifacts. This has shown a great potential in helping us understand the artifact associations that constitutes multi-artifact systems and help us facilitate the interaction with them. The concept of proxemic interactions caters very well to the flexible, mobile, and wireless nature of the systems and removes some of the responsibility of handling the added complexity of multiple artifacts being in play simultaneously.

The overall goal is to move towards multi-artifact interaction designs that deliberately exploit the synergetic effects that emerge from artifact compositions and take advantage of the new opportunities this gives us without compromising user experience. The contribution of this paper is to identify concepts of multi-artifact systems that we find to be of particular significance to an artifact ecology context and explore proxemic interactions [4] as a possible framework to reveal opportunities and address design challenges for each of the identified concepts. The analysis is based around multi-artifact systems from our previous work in the music consumption domain.

Our focus lies in the interaction between humans and artifacts on a conceptual level, although it is clear that interaction designs spanning multiple artifacts is highly dependent on a comprehensive and flexible technical infrastructure for artifact discovery, connection, and communication. Therefore, we work under the assumption that this is or will be available to some extent, but acknowledge that some of the challenges are in the interaction itself.

First, we present related work on artifact ecologies, proxemic interactions, 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 to identify characteristic concepts of multi-artifact systems and discuss the application of proxemic interaction before we conclude the paper with implications for future work.

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II. Related Work

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

A. Artifact Ecologies

In a study of the social role of products, Forlizzi [5] introduces 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. A product for example 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 products surrounding us. Jung et al. [2], places 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. The limitation of the framework is that it does not take into account what happens when different personal ecologies intersect in multi-user interactions.

Jung et al. [2] argues that artifact ecologies are dynamically evolving. Bødker and Klokmose [3] 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 [6] 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. [2] describes artifacts as physical objects, Bødker and Klokmose [3] found from their study that this does not always tell the whole story and that something more may be needed to systematically address the software as well.

B. Proxemic Interactions

According to Hall [7], interactions between individuals are highly influenced by interpersonal distance. There is for example a significant difference in how we interact with a person standing right in front of us compared to a person we see from across the street. A noteworthy contribution of Hall's work is the definition of discrete proxemic zones surrounding us, called the *intimate*, *personal*, *social*, and *public* zone. Each characterizes the interaction with people in our surroundings based on the immediate distance.

Vogel and Balakrishnan [8] adopts this notion in their framework for shareable interactive ambient displays and uses it to define what they refer to as *interaction phases*. This is a very direct interpretation of Hall's proxemic zones [7], which allow a large display to adapt to the user, based on distance in much the same way as people adapt to other people approaching. Greenberg et al. [4] have later expanded on the idea of proxemics as a means to describe relations in small space ubicomp environments that include multiple users, devices, and non-digital features. In their framework, they operationalize proxemics through five dimensions of proxemic interactions: *Distance*, *orientation*, *movement*, *identity*, and *location*. In addition to the theoretical framework on proxemic interactions, Marquardt et al. [9] have presented a proximity toolkit, which gives developers and interaction designers easy access to a prototype environment for proxemic interactions. The toolkit has been used in the development of prototypes such as the Proxemic Peddler [10].

Although previous work have established a deeper understanding of proxemic interactions and the potential of the framework over the last few years, Marquardt and Greenberg [11] notice that little work is applying the theory to interaction designs in ubicomp research. In their work, they elaborate on how proxemic interactions can address particular challenges of ubicomp interaction design. The six core challenges they identify in relation to proxemics are *revealing interaction possibilities*, *directing actions*, *establishing connections*, *providing feedback*, *avoiding and correcting mistakes*, and *managing privacy and security*.

Proxemic interaction shows great potential, but also comes with a risk. Because proxemic interaction relies on close tracking of people and devices, it comes with the risk of being exploited. Greenberg et al. [12] identifies so called *dark patterns* of proxemic interactions and discuss the framework from a critical perspective. A particular challenge of systems that base decisions on implicit interactions is for example to design ways for the user to opt out of the interaction. The point of context awareness in general is that the system becomes able to infer how a user wants to interact with devices based on context. The problem is when the interaction designer is not using that information in the best interest of the user but for instance in the interest of a company that wants to sell a product.

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C. Music Consumption

Music has always been an important domain across disciplines due to its universal appeal. Holmquist talks about the field of ubiquitous music and how it formed through a digitization of music, portable music players and heightened bandwidth [13]. Although the article is from 2005, ubiquitous music has only become more relevant after the emergence of Internet streaming services and affordable multi-room music systems. However, Liikkanen et al. [14] point out that music consumption as a defined area in HCI research is extinct. They argue that research on music consumption through interactive devices continues but is marginal and needs a revival.

An aspect of music consumption with a particular relevance to our context is the role of music in a social setting. Leong and Wright [15] found that the increasing connectivity of technologies we use to consume music have prompted users to create their own configurations that allows them to obtain more meaningful social interactions through music. They comment on the future designs of music discovery beyond virtual social networks that utilizes the physical environment. Capital Music [16] is an example that allows co-located strangers to share music recommendations. Their study shows how music can influence social interactions in public spaces without people listening to music together. Another study explores this premise in tuna [17], which allows co-located users to "tune" in to other people's mobile music player.

O'Hara and Brown's [18] book contains a large collection of contributions to the social aspect of music consumption. Their work provides valuable insights into the sociality of music but is also a testament to how the technologies involved in music consumption has changed drastically in few years. Ongoing work is similarly exploring shared music experiences supported through technology and novel interaction designs. An example is Mo by Lenz et al. [19], which is a music player with an integrated speaker focusing on a shared music experience. Mo can be brought into a social setting and creates a connected music system by placing it next to other players.

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 [20]. Furthermore, Terrenghi et al. [21] created a taxonomy for what they refer to as multi-person-display ecosystems, and Anzengruber et al. [22] similarly talk about display ecosystems as the platform for social feedback. 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. 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 [23]. This view fits perfectly well with our intention of addressing interaction design for systems, which provides more than cross-platform interfaces.

A. Delimitation

In our definition and delimitation of multi-artifact systems, we acknowledge Bødker and Klokmose's [3] comment on 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 work specifically aims at 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. Video conferencing is another example that involves several artifacts, but traditionally only one from each user's personal ecology. It is thus not a multi-artifact system either. A system that merges persons' smartphones into a common interface is an example of a multi-artifact system from our perspective, as it would become a multi-artifact system in each user's ecology. The example shows the inclusion of systems that exist in the intersection between 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 should not be interpreted as if the artifacts in the multi-artifact systems are required to be co-located or that the interaction with each artifact has to happen simultaneously. We still consider systems that distribute interaction across time and space as long as the interaction is part of the same activity from the personal point-of-view. The important point is that the system provides more than a cross-platform interface. An example is the Google Chrome browser. Having a version for Windows, Android and iOS makes it a collection of single-artifact interactions, but when it starts remembering tabs, bookmarks, search preferences, etc. across artifacts it becomes interaction with a multi-artifact system.

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

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IV. AirPlayer

AirPlayer is a multi-room music system that adapts to the location of the user with the purpose of creating an implicit control of the music. It consists of a .NET C# server application and an Android client that builds on top of Apple's AirPlay protocol stack, hence the name, making it capable of streaming music from a central digital music library to speakers placed in different locations around the home. Each speaker connects wirelessly to a central music player application through an Airport Express that doubles as a Wi-Fi access point. The use of a Wi-Fi network additionally makes it possible for the user to control 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. However, the user can combine zones to play and control music in several locations simultaneously. The zone name is visible in the bottom of the main screen (see Figure 1) and by sliding horizontally, the user can manually 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. The significance of AirPlayer is its addition of proxemic interaction features that allow 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 provides the necessary logic to estimate user location and distance to individual speakers. The smartphone application continuously measures Received Signal Strength Indicator (RSSI) values from the Airport Express Wi-Fi access points and uses them to determine in which zone the user is located. Chen and Kobayashi [24] argues that indoor location is feasible through radio signal based indoor location, given an implementation of a sound method for signal propagation. Although the proxemic sensing in this prototype is not based on a sophisticated algorithm for signal propagation, in practice it performs to a degree that enables the user to experience proxemic interaction.

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 Figure 1, this means that the user interface presents information about the song playing and ensures that the user 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 explicit user interaction. Whenever the system detects a change in location, it simply adapts the smartphone application to represent the current zone. From the user point-of-view the interaction is similar to having a universal remote control that can be used to control independent music players in each room.

B. Movement

When the movement feature is enabled, music follows the user around the home as illustrated in Figure 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 adjusts the volume in accordance to the movement of the user. The movement and location feature can be enabled independently but are not strictly independent of each other. When 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.

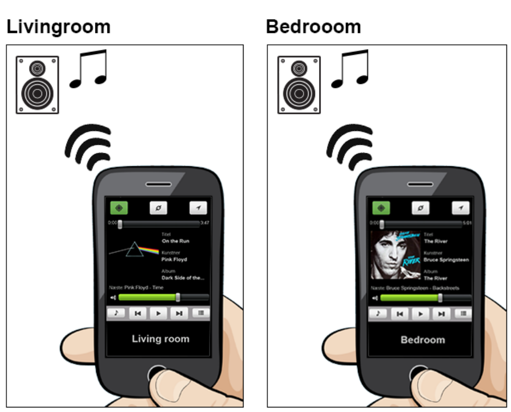

Figure 1. The location feature adapts the user interface and control to the location of the user.

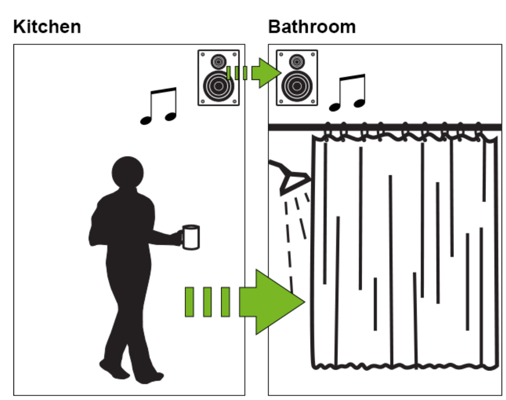

Figure 2. The movement feature makes music follow the user across locations.

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V. MEET

The second system, called Music Experienced Everywhere Together (MEET), is a multi-user, multi-artifact music system that addresses the problem domain of playing music in a social setting where there is no DJ or other dedicated control of the music. The concept of MEET is to allow several co-located users to share their music to a music player at social events, thereby creating a common music library. What is being played from the library is then controlled in a collaborative manner where anyone can nominate and vote for songs using their own smartphones or a dedicated tablet. To nominate a song simply means that the system puts a song up for display as a possible song to be played next. When it will be played, or whether it will be played at all, is up to the crowd and how participants choose to place their votes. The smartphone and tablet application is implemented in Android and the library and music player is implemented in Java/JavaFX. The Real-time Transport Protocol (RTP) and Real Time Streaming Protocol (RTSP) is used for streaming between library and music player.

The intention of a system like this, compared to for example a traditional jukebox, is to make it a social experience that tries to be fair to the users and that allows people to engage in the music control in a different way. The advantages of the approach are:

- No one can interrupt what is currently being played in order to put on another song.
- There is no playlist queue, but rather a system that dynamically changes to reflect what people wants to hear in the moment.
- The music in the library is not a large generic collection but a personalized collection of people’s own music.

A quality of music is its ability to be experienced as a background activity. Consequently, it is important for MEET to allow participation on different levels and not become the event itself. To accommodate this requirement, MEET has a built in feature that automatically nominates songs from the music library if there are less than three current nominations.

A. Smartphone Application

The smartphone application is the primary input artifact for the music player. Besides being the interface to share music to the music player, it features a nominate functionality, where users can browse the collection of music shared by users and nominate songs they would like to hear. Furthermore, the interface presents the list of nominations, giving the option to give a positive or negative vote for nominations. Each vote will simply add or subtract one point from the total score. An important quality is to utilize the users’ own smartphones, thereby making it a personal artifact representing the specific owner’s choices.

B. Tablet Application

The tablet application is a simplified version of the smartphone application that only works for nominating and voting. It primarily serves as a public input artifact used by people without a compatible smartphone and secondly as a physical interaction point for the music system in general. Because the tablet is an artifact shared among several users, the vote feature is modified to allow an infinite number of votes for a single nomination and instead introduce a 10-second countdown after a vote, where the application locks itself. The lock mechanism is added in an attempt to prevent a person from exploiting the tablet by 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 as it represents the current state of the music player to the users. An album cover represents a nomination on the situated display (see Figure 3). Size of nominations indicate score, meaning that the largest are more likely to play next. This score does not map to the smartphone application, thus the situated display is the only place where the status is visible. Figure 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.

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

VI. CONCEPTS OF MULTI-ARTIFACT SYSTEMS

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 novel in themselves, but the contribution lies in the use of them as tools to describe interaction across artifacts, which can inform a focused and structured effort in the design of proxemic interactions.

A. *Plasticity*

The term plasticity is inspired by neuroscience and the way our brain is able to change as a reaction to external influences such as changes in the environment. The term has been adapted to HCI to describe a similar behavior for non-static user interfaces. Balme et al. [25] define plasticity applied to HCI as *"...the capacity of an interactive system to adapt to changes of the interactive space while preserving usability"*. Changes of the interactive space can both be in terms of the physical environment, the resources available or virtual changes. Plasticity is meaningful for different types of artifacts. A smartphone application can for instance adapt to the location of the user (Figure 4), or a public display can adapt to the time of day or number of people in front of it.

In AirPlayer, the location feature enables the smartphone application to adapt to the location of the user, providing information about the music currently playing, as well as control of the music in this particular location. 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 form that plays a specific role in the system. An idea of introducing it into the smartphone application could be to provide more feedback on the status nominations, 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 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 thereby 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 utilization of plasticity.

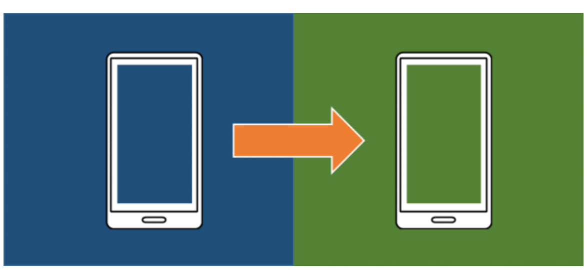

Figure 4. Plasticity allows user interactive systems to adapt to the interaction space.

B. *Migration*

Migration refers to the capability of moving the interaction from one device to another while preserving the state (see Figure 5). Berti et al. describes migratory user interfaces as *"...interfaces that can transfer among different devices, and thus allow the users to continue their tasks..."* [26]. The essential concept here is the continuity in the interaction and it is where it differs from cross-platform applications, which merely presents the user to an alternative version of the same application on different physical artifacts. In the taxonomy of migratory interfaces Berti et al. [26] distinguish between different degrees of migration: Total migration, is where the entire interface migrates from one artifact to another. In partial migration, only a part migrates to the target artifact. Distributing migration is where the interface migrates to multiple target artifacts. Finally, aggregating migration, is where the interface migrates from multiple artifacts into one.

The movement feature of AirPlayer makes music follow the user around by moving music output from one artifact to another. The interesting thing about the movement feature of AirPlayer is not that it plays the same music from a central source. It is the ability to do so continuously across locations as the user moves around. In the AirPlayer example, it is the content (music) migrating between exactly two artifacts. The way it works in AirPlayer is an example of interface migration not necessarily being a matter of transferring an application state.

Migration and plasticity are somehow related concepts that both encourage more flexible and adaptable relations in 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. A possible use is to transfer the state of the situated display to a view on the smartphone application as soon as the situated display is no longer visible to the user.

Figure 5. Migration allows interaction to move between devices.

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C. Complementarity

Complementarity, as illustrated in Figure 6, is the concept of distributing a user interface across artifacts allowing simultaneously use in a collaborative fashion. A typical example is a remote control where the user input is clearly separated from the output, and one artifact is controlling another. Another type of complementary interactions have started to emerge in the form of so-called *companion apps* or *second-screen apps*, which is a mobile application that complements the interaction of another artifact. An example is an application that shows information for a TV show.

In MEET, interaction is distributed 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. However, the distribution 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. Unfortunately, the benefits come with the cost of an additional level of complexity, both technically and in the interaction design.

The complementarity between the smartphone/tablet and situated display in MEET is similar to the notion of *coupled displays* [21] where lessons can be learned from previous work. In addition, it is important to consider other modalities of input and output of multi-artifact systems than the visual, as artifacts may be able to utilize these to complement each other in different ways.

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 is 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. An exception is the tablet, which can be removed without losing crucial functionality but does nothing on its own. In AirPlayer, there is similarly 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

Multi-user interaction is quite self-explanatory and is simply the concept of interactions that involve more than one user. However, it is worth making the distinction between two cases. One is where multiple users interact with a system simultaneously (Figure 7). The other is where multiple users interact with a system one at a time.

The multi-user 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's smartphone is a part of their individual artifact ecology and can serve various purposes in different contexts. 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 smartphone at this point is part of the same multi-artifact system, they are not part of any other user's artifact ecology.

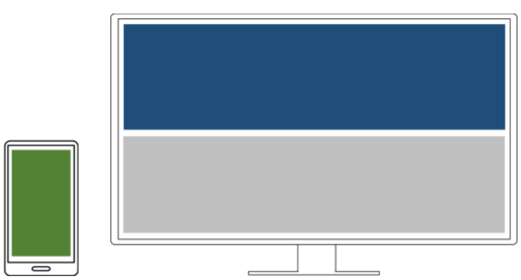

Figure 6. Complementarity allows interactions to be distributed across devices.

Figure 7. Multi-user interactions are either interactions involving more than one user simultaneously or one at a time.

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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. It is interesting to see how some multi-artifact systems are inherently designed for a single user but where it is trivial to support more simultaneous users. AirPlayer, on the other hand, is a case where it easily gets complicated if it needs to support more user even though it would make sense in an everyday situation. MEET is specifically designed to support simultaneous users and would simply be a different system if it were to support a single-user mode.

E. Comparing AirPlayer and MEET

We have analyzed the two multi-artifact music systems, MEET and AirPlayer and have identified four concepts of multi-artifact interactions: *Plasticity, migration, complementarity*, and *multi-user*. In AirPlayer we identified the concepts of plasticity, migration, and complementarity and in MEET we identified complementarity and multi-user (Figure 8). Complementarity was the only overlapping concept and served a similar purpose in both systems, namely to distribute part of the user interface onto a smartphone. A difference is that in AirPlayer there was no other visual interface besides the smartphone application. The multi-user concept differs from the others, as it does not refer to the artifacts. It is therefore interesting to see how important it is to the way a multi-artifact system is designed.

We do want to stress that the concepts are not individual solutions to multi-artifact interaction design. There lies great opportunity in combining the concepts as was also evident in our analysis. Plasticity, migration and complementarity in AirPlayer serves a particular purposes for a part of the system and a strength of the combination can be seen in the movement feature. Having the music follow you around could be achieved by simply playing it from the smartphone itself, but the music system installed in the home is of a much higher quality and through migration, music can still follow the user around. The convenience of controlling music on the smartphone, offered through the complementary interface, is on the other hand preferable. Partial, distributing, and aggregating migration can be used to switch between complementary artifact compositions.

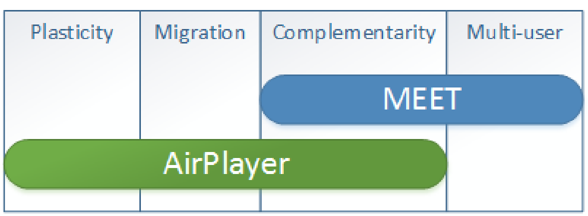

Figure 6. Utilization of discussed concepts in the two systems.

VII. Proxemic Interactions

In this section, we discuss the use of proxemic interactions as a possible interaction framework for multi-artifact systems in artifact ecologies. We specifically revisit the four identified concepts of multi-artifact systems described earlier, and discuss possible opportunities and challenges in the application of proxemic interactions to realize them. The discussion is based on our experiences from the studies of the music systems as well as insights from previous work on proxemic interactions.

A. Proxemics and Plasticity

Plasticity represents the very basic concept proxemic interactions was defined for: Adapting the user interface of interactive systems to better accommodate the spatial organization of people, digital artifacts and non-digital objects. This is what Vogel and Balakrishnan [8] demonstrates in their work on a public display that adapts to the distance of a user in a seamless way through four interaction phases very analogous to Hall's [7] proxemic zones. Similar work on proxemic interactions focuses on the distance between a user and a large display, and there is a great potential in the use of adapting user interfaces of artifacts based on the proxemic relations to nearby users.

In AirPlayer, we saw how plasticity was used to adapt the content of the smartphone interface according to the *location* of the user. A noteworthy detail here is that it is the content that changes and not the state of the user interface. Another aspect of plasticity is to allow the user interface to adapt to accommodate the surroundings. In MEET, it could for example be interesting to let the interface of the situated display adapt to the number of users in front of it. This could be used to either improve the experience of current users or help attract more.

A general challenge with proxemic interactions as a way of automating plastic user interfaces is the dilemma of how much the user needs to understand the decisions made by the system. A smartphone typically uses a proximity sensor to disable the touchscreen when a call is picked up and the phone is being held in a position close to the user's ear. Not everyone knows this happens and as long as it prevents accidentally pressing unwanted buttons, the feature serves its purpose. In the design of proxemic interactions that adapt the user interface, it is however important to take into consideration how much the user is kept in the dark.

B. Proxemics and Migration

The idea of interface migration is very relevant in an artifact ecology context as we already own and interact with several artifacts capable of performing the same tasks. Without some sort of preserved state across artifacts, we end up restarting interactions every time we switch between them. Which artifact is appropriate for the task in a given point of time depends on various factors and presents a challenge that does not seem to be completely solvable by proxemic interactions alone.

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In AirPlayer, the music migrates from artifact to artifact, depending on the movement of the user, i.e., the content. This example already shows how it can make sense to base the migration on proxemic relations. The implementation of proxemic interactions in AirPlayer is rather coarse-grained and only works on a room level. The *location* dimension in proxemic interaction theory differs from *distance* in that other features of the location can be significant. In the AirPlayer example, the type of room could for example be meaningful to the decision about migrating and if the user left the house, it could make sense to perform a total migration to the smartphone.

More generally, proxemic relations seems like a natural approach to interface migration. Many of the challenges identified by Marquardt and Greenberg [11] apply to interface migration such as revealing migration targets, directing actions and establishing connections. A general challenge that however also would apply to migration is how to opt out or how to avoid automatically opting in. It is easy to assume that the user would always want to migrate the current task to the nearest and/or best artifact. However, there could be situations where this is not the case. It would for instance not be appropriate to migrate mobile internet browsing to every public display a user passes by even though it provides a larger screen.

C. Proxemics and Complementarity

Unlike plasticity and migration, complementarity as a concept does not infer any ability to adapt or change the interface of an interactive system. It rather describes how artifacts can complement each other to allow for an augmented interaction experience. The concept is still relevant to discuss in relation to proxemic interactions as the procedure of connecting artifacts and making meaning of current associations is not a trivial task.

Results from the field study of the complementary interface of MEET shows the importance of the spatial organization of users and artifacts in the physical environment. In cases where the user had great visibility of the situated display, the most important property was the coordination of visual feedback between the situated display and the smartphone application. However, when either the users were at a distance or otherwise unable to see the display clearly, they would be highly dependent on the limited feedback given from the smartphone application. It can be argued that a redesign of the interface or added features would solve this problem, but an important aspect of the smartphone application is also the simplicity as the users were engaged in a social activity as well.

In an artifact ecology context, there generally seems to be an unlocked potential in utilizing proxemic interactions to combine plasticity with complementarity. Mobile artifacts serve multiple purposes that often overlap. Configuring the roles of artifacts in our immediate surroundings is currently up to the user and as the number of artifacts grow, it becomes a difficult task to get the best out of the artifacts in a given situation. Here we see a potential for proxemic interactions to adapt the interface of the individual devices to complement other artifacts in its proximity. The limitation of proxemic interactions in relation to plasticity is that spatial relations do not uniquely characterize an activity. The couch in front of the TV can be the place where a user watches movies while using a smartphone as a remote control, but it might as well be where he takes a nap.

D. Proxemics and Multi-user Interactions

Supporting multiple co-located users in multi-artifact systems is far from a trivial challenge. The *identity* dimension of the proxemic interaction framework do acknowledge the importance of distinguishing between users. This is similar to how we might feel more comfortable having a conversation very close to our spouse than to a stranger, and in the interaction design of multi-artifact systems this makes sense as well. Designing proxemic interactions based on the identity of multiple users is very useful and can help in managing privacy and security through proximity-dependent authentication [11]. A laptop should, e.g., react differently if it is aware that the owner is sitting in front of it with a smartphone than if it is an unauthorized user. However, there are other underlying challenges of proxemic interactions in multi-user scenarios.

Commercial systems heavily rely on a model similar to the artifact ecology with a single user in the center. Everything is built around user profiles, which inherently are meant for one user at a time. The problem is that it is not always obvious what it means to support multiple simultaneous users. The idea of the movement feature in AirPlayer, where music follows you around is an example that makes perfectly good sense for one person. It is however difficult to design appropriate behavior 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 be defined to cope with this specific problem, but what could be more interesting is to explore generic approaches. As it may seem trivial to take the number of intended users into account for a particular context, we find that existing solutions shows it is an important area to do more work to understand the multi-user dynamics of artifact ecologies.

VIII. Conclusion and Future Work

The work in understanding artifact ecologies becomes important as the number of relationships among artifacts increase in complexity. 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, which informs a discussion of the concepts in relation to proxemic interactions.

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The discussion has revealed specific pointers to proxemic interaction's potential for the design of multi-artifact systems and identified limitations of spatial relations as context. As the identified concepts are deduced from the interaction design of two multi-artifact systems, we make no claim of completeness. A next step would therefore be to get a broader understanding of interactions with multiple artifacts on a conceptual level with the goal of creating design guidelines for proxemic interactions in multi-artifact systems that do not only work well in isolation, but fits into an artifact ecology.

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