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**The 4C Framework**

*Principles of Interaction in Digital Ecosystems*

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# The 4C Framework:
# Principles of Interaction in Digital Ecosystems

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## ABSTRACT

Recent years have seen an increased research interest in multi-device interactions and digital ecosystems. This research addresses new opportunities and challenges when users are not simply interacting with one system or device at a time, but orchestrate ensembles of them as a larger whole. One of these challenges is to understand what principles of interaction work well for what, and to create such knowledge in a form that can inform design. Our contribution to this research is a framework of interaction principles for digital ecosystems, which can be used to analyze and understand existing systems and design new ones. The 4C framework provides new insights over existing frameworks and theory by focusing specifically on explaining the *interactions* taking place within digital ecosystems. We demonstrate this value through two examples of the framework in use, firstly for understanding an existing digital ecosystem, and secondly for generating ideas and discussion when designing a new one.

## Author Keywords

Digital ecosystems; multi-artifact; multi-user; framework; structures; relationships.

## ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

Ubiquitous computing (ubicomp) has not yet reached a level corresponding to Weiser's [28] vision of invisible computers seamlessly integrated into our environment. However, digital interactive artifacts remarkably similar to his notions of pads, tabs and boards constantly surround us. Smartphones, tablets, laptops, TVs, and smart watches, each capable of accessing various services and serving

several and sometimes overlapping purposes, have become part of our everyday lives. Consequently, the ways we use digital artifacts have changed. We have become users of networks of artifacts rather than of individual ones [13] and we share and connect to each other's digital artifacts in different ways than we did just ten years ago [15]. Access to digital services and content has become fragmented, and so a need for our artifacts to work together has grown. Today it is therefore important to be able to design ubicomp systems where the user's interaction spans across multiple interconnected digital artifacts.

Understanding and designing multi-artifact interactions is however not only a question of accommodating changes in how we use our existing interactive artifacts. There is also a need to address the challenge of unlocking the full potential of the artifacts and infrastructure available to us. The idea of using digital artifacts together has existed for a long time (for example Rekimoto's Pick and Drop [24]) but questions still remain open in terms of designing interactions meaningful to ubicomp environments. It is, for example, still not a trivial task to take a picture using a smartphone, and then show it on a large screen nearby. Neither is it clear how to provide feedback to a group of people using a system together. How to pursue these issues appropriately is also a challenge in itself.

We believe that approaching the challenge of multi-artifact interactions in a holistic way, as an ecosystem, can help us discover new interaction design opportunities. Recently, more theoretically founded ecosystem approaches have been published in the HCI literature (e.g. [6, 12, 13]). As a contribution to this research direction, we present the 4C framework (Communality, Collaboration, Continuity, and Complementarity), which can help understand and design interactions for digital ecosystems by dividing these into 4 themes and 8 principles. The framework emerged by analyzing existing, real-world digital ecosystems driven by the question: What makes a digital ecosystem more than simply a collection of artifacts?

The next section presents related work and theoretical background. The 4C framework is then presented. The value of the framework is then demonstrated through an example case of analyzing an existing digital ecosystem and an example case of informing the design of a new one. Finally, we discuss implications for design and research.

**RELATED WORK**

In the following we present related work in the areas of multi-artifact interactions and ecosystem thinking in HCI.

The idea of using several artifacts together has always been important within ubiquitous computing. Rekimoto [24], for example, envisioned nearly two decades ago what he called multiple-computer user interfaces, and argued that interaction techniques must overcome the boundaries among devices in multiple-computer environments. Other research following the same line of thinking has since emerged where various aspects of multi-artifact interactions and "digital ecosystems" have been investigated. Wäljas et al. [31], for example, presented a framework for cross-platform service user experiences and found that users may not be as sensitive to consistency issues across platforms as is often assumed. Trimeche et al. [27] have introduced a phone-centric approach to what they call a multi-device ecosystem, while Kawsar and Brush [15] have studied use patterns of connected devices in private homes. Looking at commercially available "ecosystems of connected devices", Levin [18] demonstrates a variety of ways that devices can relate to each other to form a powerful whole encompassing consistent, continuous, and complementary experiences of users. Because a large part of our use of digital artifacts involves displays the visual aspects of digital ecosystems play an important role. Previous research on this matter involves a taxonomy for multi-person-display ecosystems [25] and studies on how to use mobile devices together with other devices [1, 11]. Related to this, previous research has also investigated how collaboration between users can be facilitated in multi-device environments [16, 23].

Complementing this technical and application-oriented work, theoretical work has used holistic and ecological thinking as a way of understanding multi-artifact systems and interaction from the point of view that we cannot fully understand an individual artifact if we do not investigate it as a part of a larger whole. Notably, Forlizzi [12], Jung et al. [13], Bødker and Klokmose [6, 7], Bardram [3], Nardi and O'Day [19], and Hutchins [13] all provide important insights into the relations and dynamics of people's orchestration of artifact ecologies. They also emphasize the importance of inter-artifact relationships to our perception of both individual artifacts and artifacts in concert.

Placing *the artifact* in the center, Forlizzi [12] introduces a "product ecology" framework to describe interrelated systems of a product, other surrounding products, people, activities, place, and social and cultural context of use. This framework facilitates analyzing and describing the dynamic social relationships surrounding interrelated products, and examining how users adapt to it. With a focus on *the individual user* in the center, Jung et al. [13] introduces "personal ecologies" of artifacts as a way to understand a set of digital artifacts and how they interconnect with a user. They define the personal ecologies 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"*, and based on empirical studies they present a categorization of artifact properties into physical, functional, informational and interactive aspects. Adding to this, Bødker and Klokmose [6] elaborate on the notion of personal artifact ecologies through the Activity Theory based Human-Artifact model as a framework for understanding the way people perceive and appropriate artifacts within an ecosystem. They furthermore argue that there might be a need to change the conception of an artifact as a physical device, and that a more inclusive notion will help describe the role of a device in specific relationships better [7].

Also grounded in Activity Theory, Bardram [3] presents the Activity-Based Computing (ABC) framework for designing ubicomp systems for collaborative work spanning across several interactive artifacts. In this framework *the activity* is placed in the center, and focus is on representing those in a computerized system in a way that supports them being persistent, stateful, and distributed across networked computers so that users can move work activities with them while roaming between devices. This is done through design principles of activity-centered resource aggregation, activity suspension and resumption, activity roaming, activity sharing, and activity awareness. Similarly, Nardi and O'Day [19] also put human activity in the center in their notion of "information ecologies", which they describe as systems of *"people, practices, values, and technologies in a particular local environment"*. In this work, particular attention is furthermore brought to the relationships between people, not just artifacts, and the habitation of technology in a particular location, focusing attention beyond a single person interacting with technology, and proposing a sensitivity to the notion of locality. The latter has also been explored by Bell [4] who uses the term "cultural ecology" to describe the cultural properties of collections of interrelated artifacts in particular localities, such as in a museum.

From the related theoretical perspective of Distributed Cognition, which like Activity Theory has its roots in Vygotsky's cultural-historical psychology (cf. [29]), Hutchins [13] takes an ecological approach to how people process and interact with information and artifacts in the world, emphasizing the social as well as situated aspects of cognition, and putting *groups of people* in the center. From the perspective of Distributed Cognition, people and artifacts are all ecological elements of a cognitive ecosystem, and human knowledge and cognition are not limited to the individual, but distributed by placing, facts, knowledge and memories onto artifacts, people, and tools in our environment. This perspective is particularly useful when analyzing and designing complex collaborative systems involving multiple people and artifacts/tools operated in concert as a larger whole, such as the control systems on a ship [13].

These frameworks and theoretical perspectives are all valuable for understanding and designing multi-user and multi-device digital ecosystems in that they promote exploring a holistic view including artifacts, people, activities, groups, etc. This allows us to describe and understand, theoretically, different holistic aspects of ubicomp systems involving multiple users, devices and activities, such as the complementing properties of different artifacts for a group of friends finding their way using several map artifacts [6], the mediating role of shared work activities amongst collaborating roaming nurses in a hospital [3], or the joint sense-making and interaction taking place in the operation of a complex control system [13]. However, we feel that these existing frameworks and theoretical perspectives are limited in their ability to inform specific understanding and design on the level of specific user interface and interaction techniques. While we are able to understand the dynamics and relationships between artifacts, people, activities, groups on a high level of abstraction using, for example, Activity Theory or Distributed Cognition, such understanding rarely explains what specifically makes a particular interface design or interaction technique perform well, in a way that is easily applicable to a different design case. It is often also very difficult to translate such abstract understanding into concrete interaction design for digital ecosystems.

## FOCUSING ON INTERACTION

Contributing to the work on digital ecosystems, we suggest a complimentary way of understanding digital ecosystems where we focus explicitly on the interaction between users and digital artifacts instead of looking at ecosystems as people, products, activities, or groups. From such a perspective, digital ecosystems can be described as a network of nodes that interact with each other through relationships [22]. For a digital ecosystem, this network consists of users and digital artifacts, dynamically bounded by the users' activities (Figure 1).
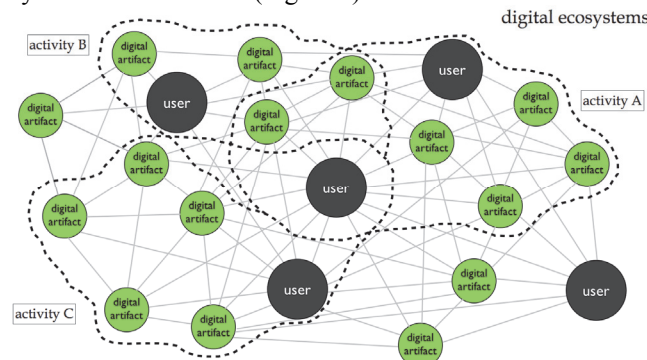


**Figure 1. Digital ecosystems of users and digital artifacts bounded by activities and related through interactions**

A user activity could, for example, be *working at the office* including the artifacts being used in this location, or it could be *watching Netflix at home* including other members of the household and their relevant digital artifacts. Both activities could involve several users and several artifacts.

Putting the interaction between users and digital artifacts in the center, four basic structures of relationship emerge: 1) many users interacting with many artifacts, 2) one user interacting with many artifacts, 3) many users interacting with one artifact, and 4) one user interacting with one artifact. These are illustrated in Figure 2.
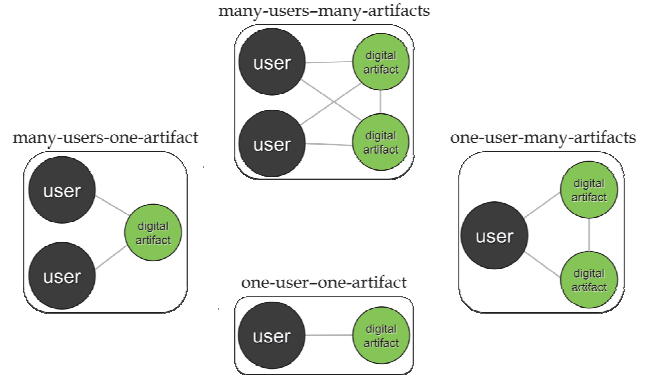


**Figure 2. Four basic structures of relationships between users and digital artifacts**

### Many Artifacts and Many Users

Out of these four structures, it is mostly the three structures involving *many artifacts* or *many users* that are of interest for digital ecosystem interaction design as something distinct from traditional personal computing. Single-user interaction with one dedicated artifact, for example a user and a PC application, is a well-researched case within HCI, and present well-known challenges and possible solutions for researchers and designers. Hence, while all four relationships appear in the interactions within a digital ecosystem, we will narrow our focus to interactions involving many users or many artifacts, or both.

### Sequential and Simultaneous Interaction

In looking at users' interaction with several digital artifacts, this can be further divided into two, depending on whether the interaction is *sequential* or *simultaneous*. In sequential interaction, users will start doing something with one digital artifact, and then continue it with another. This could, for example, be checking email on one's phone, and then moving on to a laptop computer to read a particular one in detail. In simultaneous interaction, users do something using several digital artifacts at the same time. This could, for example, be getting an overview of one's calendar on the large screen of a desktop computer while sending a meeting invitation from one's phone.

### THE 4C FRAMEWORK

Based on our analysis of ecological thinking and existing cases of digital ecosystems that are either commercially available or reported in the literature, we have developed the 4C framework for describing, explaining, and informing interaction design in digital ecosystems. The framework is depicted in Figure 3, and described and exemplified in the following sections.
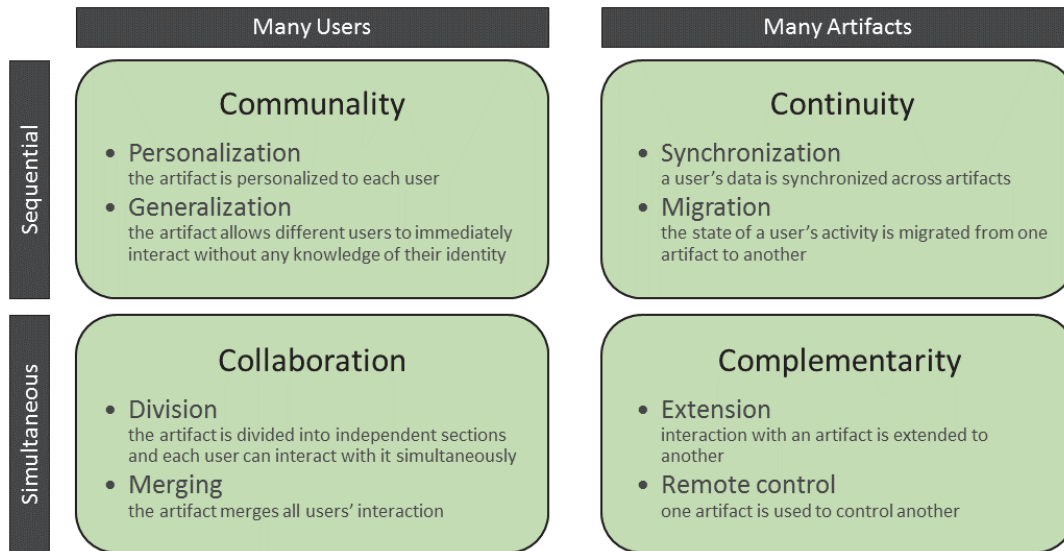
**Figure 3. The 4C framework of principles for interaction design in digital ecosystems**

The 4C framework combines the different structural relationships of many users and many artifacts with the differentiation between sequential or simultaneous interaction in a 2x2 matrix of four themes of communality, collaboration, continuity and complementarity. Under each theme we have identified and listed two specific principles of interaction design for digital ecosystems. While the four themes are meant to be comprehensive within the scope of the framework, the listed interaction design principles are not complete, but open for additions and refinements.

**Communality**

The first theme covers situations of sequential interaction involving several users. We refer to this as cases of *communality* in reference to communal computing where artifacts are shared between users, but with an emphasis on each user interacting with the artifact at a time. This could be in a public setting where communal computing has, for example, been used to describe computer resources made available in libraries [10]. The concept can however be applied widely to, for example, public displays or tablets shared among family members.

We have identified two distinct principles that facilitate communality in different ways. The first is *personalization,* meaning that the relationship between users and artifacts is individual and tailored to each person. A common example of this is the use of accounts or profiles on network services like Facebook, where each user has access to something particular to their person. The second principle is *generalization,* meaning that the relationship between the artifact and the users is not a personalized one but the same as for everybody else. We use the principle to describe cases where an artifact can be used immediately by anyone without "knowing" who the user is. This could, for example, be in the case of a ticket machine at a train station,

or the projector in a meeting room, which does not necessarily need to know who you are to provide its service or functionality. While this might seem trivial, we consider this principle as important as personalization because we believe that a decision to implement a generalization rather than a personalization principle can have great impact on how a digital ecosystem is perceived and used, and because forcing a user to login might sometimes be irrelevant.



**Figure 4. Personalization and generalization: Kodak's Facebook photo-printing kiosk, and a typical ticket machine**

**Collaboration**

The second theme covers situations of simultaneous interaction by many users, which we refer to broadly as cases of *collaboration*. Collaborative use of digital artifacts [16, 23] has long been a topic within the area of CSCW, and like this research field we use the term collaboration in a broader sense than describing just ways of working together and coordinating activities, to include all kinds of social computing situations for recreational and social activities. Broadly speaking, simultaneous collaborative interaction in a digital ecosystem is for the purpose of doing, or engaging in, a shared activity or task involving joint interaction with one or more shared digital artifacts.

**Figure 5. Division in a multi-player car racing game (left), and merging through shared controls on a mixing desk (right)**

Within the theme of collaboration we have identified two distinct principles of division and merging. *Division* means that the interaction with an artifact is split between users and provides them with individual parallel points of attention. The most common example of this principle is spatial partition of graphical user interfaces, such as split-screen views in multi-player video games, or large displays with separate workspaces, where people can interact independently through different views. Division can also be done by other means, such as separated audio channels, where different users hear different sound. The principle of *merging* means that several users' simultaneous interaction with an artifact is done "over the top of each other" through one shared representation. This could, for example, be in the case of a multi-user board game on a shared tablet where several users' interactions are merged visually into one, or the case of a large mixing desk where different people can jointly and simultaneously manipulate the sound of different instruments through merged physical controls.

### Continuity

The third theme addresses situations of sequential interaction involving several artifacts. We refer to this as cases of *continuity,* where an interaction starts on one artifact and then continues on another. This enables people to use several artifacts [31] and re-access content on a different device [2]. Such continuous interactions can be facilitated by keeping data consistent across artifacts, or by allowing activities started on one artifact to be continued on another one, exactly where it was left off.

Our framework describes two principles of continuity in sequential interaction within a digital ecosystem, namely synchronization and migration. The principle of *synchronization* simply means that data and data structures in a digital ecosystem is kept consistent across all devices. When an artifact synchronizes with an ecosystem, content and its organization is replicated to this artifact, and when changes are made on one artifact this is applied to all other artifacts as well [17]. Well-known commercial examples of the synchronization principle in digital ecosystems are "cloud-based" storage services like Dropbox, Google Drive and iCloud where one's files are automatically replicated, or made accessible, across devices. Other examples include email and calendar services that facilitate continuity in the interaction from one artifact to another by synchronizing information content. The principle of *migration* refers to the

well-researched ubiquitous computing concept of allowing users to switch between artifacts by transferring the state of their activity or interaction from one artifact to another, either partially or completely [3]. This is, for example, seen in Amazon's Kindle, where people can continue reading a book on one device from where they left off on another one. Another example of migration is Apple's AirPlay where one might browse media on an iPhone, and pass on its playback to a large display or sound system.



**Figure 6. Synchronization of media files using iCloud (left), and migration of media file playback using Airplay (right)**

### Complementarity

The fourth theme is about simultaneous interaction with multiple artifacts. We refer to this as *complementarity,* where interaction with one artifact adds to the interaction with another artifact, and these jointly make up a larger whole. This is similar to the concept of "composition" in cross-platform design described by Wäljas et al. [31], but with focus on simultaneous interaction, and the effect created when using several digital artifacts together as one.

We have identified two principles of complementarity in digital ecosystem interaction design. The first one is *extension*, which describes the case where one digital artifact directly adds to another one. This could simply be the use of several smartphones and tablets to create a larger display area [18, 20], or the use of what has been called a "companion app" to provide supplementary functionality for another device. As an example of this, Adobe's Nav App moves selected tools in Photoshop onto an iPad, making it work in a similar way to a painter's palette in concert with the canvas on an easel. The other one is *remote control,* where complementarity is achieved by one digital artifact simply controlling another, as is well known from traditional TV or sound system remotes. While perhaps seemingly trivial, this principle of interaction in a digital ecosystem is in fact very common, and many companion apps provide exactly this functionality for, for example, media players or home automation systems.



**Figure 7. Adobe's Nav App extending Photoshop onto a tablet (left), and a remote control App for a media center (right)**

## USING THE 4C FRAMEWORK

In this section we will demonstrate the value of the 4C framework for understanding an existing digital ecosystem, and for designing a new one. As an example of an existing digital ecosystem we have chosen the Netflix online video on demand service. Exemplifying the design of a new one we describe how the framework was used to design a multi-device shared music player system for parties or other social gatherings.

### Understanding a Digital Ecosystem: Netflix

Netflix is an online streaming service that allows users to watch various video content on different devices including PCs, smartphones, tablets, gaming consoles, and compatible TVs. Through subscription, Netflix provides a collection of movies and TV series that can be browsed online, removing the need for physical media and the need for users to download and store media content. The home screen and interface for browsing content is shown in Figure 8.



Figure 8. Netflix provides an interface designed for a large screen where the user can browse for video content.

Netflix is an interesting case for digital ecosystem research. It is sufficiently complex as the service can be distributed across many artifacts and users, but it is also appropriately simple as it focuses on a delimitated activity, and revolves around one primary type of content. As a case that involves multiple users and multiple artifacts, it can be used to illustrate the insights enabled by the 4C framework. We will do this by going through each of the four themes of the framework in relation to the interaction with Netflix.

#### Communality

Netflix supports communality through *personalization* but not through *generalization*. In order to access the service, users must purchase a subscription plan, which involves creating an account and using this to log in to the service. The content presented will then be tailored to the users profile, reflecting, for example, their geographical location and what has previously been watched. Extending on its ability to personalize the service, Netflix additionally allows up to five people in the same household to use the service individually within one subscription. This is done by creating additional user profiles within the same account (Figure 9), after which the recommendation engine is able to provide personalized suggestions to a particular user, facilitating communal use of the shared artifact.
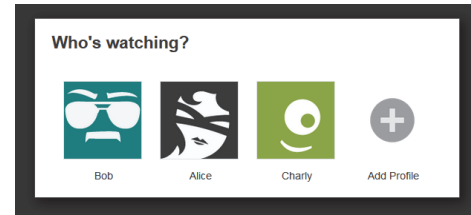


Figure 9. When accessing Netflix, the user can specify who they are, which influences what content is presented to them

Netflix does not make use of the generalization principle, as there is no mode where content is not tailored to a profile. Even before the profile-switching functionality was introduced, the service revolved around making suggestions through the recommendation engine based on preferences and viewing history. If one was to implement the principle of generalization in Netflix, this could be done by disabling the recommender system, or by basing recommendations on something other than personal preferences and history of interaction, for example, current topics or events.

#### Collaboration

Netflix supports collaborative aspects of use through *merging* but not through *division*. When several people are watching Netflix together, their combined interaction, for example through multiple remote controls, is merged onto shared artifact, typically a large display viewable by all. Hence they will have to coordinate and negotiate their joint interactions towards this shared point of focus. The merging of interactions, however, does not take into account the personalized profiles of the different people watching it together. Because only one profile can be active on the same device at the time, a group of viewers have to choose one of their profiles to use (Figure 10) and the content presented is therefore not tailored to the merged preferences of the group. Likewise, when watching Netflix as part of a group while using someone else's profile, this activity is not registered in ones own viewing history, and therefore not taken into account in later recommendations. As a common result of that, Netflix often recommend a movie or TV show that one have in fact already watched on Netflix.



Figure 10. Who's watching? When watching Netflix together in a group, people's individual profiles cannot be merged

Netflix does not use the division principle in its user interaction. If one was to imagine division in Netflix, this could, for example, be done through a picture-in-picture or

a split-screen view. While this would perhaps not be an obvious thing to offer in a service like Netflix, combining it with divided audio could enable different people to watch different content on the same large screen display. If the streaming service was extended to include live TV, division could also be used to facilitate the viewing of multiple sources by multiple people, for example during sports events with parallel games, or big news events. Using a split screen design could also enable divided interaction where one user could be watching a video on half of a large shared display, while another is browsing content, looking up information online, etc. on the other half.

*Continuity*

Netflix supports continuity in the interaction across several devices in sequence through both *synchronization* and *migration*. Continuous use from one artifact to another is supported primarily because Netflix synchronizes data for the individual user across different devices. However, because Netflix streams video rather than downloading whole media files to the user's individual devices, this synchronization is limited to metadata about what content has been flagged as watched, what ratings has been given, and so on. This means that the synchronization in Netflix is very lightweight compared to, for example, cloud storage services like Dropbox that replicate many gigabytes of files. In terms of user interaction, synchronizing lightweight data files, and streaming the heavy ones, means that the continuity between devices can happen very fast, and that each digital artifact in the ecosystem does not have to have a large local storage capacity. It does, however, also rely on being online and having a reliably fast Internet connection.

In addition to this, Netflix also supports continuity by allowing interaction to migrate between digital artifacts. This means that a user can, for example, start watching a TV show on an Apple TV the living room, pause it, and then continue watching it on an iPad in the kitchen, or a smart TV in the bedroom, from exactly where it was left (Figure 11). While this works very well for individual users, it becomes problematic, however, when several users are watching together using one of their accounts (as discussed earlier), or when a household decide to simply share one profile amongst them in order to overcome the lack of support for dynamic group watching.
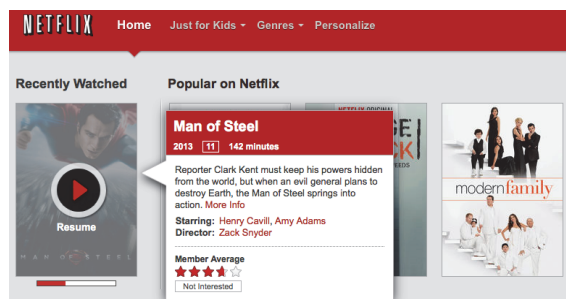


**Figure 11. Resuming recently watched content facilitates continuous interaction when migrating to another device**

Herein lies another opportunity for Netflix to modify the way the interaction with their digital ecosystem is designed. If a Netflix player knows the composition of the group of people watching it, then the continuous interaction between different Netflix players through synchronization and migration can be improved

*Complementarity*

The final features of Netflix as a digital ecosystem can be described as support for complementarity through *extension* and *remote control.* When interacting with Netflix through several devices simultaneously, these digital artifacts can be used to perform complementary functions extending the interaction space onto those devices (Figure 12).



**Figure 12. Complementing Netflix on a large display by extending the interaction onto individual smartphones**

If, for example, Netflix is accessed on a Sony PlayStation, smartphones on to the same wireless network can then be used to add new interaction capabilities, allowing users to pass on a video stream to the PlayStation, or to browse through the Netflix library for what to play next, without interrupting what is currently being displayed on the PlayStation display.

Finally, when accessing Netflix on a smart TV this usually involves not only the TV display itself but also a remote control for operating on-screen menus and controls (Figure 13). This complementary simultaneous interaction can both be done by traditional physical remote control devices, or through specialized "remote" Apps for smartphones remotely controlling video playback in a browser window.



**Figure 13. Netflix operation built into a dedicated remote control, and running as an application on a smartphone**

**Designing a Digital Ecosystem: MEET**

We will now change focus and demonstrate the use of the 4C framework when *designing* a new digital ecosystem. As a part of a previous research project we designed and implemented a prototype digital ecosystem for shared

music playback at parties or other social gatherings. The system, called MEET, seeks to enhance the experience of music listening in a social context by allowing users to share music from their own collection at home by streaming it over the Internet to a shared player at the party or gathering, and to influence what is played from the unified pool of songs available. This is done through the joint orchestration of several digital artifacts. While other shared music players allows users to directly control music playback, and access an enormous library of music, MEET facilitates a more social type of interaction around the music by reducing the amount of available music to only that in the personal collections of the people present, and by letting people nominate and vote for the songs to be played.



**Figure 14. Shared 42" display in the MEET ecosystem. The song in the middle is currently playing. Nominated songs float around the edges and grow in size as they are voted for**

MEET integrates several types of digital artifacts including a 42" situated and shared display for showing what is currently playing and nominated (Figure 14), shared tablets and personal smartphones for music nomination and voting, a PC for running the music player application, and several PCs at people's homes for hosting and streaming the actual music files. For more information about MEET, see [25].

The MEET prototype was designed using the principles of the 4C framework. In the following, we will describe some of the design considerations these principles inspired.

*Communality*
We designed MEET to support communality through both personalization and generalization. Personalization was achieved by letting people use their smartphones to share music from their collection at home, nominate songs to be played, and to vote for the nominated songs. In doing this, the interface on each individual smartphone is personalized to reflect ones own music library, nominations, and history of votes (Figure 15). Furthermore, when a song is playing, it appears on the shared display along with a photo and name of the people who nominated and voted for it, and the person (or people) whose music collection the song comes from. Our motivation for this particular design choice for the MEET digital ecosystem was that we considered smartphones to be personal devices, rather than shared ones. Exploiting this personal user-device relationship also made it possible to create a simple "gateway" between the shared music player and the personal music libraries at home of the individual people at the party.
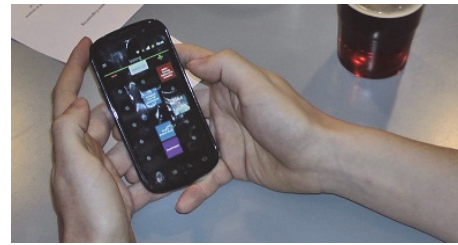


**Figure 15. Nominating and voting for songs through a personalized interface on one's smartphone**

While the personalized interaction is important in MEET, we also recognized early on in our design considerations that some people might not have, or have brought, a smartphone, or perhaps wish to interact in a more casual way than the one afforded by a personalized interface. We were therefore inspired to also explore the principle of generalization in the interaction design for MEET. In response we introduced an additional digital artifact to the ecosystem in the form of a shared tablet with a simplified version of the personalized smartphone interface. On this shared tablet, people could anonymously browse, nominate, and vote for music, without their photo and name appearing on the large screen display. By deliberately leaving out the personalization functionality, the tablet interface reduced necessary interaction steps and login procedures, which would constrain quick and smooth interaction, and made it possible to quickly pass the device around between people, and to nominate and vote for songs in a small group of people rather than only by oneself (Figure 16). This, we wished, would facilitate interesting social interaction different from that with personalized devices.



**Figure 16. Interacting with MEET as a group using a generalized interface on a shared tablet**

*Collaboration*
MEET was designed to support collaborative use through merging but not through division. Users interact socially through a large shared display, which shows information about the song currently playing, and the ones nominated for votes. This display is placed in a central location where it is viewable from most of the room and from a distance. Exploring the principle of merging, we deliberately designed the shared display to represent the combined interaction of all users, through nomination and voting for songs (Figure 17). The merged representation shows the current state of the music player with high-resolution album covers, and details about the song that is playing including

who nominated it, who have it in their music collection, and who voted for it. We also use the merging principle to reflect the current state of votes for nominated songs, by making album covers increasingly larger in size as votes are received for a particular song
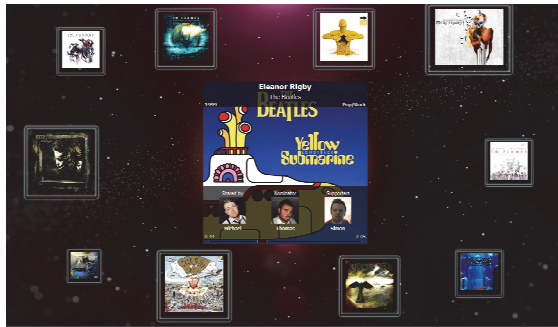


**Figure 17. Joint interaction with MEET merged into one shared interface representation of the music player**

The principle of division did not make it into the implemented version of MEET. In earlier design ideas we considered dividing the large shared display into smaller personal interaction spaces that could then be used for individual browsing and voting using either a touch screen for the large display, or using one's smartphone as a remote control. However, this idea was abandoned in benefit of using the principle of extension for providing additional specialized interfaces on smartphones and tablets.

*Continuity*
In terms creating continuous user interaction, we designed MEET to make use of both the principle of synchronization and migration. One of our very early design decisions was to synchronize the data structure of the user's music library at home, but not the actual media files, to their smartphone. We decided this for several reasons, firstly because this would limit the amount of data storage needed in individual devices. Secondly, we wanted to explore the possibilities of designing a music sharing system that does not violate copyright by illegally copy and exchange of files. The design discussions around the principle of synchronization led us to explore an approach where songs are streamed to the shared player, at the users' physical location, from a server application on their PCs at home containing the actual media files. The continuity in user interaction facilitated by this design is that people can manage and organize their music collection on one digital artifact at home, and decide what to "bring with them" to a party or gathering, and then continue this interaction on their smartphone when connected to the shared MEET player. As an alternative, some of our other design ideas included synchronizing actual media files between the users' PCs and smartphones, which is normal practice for many people, and then only streaming music "locally" between smartphone and the MEET player, in a similar manner as Apple's AirPlay. However, we found the streaming-from-home idea more intriguing to explore.

The principle of migration simply inspired the fundamental flow of interaction with MEET where the user uses several digital artifacts in sequence. Firstly managing their music collection at home on a traditional PC, secondly browsing music on their smartphone, and thirdly passing on nominated songs to a shared display, where others can then interact with them too through casting of votes.

*Complementarity*
The final design decisions for the interaction with MEET were informed by the principles of extension and remote control. As described before, rather than dividing the shared display into separate interaction spaces for different users, we chose to complement the display with companion apps on smartphones and tablets, and thus extend the interaction onto those devices. This makes it possible for several users, individually or in groups, to interact simultaneously with the player using a range of devices (Figure 18).



**Figure 18. Extending the MEET interface onto several devices for simultaneous complementary interaction**

Lastly, the design principle of remote control made us discuss what opportunities our music player presented for simply using one digital artifact to control another. In an early iteration of design, we considered simply including elements of remote control, such as volume and simple playback controls, in the companion app used also as extension of the shared display. However, since we did not actually wish to give all users that level of control, but rather restrict them to interact through nominating and voting, we deliberately limited the companion apps in that respect. Instead, we built *one* very simple remote control, intended for the host of the party or gathering, in order to provide a central point of controlling basic playback functionality, such as the volume and the ability to pause or skip to the next song.

**DISCUSSION**
We have designed and presented the 4C framework, which addresses interaction in digital ecosystems. We divide these interactions into four themes of communality, collaboration, continuity, and complementarity, which we have illustrated above through eight specific principles of interaction. While the primary contribution of our paper lies in the framework itself, and in our demonstration of its use for understanding and design, a secondary contribution lies within the design and research implications of our work on digital ecosystems. We will unfold these in the following.

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**Implications for Digital Ecosystems Design**

As we have become users of ubiquitous and networked digital artifacts, we believe that in order to design future systems well, we need to move away from the approach of designing for each individual component first, and then combining them. Instead, we suggest adopting the opposite, holistic, approach, where we start by looking at the digital ecosystem as a whole, and then move on to the specific artifacts. Our 4C framework is aimed at facilitating this holistic approach, by guiding/challenging/inspiring the designer through the four basic themes and their corresponding eight principles of interaction. As we have illustrated with the MEET case, the framework proposed could be used as a guide for designers to discuss possible interaction principles for a particular activity, and use this to decide what kinds of digital artifacts could meaningfully be part of the ecosystem.

At the same time, we believe that the possibility to combine the principles that we have defined can lead to design decisions and interactions that have not yet been seen. For example, in order for two people to watch a movie on Netflix they have to select one of their profiles, login to the system and enjoy the movie. But is this the only way of doing so? Why not *merge* their accounts as long as they are together and have a movie appear in both their account's history? Of course the Netflix example is a very simple form of a digital ecosystem, but nevertheless we believe that the basic principles that we have defined can be combined in ways that can be both innovative and very meaningful for the users.

Our framework also provides a mechanism where designers can break down complex digital ecosystems into more manageable parts and then focus on designing for them. Here we have addressed some of the challenges formulated by Rekimoto [24] on how to interact with multi-computer interfaces. We would like to stress though, that at the same time the challenges of deciding what artifacts to include in a digital ecosystem, and how they can meaningfully facilitate an activity, still remain. However these issues lie outside the scope of the framework, although they might be informed by a design discussion based on its themes and principles. Understanding users and the context in which an activity takes place is a fundamental challenge for every interaction design process. The 4C framework is based on that very assumption.

**Implications for Digital Ecosystems Research**

The 4C framework further introduces implications for research. While we have shown the applicability of the framework for designing a new digital ecosystem, the design principles presented have emerged primarily through analysis of existing digital ecosystems. Hence, an important research question is if the identified principles can be used for describing all interactions within a digital ecosystem. This is a question we cannot answer here, but we speculate that the presented principles are not complete, and that the

framework can be extended with more principles as they emerge or are identified. As more principles are added, the value and usefulness of the framework for understanding as well as designing digital ecosystems will increase.

Interactions with digital ecosystems are highly dynamic as they relate closely to the changing activities that people engage in. Thus, another research challenge is how we facilitate users switching between different digital ecosystems, or interact with several at the same time. Work in context-awareness, sentient computing, and activity recognition provide interesting potentials for dealing with this challenge, and we believe that this presents an opportunity for research synergy in relation to the development of new principles of interaction in digital ecosystems – and perhaps even for interaction with ecosystems of digital ecosystems.

**CONCLUSIONS**

We have presented a framework of interaction principles for digital ecosystems that helps identify and understand the different types of interactions that emerge in people's joint orchestration of multiple digital artifacts as larger wholes. Creating this framework has been driven by the question of what makes a digital ecosystem more than simply a collection of artifacts? The presented framework can be used to analyze and understand the interaction design of existing digital ecosystems, as well as inform design ideas, considerations and discussions when faced with the challenge of designing new ones. We have illustrated the themes and principles of the framework through a series of examples, and we have demonstrated the use of the framework for understanding as well as designing a digital ecosystem through two example cases.

The presented 4C framework provides new insight over existing frameworks by focusing specifically on the user-artifact *interactions* taking place in digital ecosystems, by describing, exploring and explaining these interactions. This focus complement existing application-oriented and theoretical work on multi-artifact interactions, and digital ecosystem thinking in HCI, such as existing work on ubiquitous computing using multiple devices, and the theoretical perspectives of Activity Theory and Distributed Cognition on artifact ecologies and group interaction, which we have outlined and discussed in relation to our own work. Focusing on the relationships between users and artifacts, we have been able to distil specific principles of interaction that can be applied to the design of digital ecosystems.

In closing, we would like to emphasize that we do not argue that focusing on single users' interaction with single digital artifacts is no longer important. What we argue is that the focus is widened to include, explicitly, a more holistic view on the multi-user multi-artifact interactions that happen within the ubiquitous computing environments and digital ecosystems emerging around us. We believe that our framework contributes a step in that direction.

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