Visual and Functional Adaptation in *Ad-hoc* Communities of Devices

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Abstract
In this position paper, we introduce our vision of interacting with future ubiquitous computing. It is based on a *visual* and *functional* adaptation of user interfaces to the presence and proximity of devices and users. We believe that this kind of adaptation based on proxemics is the key to a more social, natural, and usable interaction with digital technology. We discuss the promise of this novel style of interaction and its challenges based on previous and related work.

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Proxemics; multi-device; multi-display; mobile devices; ubiquitous computing

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

Introduction
Based on the idea of Greenberg et al.'s *proxemic interactions* [2], we are convinced that we can achieve a new quality of human-computer interaction (HCI) by letting devices adapt their visual presentation of content and their functionality to the current spatial configuration of neighboring devices and the presence of users. In particular, our vision is to enable users to create *communities of devices* in an *ad-hoc* fashion, as

we have formulated in [6]: "All devices contribute their different input and output capabilities for the common goal to provide users with a seamless, usable, and accessible UI. Users should experience this community of cooperating devices as a single UI that always makes optimal use of the currently available interaction resources in the environment, e.g., available displays, pen/touch/speech input, tactile output. Ideally such a community 1.) automatically adapts to the many possible changes in the kind and number of available devices, their spatial configuration, and the number of users, 2.) is robust against breakdowns or loss of interaction resources, and 3.) readily adds or removes further interaction resources and devices. Furthermore, users should not be concerned with configuration and setup anymore. Instead this happens implicitly as a by-product of normal use (e.g., bringing multiple devices to the same room, placing them side-by-side and shifting them around, handing them over to others)."

Promises of *Ad-hoc* Communities of Devices

The promises of *ad-hoc* communities based on proxemic interactions are manifold: For example, in previous work, we envisioned how multiple tablets can be joined to become an *ad-hoc* interactive tabletop [6] and thus can reintroduce the benefits of natural around-the-table-collaboration into work and play without expensive tabletop hardware. Such an around-the-table style of collaboration based on multiple tablets appears very promising because it can support different working styles and smooth transitions between tightly-coupled collaboration and loosely-coupled parallel work including private views [21]. Potentially, it can also turn tasks such as collaborative searching, negotiation, and decision-making into a fun and social experience [5]. With Twister Search [17], we have already shown how a combination of tablets and a tabletop can be used to facilitate collaborative search. In a next step, we want to realize a similar system only based on multiple co-located tablets. This resonates with Lucero et al. who argue for mobile collocated interactions, e.g., with multiple smartphones, to overcome the antisocial consequences of today's mobile phone use where devices become substitutes for connecting with each other face-to-face [10]. They believe that co-located interaction with mobile phones could be the key to reestablishing and enriching face-to-face physical interactions. These face-to-face physical interactions are also desirable in the context of our research goals for future sustainable and connected cities[1]: We want to use computing technology to foster social connectedness and collaboration among co-located city dwellers and by this follow Weiser's original vision of a ubiquitous computing that poses no barriers to personal interactions but brings communities closer together [22].

Apart from this social aspect, there are also economic and ecological considerations that motivate our research in this field: First of all, mobile devices are widely available within real-world environments (e.g., schools, libraries, pubs, future cities) and not only in research labs or high-tech studios with tabletops, large screens, or motion capturing systems. This is particularly true for organizations, communities, or countries where financial resources are scarce. Since mobile devices are already produced in large quantities they are far cheaper and, in many respects, more robust than large touch screens, interactive tabletops,

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[1] http://www.cities.io/project-themes/enabling-connected-communities/

or other collaborative and shareable user interfaces. Nevertheless their interactive and computational resources are now getting powerful enough to enable demanding scenarios of use, e.g., a multi-device environment for searching, visualizing, and making sense of large information spaces. Additionally, an *ad-hoc* community also makes better use of all available resources and thus is more sustainable and cost-effective and does not waste computing power and raw materials by leaving the personal mobile devices mostly idle in our pockets.

However, there are also great research challenges that we have to address before we can deploy such systems in the real-world. In the following, we will introduce two challenges based on previous and related work and to better structure the problem space.

The Challenge of Sensing Proximity

For *proxemic interactions*, it is necessary to track proxemic dimensions such as distance, orientation, movement, identity, and location of devices and users [2]. Therefore the first challenge is to sense such dimensions with mobile, low-cost solutions that only need a minimum or no instrumentation of the environment, the devices, or the users.

Computer Vision

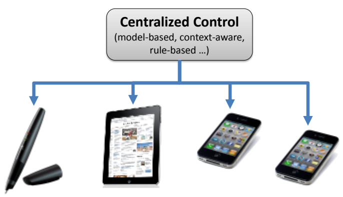
Today's toolkits for proxemic interactions (e.g. [11]) typically use advanced vision-based 3D motion capturing systems from Vicon or NaturalPoint. These systems are powerful, fast, and precise, but also very expensive and must be installed and calibrated in each room. Therefore they are not an option for *ad-hoc* usage scenarios at different locations. A cheap alternative are low-cost depth cameras such as the Microsoft Kinect. However, in spite of first successful uses of depth cameras for this purpose [19], we believe that the existing SDKs still do not enable a reliable tracking of individual users and/or devices without a great development effort and great expertise in computer vision. Other vision-based approaches like [7] let mobile devices display fiducial markers or color transitions as identifiers, so that a camera facing the devices can determine their size, position, and orientation to create tiled displays. However, users cannot move the displays anymore after this process without having to repeat it. Another vision-based technique is letting mobile devices locate themselves by detecting a marker with their front facing cameras, e.g., a marker on the ceiling [8]. This might prove difficult in real-world or outdoor scenarios without prepared ceilings. It also necessitates a calibration phase to establish the initial spatial relations and its accuracy in real-world scenarios is still unclear.

Ir, RFID, NFC, and Radio Signal Trilateration

Non-vision-based approaches use wireless radio signals, e.g., using NFC [9] or Qualcomm SRCT [12], that can reveal a device's position and orientation relative to one or multiple receivers, e.g., by using multiple tags or signal trilateration. Other approaches use multiple magnetic sensors [4] or infrared IrDA transceivers [13] that are attached to each edge of a device to detect whether there is another device with the same sensors lying directly next to it or not. However, all these approaches suffer from either having to attach sensors to the mobile devices or having to rely that certain radio transceivers are built into a device, which is not the case for the great majority of popular mobile devices (e.g., Apple iPad or iPhone).

Centralized Control vs. Emergent Behavior

In traditional *top-down* design, the desired behavior is defined in models or rules that are used to control the global state of the device community. A centralized control is in charge of executing and applying them.



In self-organizing *bottom-up* design, the global behavior of the community emerges from numerous rule-based local interactions between the devices and is based primarily on local information instead of global information.

Source: [6]

Co-located Binding Gestures: Bump and Stitch

In conclusion, there is no sensing technique yet that enables a real-time, precise tracking of proxemic dimensions of multiple devices and users and does not necessitate an instrumentation of the work environment or the devices and an initial calibration phase. In our projects, we will therefore use a hybrid approach that uses data about the presence and identity of devices in a room (e.g. based on sharing the location data that is provided by mobile operating systems) together with interactive binding gestures to establish spatial relations. We will use pairing interactions such as "bumping" devices into each other or using stitching gestures with fingers or pens across screens as already introduced by Hinckley et al. in 2003 [3]. Commercial products such as Bump [1] or research prototypes such as MIT's Swÿp [20], mosaic.io [14], or Pinch from the Tokyo University of Technology [15] use similar techniques and can be considered applications of Hinckley's pioneering work.

In contrast to real-time tracking of proxemic dimensions with motion capturing, the precision and time resolution that we will achieve this way is of course very limited. However, combinations of location data, bumping, and stitching gestures still reveal which devices are placed next to each other and their relative position and orientation at the time of stitching. We believe that this will be enough for exploring first scenarios of *ad-hoc* communities of devices.

The Challenge of Proxemic Interaction Design: Top-Down or Bottom-Up?

As we discuss in [6], in our vision of future HCI, many co-located interactive devices are joined into an *ad-hoc* community of devices that serves users as a single usable and seamless UI. Thereby, we want to make use of the principles of *self-organization* to achieve the same degrees of improved adaptability, scalability, and robustness that have been observed when using *self-organization* for the engineering of other information systems in the past [16]. "*Self-organization* can be observed in many biological or natural systems and often leads to an almost magical and nearly optimal use of resources that is not result of an external ordering influence or a top-down design. For example, *self-organization* can be observed in flocks of geese: By following simple rules based on local information like the line of sight and air drag, each goose reacts individually to changes in the flock and the sum of theses reaction results in forming a V-formation. This bottom-up emerging behavior greatly improves aerodynamics and the range of the flock" [6].

In [6], we also discuss that in a *self-organizing* UI, the UI has to react and adapt to each possible configuration and change in the environment without a centralized control as an "external ordering influence". Instead the desired behavior emerges from the execution of many local rules defining proxemic interactions between devices and users. "The more these rule sets focus only on local information and avoid reference to a global pattern, the more the device community will react sensible and stable to unpredictable changes in the environment. Thereby an illusion of "intelligent" behavior is achieved without the need for upfront abstract modeling of each possible state or solving problems of (semi-)automatic generation of UI design or strong AI. Our hope is that by defining simple rules of adaption based on proxemic interactions between devices, the deterministic preciseness of classic *top-down* design and modeling is traded in against less controllable, but more adaptable, robust, and scalable *bottom-up* designs that introduce a certain degree of vagueness but automatically adapt to the dynamics of ad-hoc real-world usage" [6].

With regard to the software representation of these rules within each device, we imagine to use novel, non-imperative programming models. For example, based on our work on Reactive State Machines that define interactive behavior using finite state machines [18], we could imagine a reactive state machine on each device that receives and processes all kinds proxemic or non-proxemic interaction events. Another approach could be to explore the use of functional programming languages such as F#.

Conclusion

In this position paper, we introduced our vision of interacting with future ubiquitous computing. This vision is based on a *visual* and *functional* adaptation of user interfaces to the presence and proximity of devices and users. By this, we want to enable users to create *ad-hoc* communities of mobile devices which could reestablish and enrich face-to-face physical interactions in different environments, e.g., in future connected and sustainable cities. We believe that this kind of adaptation based on proxemics is the key to a more social, natural, and usable interaction with digital technology. For this adaptation, we hope to make use of principles of *self-organization* to achieve a bottom-up design that helps us to achieve the same degrees of adaptability, scalability, and robustness that have been observed when using *self-organization* for the engineering of other information systems in the past.

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