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What is a Digital Ecology? Theoretical Foundations and a Unified Definition

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Abstract. There is an ongoing discussion in HCI on the need for new theories, methods and techniques to assist researchers and practitioners in both the design of better digital artifacts and effective evaluation of them. As part of this discussion we observe a recent trend where researchers from the IT domain present various definitions of ecologies, approaching the question, "What is a digital ecology?" from various perspectives. This paper reviews existing definitions, comparing their strengthens and weaknesses and presents a unified definition of *digital ecologies*, through a theoretical discussion based on systems thinking. It is our ambition that this paper will inspire deeper consideration on what constitutes a digital ecology and how this view of technology affects existing design and evaluation methods and techniques.

Keywords. Digital ecologies; systems thinking; process; structure; patterns of organization;

1 Introduction

Intelligent technologies are becoming an ever-increasing part of our daily lives. They provide us with opportunities, influence our habits and are constantly evolving our current practices. The kinds of interactions we enact with these new technologies are also rapidly changing, especially in the area of ubiquitous and mobile computing, such that practitioners and researchers are constantly being challenged. Practitioners try to keep up and become familiar with new technological advances in order to design and produce new hardware and software, or as we call them, *digital artifacts*. On the other hand, researchers are challenged on how to apply/transform existing theories, methods and techniques. At the same time the users are also evolving. They are constantly interacting with digital artifacts, using many different applications on a variety of devices. These users are by no means passive receptors of information. Most of them are technologically educated, have high expectations and intentionally select which digital artifacts to include into their everyday life.

At the same time there is an ongoing discussion in HCI research in relation to the need to create new methods and techniques for designing and evaluating digital artifacts [1, 2]. With the coming of 3rd wave HCI [2] and recent shifts towards interaction design and user experience, HCI has embraced new theoretical directions. Notions like attractiveness, pleasure, value, etc. have became significant factors in both the design and evaluation of digital artefacts. With these new approaches to designing and evaluating digital artifacts comes the realization that these intelligent technologies do not always exist or operate in isolation, but are rather part of a collection of devices and software that operates together and even interdependently. Often such sets of related technologies and user are referred to as an *ecology*. In searching the HCI Bibliography literature though, we observe that the term *ecology* has various and differing definitions. This variety of definitions shows that HCI is evolving and the fact there are so many alternative perspectives provides a basis for our discussion in this paper. When theoretical concepts are introduced into a research field like HCI, in the beginning many different perspectives are discussed and put forward by different researchers, then, over time common ground is established. This paper contributes to this evolution towards a shared definition of what is meant by *digital ecology*, and how this view affects existing design and evaluation techniques and methods for intelligent HCI design.

This paper is structured in the following way. Initially we present a discussion on what is an ecology/system in general, we elaborate on the different types of ecologies and their fundamental properties, and then we present how the term ecology is used in HCI and the broader Computer Science field. Afterwards, we provide a discussion on the different definitions of ecologies from our literature review and conclude by presenting a unified definition of a *digital ecology*.

2 Background

Systems' thinking is the basis for the theoretical discussion of this paper. Systems thinking (or ecological thinking) emerged during the 1920s in various scientific disciplines [4]. According to the systems' view, the essential properties of an organism, or a system are the properties of the whole that none of the parts alone have [4]. This signifies, according to Aristotle, that "*the whole is something besides the parts*" [6]. The study of these emergent properties [5], which are meaningless for the parts, but crucial to the whole, constitutes the basis of the ecological way of thinking.

Ecologies can be described through the network metaphor: "*Ecology is networks… To understand ecosystems will be ultimately to understand networks*" [15]. The network metaphor implies that every ecology can be understood as nodes that interact among each other through relationships. Furthermore, each node can be perceived as a network itself and the ecological way of thinking focuses on understanding the emergent properties of a network.

Ecologies are characterized by three properties: *process*, *structure* and *patterns of organization*. Capra [4] defined these properties by adding the notion of *process* to Santiago's Theory of Cognition, which was proposed by Maturana et al. [13]. According to Capra, "*Patterns of organization are the configuration of relationships among the system's components that determine the system essential characteristics. In other words, certain relationships must be present for something to be recognized as –say- a chair, a bicycle, or a tree… The systems' structure is the physical embodiment of its organization*". Both Capra [4] and Checkland and Scholes [5] use the same bicycle example in order to explain the system/ecology concept. If we think of a bicycle as an ecology then the different physical components (pedals, brakes, etc.) constitute its *structure*. The *patterns of organization* are the configuration of relationships among these physical components. These patterns of organization define that the ecology we are observing is a bicycle and we can find the same patterns embodied in many different structures, for example a city bike, a racing bike, or a mountain bike. *Process*, according to Capra is the way these patterns of organization are created/emerge in order to form structures. Process is also the key characteristic in separating between two types of ecologies: *living* and *non-living ones* [4]. In the bicycle example, which is a non-living ecology, the process of creating the patterns of organization lies in the designer's head (outside the ecology). Designers create sketches that describe the components of a system, produce diagrams and flows that describe the relationships between the components and the process of creating those exists outside the actual ecology. On the other hand, in a living ecology like, for example, the human/user we are designing for, the process of creating the patterns of organization lies in the ecology itself. Consequently, the fundamental difference between living and non-living ecologies is that a living ecology is *autopoietic* [13] because the patterns of organization emerge from the ecology itself through feedback loops and can even alter the structure of the ecology.

Since HCI is dealing with the design and evaluation of digital artifacts we can use the term *digital* in order to specify the special case of non-living ecologies that include digital artifacts, which are defined and developed by practitioners and designers. The following section presents the definitions of digital ecologies that we located in a literature review.

3 Ecologies in HCI

Ecological ways of thinking are not new to HCI (for example [17, 14]). Recently though we observe that many researchers present their own views on what is a digital ecology. One of the most influential definitions of an ecology was provided by Forlizzi [8] defining a ***product ecology***, "*The product ecology is an interrelated system of a product, surrounded by other products, often acting as a system; people, along with their attitudes, dispositions, norms, relationships and values; products; place, including the built environment and the routines and social norms that unfold here; and the social and cultural context of use… Each product has its own ecology; the components of the product ecology are interconnected in several ways…*"

Forlizzi [8] positions at the centre of her definition the product: the digital artefact. Her theoretical starting point is social ecology theory, which focuses on the social use of products/artefacts. According to her view each digital artefact creates its own ecology and all the relationships with other products, users and places, as well as social norms and routines, are part of this ecology. An alternate view was introduced by Jung et al. [10] in their definition of a ***personal ecology***: "*We define a personal ecology of interactive artefacts as a set of all physical artefacts with some level of interactivity enabled by digital technology that a person owns, has access to and uses*". Their focus is on the actual use as they try to provide means to understand how users interact with and use various digital artefacts in their personal lives. Their theoretical foundations of mainly lie in the artefact concept.

Successfully applied in the HCI field by Nardi and O'Day is the notion of an ***information ecology*** [14] defined as: "*a system of people, practices and values and technologies in a particular local environment*". They position information at the centre of their definition as they study the complex relationships between humans and digital artefacts and incorporate activity theory as their theoretical foundation. Their focus is not only on technology, but also on users' activities and they argue that information ecologies are (re)designed as the members of an information ecology shape new practices and new technologies. The same theoretical foundations are also used by Bødker [3] as she incorporates activity theory and *personal ecologies* [10] in to the human-artefact model.

An approach that draws inspiration from nature comes from Vyas and Dix [18] who say that, "***Artefact ecologies** refer to a system consisting of different digital and physical artefacts, people, their work practices and values and emphasis on the role artefacts play in embodiment, work coordination and supporting remote awareness*". Some definitions try to relate ambient and ubiquitous computing with ecologies using more general and descriptive approaches. For example, Goumopoulos and Kameas [9] state that, "***Ambient ecologies** is a space populated by connected devices and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way.*" Resmini and Rosati [16] define, "***ubiquitous ecologies** as emergent systems where old and new media and physical and digital environments are designed, delivered and experienced as a* *seamless whole*". Enquist et al. [7] focus on ***interaction ecologies*** as, "*constituted as a functional set of artefacts, people and the surrounding environment, in combination with the rich interaction between people and devices we identify as an interaction ecology*". Some have a more technical perspective: Marquardt [12] defining a ***ubicomp ecology*** as a "*collection of large interactive spaces, information appliances, portable personal devices and non-physical objects*"; Wang and Deters [19] defining ***service ecologies*** "*composed of autonomous service consumers and autonomous service providers*"; and Indrawan et al. [11] defining ***device ecologies*** as, "*the whole interactions of the information appliances, human and its environment such as temperature, humidity, and time are the make up of a digital ecosystem*".

4 The three Structural Levels of Studying Digital Ecologies

Three of these definitions of ecologies have a strong theoretical starting point: *product ecologies* [8], *personal ecologies* [10] and *information ecologies* [14]. The first two, although having different focuses, constitute two sides of the same concept. Both approaches provide us with a lens to study digital ecologies. *Product ecologies* focuses on the product and generalizes by studying how different users interact with it, while *personal ecologies* focuses on a single user and generalizes by studying how different artifacts (products) are used by a single user. According to Jung et al. each of the users we are designing for experience their own *personal ecology* comprised from all the digital artifacts they interact with. These artifacts might belong to them, to the company they work for, might be public, etc. Thus, we can characterize a *personal ecology* as a network where the nodes are comprised by all the digital artifacts a user may interact with, including the user himself (Figure 1).

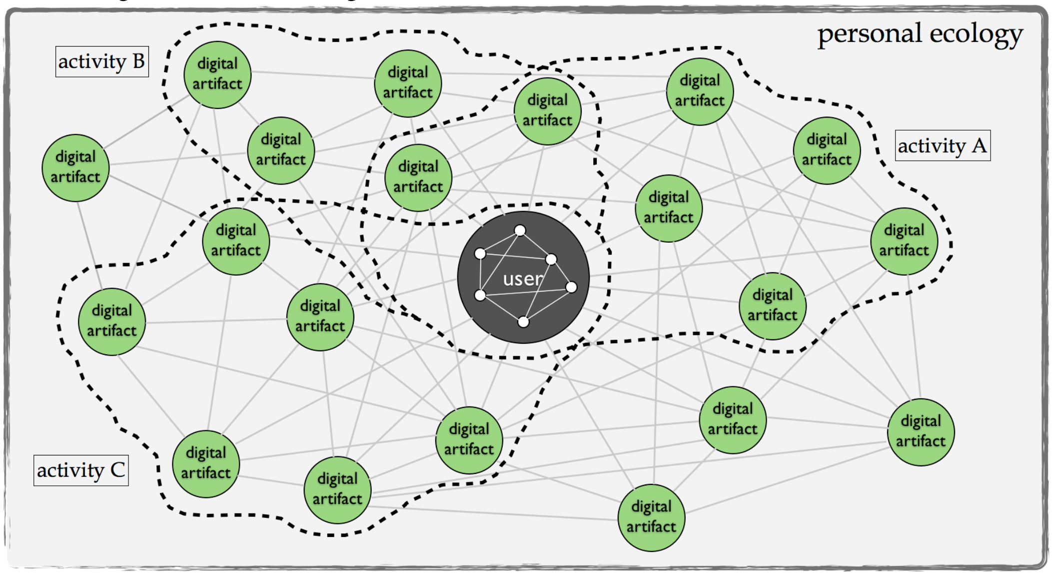

Fig. 1. A user's personal ecology as a network with interrelated nodes.

Jung et al. [10] propose that each user owns one *personal ecology* that is transformed, either by adding new digital artifacts (new nodes), or by changing the relationships between existing nodes. The patterns of organization between these digital artifacts and the structure of the *personal ecology* can be defined by designers, by the user, or both at the same time. Thus, we can find a set of digital artifacts that designers develop to be operated in a certain way (for example the family of products created by Apple™), or we can have the case where users enhance their everyday life with applications, services and hardware from various manufacturers and they decide the relationships among them. *Product ecologies* on the other hand focus on a single node of the *personal ecology*, the digital artifact. Therefore, for Forlizzi [8] an ecology is defined by selecting one digital artifact and studying it across many users' *personal ecologies*. For a single *personal ecology*, Forlizzi focuses on one digital artifact, unveiling its relationships with the rest of the nodes.

Using Figure 1 as a starting point we can see that the previously mentioned definitions fit the same picture. Maturana and Varela [13] focus on a single node of the network: the living system, which in our case is our intended user. Forlizzi [8] focuses on another node of the network: the digital artifact. We define the study of a single node of a user's *personal ecology* as the first structural level of digital ecologies. We argue that studies that are focusing on the first structural level are extremely effective on understanding in depth how a digital artifact is experienced. Jung et al. [10] focus on the whole *personal ecology* and we define that as the as the third structural level of digital ecologies. We believe that research that focuses on this level is extremely useful in understanding how technology is incorporated in to the everyday life of individuals.

The rest of the definitions are descriptive and try to define new digital ecologies by describing a subset of a user's personal ecology. We define these subsets as the second structural level of digital ecologies. The difference between the definitions that belong to the second structural level lie in the way the boundaries of the ecology are defined. The three structural levels of studying digital ecologies is depicted in Figure 2. All of them use the digital artifacts themselves as a means to specify the network boundaries. For example, a new *ubicomp ecology* [12] for a museum is defined by the installed/used digital artifacts, in this case, the boundaries of the network lie within the boundaries of the digital artifacts. This approach is limited and we argue that although not helpful in designing new ecologies, it is very helpful in describing them. We therefore propose that the most suitable way of defining the boundaries of a new digital ecology is the *activity* a user is engaged in, an approach which is also adopted by *information ecologies* [14]. When designers define new structures through their sketches and specify the relationships between components they are attempting to create a new network of nodes. The boundaries of the network can be specified by the *activity* they are designing for. In Figure 1 we see how different sub-networks are created (either by designers, or by the user himself) inside the *personal ecology* [10] of a user with their boundaries determined by an activity.

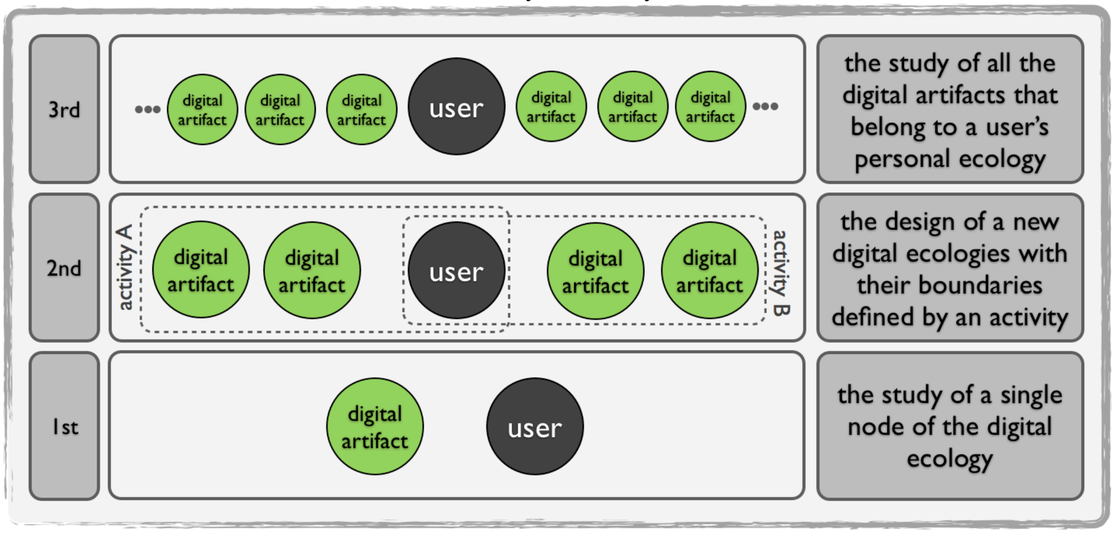

Fig. 2. The three structural levels of studying digital ecologies.

5 A New Digital Ecology Definition

Given our definition of the three structural levels of studying ecologies we can provide a definition of a digital ecology. Almost all previous definitions contain notions like *environment*, *value*, *meaning*, *practices*, etc. In adopting the systems view of an ecology as a closed network of nodes, which can be influenced from external environmental parameters, it is clear that such notions do not belong to a digital ecology definition. Therefore, we propose that *environment* is not part of a digital ecology. It may influence the way a digital ecology behaves, or how a user perceives it, but it is not an intrinsic part of a digital ecology. The same is the case with notions like *temperature*, or *time*. Additionally, notions like *value*, *meaning*, *space*, etc., are also not part of the digital ecology, but properties of the *activity* and/or the *user*.

We will illustrate our argumentation by using an example of designers wanting to create a new digital ecology to enhance the activity of "visiting a museum". The designer's aim is to specify which digital and non-digital artifacts will be included in the ecology (define the structure) and how these nodes will interact with each other (define the patterns of organization). The first step they need to take is to specify the boundaries of the network by defining the boundaries of the activity. When does the activity of visiting a museum start? Is it when visitors enter the museum, when they ask their friends to go to the museum, or when they are at home checking the museum website? The boundaries are specified by the *activity* as it exists in the designers' minds. Therefore, does the surrounding environment (sound level, light, etc.) that one experiences while being inside the museum belong to the digital ecology? We believe this is not the case. Such parameters influence the way the digital ecology is perceived and experienced (and thus need to be taken into consideration), but are not constituent parts of the ecology. They are simply external parameters that belong to the environment and may affect the ecology. Does the digital ecology have meaning and value? We believe not. The users find meaning and value as they engage in a specific *activity* with, or without technology. In the case of the museum visit, the design of the patterns of the organization among the network components allows for meaning and value to flourish, but these are not intrinsic properties of the ecology.

Therefore, we define a ***digital ecology*** as: "*A closed set of digital and non-digital artifacts and a user acting as nodes of a network where its boundaries are specified by an activity and the structure and patterns of organization are either user and/or designer defined*." This definition is narrower than *personal ecologies* [10] and we argue that it is more useful for practitioners and designers when trying to define/design new digital ecologies. For us a *digital ecology* is always a subset of a user's *personal ecology* and belongs to the second structural level. It is created, either by inserting new digital artifacts in to a user's *personal ecology*, or by changing the patterns of organization among existing ones.

6 Conclusions

Motivated by the existence of various definitions of digital ecologies, we conducted a review and discussion in relation to their theoretical foundations, their weaknesses and strengths. We presented a unified way to view these definitions by categorizing them into three structural levels and proposed a new definition of what constitutes a *digital ecology*. In our definition we argue that a digital ecology is a network comprised of digital and non-digital artefacts and a user, acting as nodes, where its boundaries are defined by an *activity*. Users may experience many digital ecologies, as they are engaged in various activities, but all of them are a subset of their own *personal ecology*.

In general we believe that intelligent HCI design will benefit from embracing the ecological way of thinking, just as other scientific fields have benefited from the notion that the whole is more than the sum of its parts. HCI is progressing in this direction and this in turn creates opportunities for new methodologies and techniques that can facilitate this holistic point of view and result in both the design of better digital artefacts and effective evaluation of them.

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