Research Article

Andrii Matviienko*, Abdallah El Ali, Christin Hilmer, Yannick Feld, Wilko Heuten, and Susanne Boll

Designing Metaphor-Based Ambient Tangible Artifacts to Support Workspace Awareness

Abstract: Current asynchronous (e. g., email) or synchronous (e. g., video-conferencing) communication methods in the workspace can be obtrusive and fail to mimic spontaneous interpersonal communication. This can cause difficulties in forming close relationships among working colleagues. To examine this problem, we conducted a needs assessment study consisting of an online survey, a focus group, and a co-design session to gather a set of system requirements and metaphors as a base for future system designs. Based on the results, we designed two metaphor-based ambient tangible systems to support awareness among working colleagues: *AwareCups* and *AwareHouse*. Furthermore, we evaluated these systems in a short field study with 22 participants and found that both systems are highly intuitive and easy to use. We discuss the solution space for metaphor-based tangible awareness systems and the effects of the outcomes on the potential increase of awareness among colleagues.

Keywords: Workspace awareness, ambient tangible artifacts, metaphor-based design, implicit communication

1 Introduction

Existing asynchronous and synchronous communication methods can be obtrusive and lack interpersonal communication cues. For example, on-screen notifications from electronic calendars [17], desktop pop-up applications and smart phone reminders are widely used nowadays as awareness and notification systems, but they can suddenly disrupt and leave workers with unfinished tasks [1]. To overcome these problems, we employ a combination of metaphors and tangible awareness systems.

Paul Watzlawick formulated the first axiom of communication: "You cannot not communicate" [70]. Thus, even if people do not intend to explicitly communicate, their behavior and actions, e. g., opened/closed door of their offices or light in windows, implicitly express information that can be perceived and interpreted by another person – we call these expressions *implicit cues*. Since implicit cues provide an additional information about a situation and help avoiding interruptions, we decided to use their advantages to represent lacking interpersonal communication cues via *metaphors*. In our work, we refer to metaphors from people's social, behavioral and communication experiences, since we aim to enrich awareness systems with interpersonal communication cues [31]. Metaphors have a rich tradition in Graphical User Interfaces (GUI) design (e. g., Desktop, iTunes Music Library) and previously used in GUI research [55], and remain a central element for user interfaces, particularly in human-computer interaction [10]. They are known for simplifying an understanding of systems' functionality and providing known interactions and communication paradigms for screen-based interfaces [13, 27, 45]. Therefore, we aim to better understand awareness needs and the solution space for metaphor-based artifacts.

Within the scope of this work, we focus on one kind of awareness – *workspace awareness* – the collection of up-to-the-moment knowledge of another person's interaction with a shared workspace [24]. Workspace awareness involves knowledge regarding the location and current/future activities of others [25]. To increase workspace awareness and to prevent disruptions of workflows at workspace, we aim to build systems that can be integrated seamlessly into working environments and convey information to a user unobtrusively, without overloading a user with additional information [71].

Newly emerged awareness system allow people to be aware of each other's presence [54, 15, 69], location [39],

*Corresponding author: Andrii Matviienko, University of Oldenburg, Oldeburg, Germany, e-mail: andrii.matviienko@uni-oldenburg.de
Abdallah El Ali, University of Oldenburg, Oldeburg, Germany; and CWI (Centrum Wiskunde & Informatica), Amsterdam, The Netherlands, e-mail: a.elali@cwi.nl
Christin Hilmer, Yannick Feld, Susanne Boll, University of Oldenburg, Oldeburg, Germany, e-mails: info@christin-hilmer.de, yannick.feld@uni-oldenburg.de, susanne.boll@uni-oldenburg.de
Wilko Heuten, OFFIS – Institute for Information Technology, Oldeburg, Germany, e-mail: wilko.heuten@offis.de

activities [57], or even emotional states [67, 68]. More-over, *tangible* awareness systems are considered to be more intimate and aesthetically pleasing in comparison to screen-based awareness systems [65, 66]. Therefore, our approach relies on tangible systems, since they are also known to facilitate the smooth transition of attention between foreground and background [37, 36], thus enabling users to be peripherally aware. We also decided to focus on systems with a working mapping of one-to-many (e. g., emails, instant messages, etc.), since this is most common in office environments. Due to the nascent nature of our work, we focus on tangible awareness systems based on metaphors that represent implicit interpersonal cues for a single person in a private environment. This brings us to our research question: How can we support the design of metaphor-based tangible awareness systems for potential interaction with working colleagues?

To explore this design space, we followed a Human-centered design approach [16], where we initially collected a set of information needs, scenarios, system requirements and metaphors from an online survey, a focus group, and a co-design session. Further, we designed two tangible ambient awareness systems based on metaphors and resulting system requirements, which convey information needs about other colleagues in an unobtrusive manner. Finally, we evaluated both systems in a field study with 22 participants and showed that they are highly intuitive and easy to use.

Our two main research contributions are:
1. We provide an understanding of awareness needs and the solution space through a systematic methodological process to support the future development of tangible awareness systems based on metaphors.
2. We present two metaphor-based designs for awareness tools and show that they provide intuitive interaction and ease of use in a proof of concept evaluation.

2 Related Work

We build on two pillars of related work: (1) metaphors in HCI and (2) ambient tangible awareness systems. In the following subsections, we address prior work in these two areas.

Metaphors in HCI. Metaphor as a notion has originated in linguistics and is often used to indicate words with more than one meaning [64]. Lakoff and Johnson extended this term by presenting *linguistic metaphors* as "understanding and experiencing one kind of thing in terms of another" [42]. They outlined metaphors not only as an essential part of language, but also as a tool of thinking and experience. Further linguistic analyses showed that image schemas can serve as a source of new metaphors [41] and can inspire HCI to contribute to new user interfaces [34]. Image schema is an abstract representation of recurring dynamic patterns of bodily interactions that structure our understanding of the world [46]. Given the power of image schemas for generating new metaphors, Hurtienne and Israel [35] introduced a taxonomy of tangible interaction via image schemas and their metaphorical extensions. They showed that one can use metaphorical extensions to broaden new areas of tangible interfaces.

Following the advantages of image schemas due to recurring dynamic patterns of bodily interactions, Low [43] was further investigating *embodied metaphors* – human abilities of projecting the structure of bodily originating schemata onto a conceptual domain [42]. As shown by previous works, embodied metaphors play an important role for supporting physical interaction and object manipulation in augmented spaces [6, 7]. Bakker et al. [7] explored embodied metaphors by introducing a people-centered iterative approach for designing interactive learning systems, and showed that tangible systems based on embodied metaphors can clarify an interaction via affordances.

In general, the idea of using a metaphor to transfer knowledge and experience from real life into user interface design has been around as long as user interfaces existed. The strength of a metaphor is in making the learning of a system's interface easier and more effective [12] – what makes them useful and operational. After the introduction of the Macintosh graphical interface, the concept of *interface metaphor* became widely used as a guideline for design in human-computer interaction. For example, Alan Kay's concept of a person computer was a Dynabook, "a self-contained knowledge manipulator in a portable package the size and shape of an ordinary notebook" [22]. The metaphors of "desktop" and "typewriter" were particularly robust and were quickly adapted for the design of operating systems and word-processing programs accordingly. Metaphors are also a fundamental notion for skeuomorphs [23] – "objects copied from a form of the object when made from another material or by other techniques", which refer to an earlier medium or known interaction.

To better integrate tangible interfaces with conventional interfaces and suggest new design principles for future designs, Fishkin presented a taxonomy which describes tangible interfaces. One dimension of this taxonomy is called *metaphor* [20]. In the sense of tangible interfaces this metaphor dimension means: "is the system effect of a user action analogous to the real-world effect of similar actions?". Thus, it implies mimicking the real

world as close as possible via two types of metaphors from this dimension: "metaphor of noun" which refers to the shape of a object and "metaphor of verb" which refers to the motion of an object. The metaphors of light and shadows [37], snowing [65, 66] or paranormal metaphors [61] are examples of mimicking the real world via shape and motion of an object.

The previous works discuss and explore the metaphors in both graphical or tangible user interfaces which are deeply related to bodily and language experiences. In our work, we go beyond embodied and GUI metaphors and focus on the metaphors from people's social, behavioral and communication experiences which were not deeply researched before.

Ambient tangible awareness systems. Ambient tangible awareness systems were introduced into different domains since the early work by Ishii and Ulmer [37]. Such systems convey and visualize information in the periphery of human attention or environment via changes of light, sound or movement [72, 56, 9]. Early works, such as ambientROOM [38], The Information Percolator [29] or Audio Aura [51], for example, focused on the representations of digital information integrated into the environment. Their works showed that ambient light and sounds can convey information unobtrusively or increase awareness about activities of other people. Kuzuoka and Greenberg [40] investigated tangible representations of remote people within an office via digitally controlled physical surrogates of distant team members. They showed that usage of such surrogates can lead from awareness of others to light-weight establishment of informal communication. Holmquist et al. [30] presented Hummingbird, a system that provides colleagues with continuous aural and visual indication regarding their location. They showed that Hummingbird increased awareness between group members, and can be used as a complementary device for existing communication tools (e. g., phone or e-mail). Alavi et al. [2] introduced a ambient light-based awareness tool Latern and screen-based system – Shelf. The results of their study showed that both systems increased awareness regarding the work coordination between students and teaching assistants.

More recently, Occhialini et al. [52] used ambient displays based on light beams in a work-related context to represent time elapse, which enhanced group coordination and increased workspace awareness. SpiraClock [19] or AmbientTimer [50] are other examples of using ambient light as a medium to increase awareness and unobtrusive notifications in the workspace about upcoming calendar events. Altosaar et al. [3] introduced another notification systems in the workspace called AuroOrb and explored notification appliances to decrease distractions in

the workspace using progressive notifications via increase of awareness about incoming emails. Hausen et al. [28] presented StaTube as a tangible artifact to facilitate state management in instant messaging systems. They showed how peripheral awareness of ambient light can be used to improve instant messaging systems. They found that by exploiting ambient light participants felt more aware of their contacts' states due to the physical ambient representation. Matviienko et al. [48, 47] presented tangible prototypes that notify and increase awareness of colleagues via calendar events using ambient light and sound.

As seen from the examples of previous works, ambient tangible awareness systems demonstrate the advantages of using physical and ambient artifacts to seamlessly shift focus between background and foreground to facilitate an increase of awareness. Most of the previous works focused on different modalities for increasing workspace awareness and non-disrupting notifications, such as ambient light, sound or movement. In our work, we aim to better understand the design space for metaphor-based systems and demonstrate how it can benefit from a throughout methodological process with users. Therefore, within the scope of our work we aim to combine the metaphors from people's social, behavioral and communication experiences through ambient tangible artifacts to fill in the gap of conceptualizing user interfaces for awareness systems.

3 Methodology

To design ambient tangible artifacts based on metaphors, we followed a Human-centered design (HCD) approach [16] to conduct (1) an online survey, (2) a focus group session and (3) a co-design session. We chose the HCD approach because it utilizes experiences and inspirations from users at every stage of the design process. This facilitates high usability of prototypes and encapsulates user experience. Additionally, we employed the approach presented by Kim Halskov [44], starting with generation of metaphors, followed by their development and evaluation together with users. In this work, we use the advantages of existing methods to collect rich data with the help of users for future design and implementation.

Despite the focus on designing for workspaces, we explicitly looked at both working and non-working contexts and methods/representations unrelated to a specific context, e. g., dealing with a distance or presence representation, to enrich a set of metaphors and consequently a solution space from people's social, behavioral and communication experiences in these contexts. We started with an online survey as a method to initially explore the design
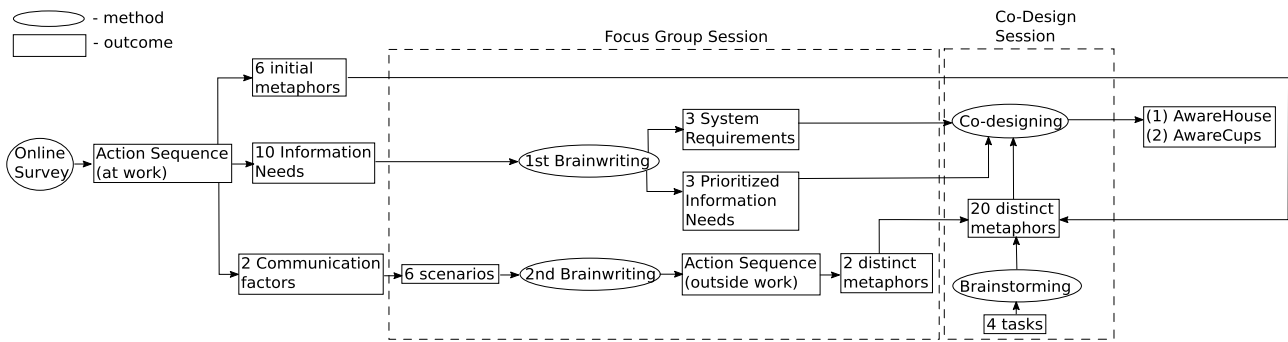
Figure 1: Schematic overview of the methodological process. Action sequence refers to the sequence of actions preceding explicit communication.

space around communication among colleagues. More specifically, the goals of the online survey were to (1) reveal the information needs of working colleagues and (2) collect an initial set of metaphors common for working environments. Having the list of information needs from the online survey, we ran a focus group session as a method for gathering system requirements. In particular, the focus group session aimed to (1) prioritize the information needs collected from the online survey, (2) collect the system requirements for tangible awareness systems, and (3) expand the list of metaphors based on the scenarios from non-working environments. Finally, due to the positive effect of participation at the moment of idea generation [58], we conducted an additional co-design session as an approach making use of collective design. In our case, the goals of the co-design session were to (1) derive initial design concepts for ambient tangible awareness systems based on information needs and system requirements collected from the online survey and focus group session and (2) expand the list of metaphors. In the following, we will walk through each of these steps and present our results in details (Figure 1).

3.1 Online Survey

The online survey consisted of two sections. The first section contained general questions regarding relationships between colleagues, working environment and common communication channels. In the second section, we asked participants two following questions regarding information they want to know about their colleague(s) and the sequence of actions they perform before starting an explicit communication with their colleague(s):

Q1: *"Imagine that you are sitting in your office and have a need to communicate with your colleague. What information would you like to have about him/her before communication?"*

Q2: *"Please describe your sequence of actions before starting an explicit communication with your colleague, such as audio/video chat or face-to-face conversation."*

We spread the survey using social networks and emails and collected 70 responses (25 female, 45 male) ranging in age from 22 to 63 ($M = 29$, $SD = 6.25$) with different indoor professional occupations from different organizations, such as researcher (30), software developer (14), engineer (7) and others (19). Most of the respondents (64 %, 45/70) had working experience between 1 to 5 years, 11 (16 %) had 5–10 years, 7 (10 %) had more than 10 years, and 7 (10 %) had less than 1 year. Sixty-four respondents work in European countries and 56 are of European origin.

3.2 Focus Group Session

The focus group session consisted of three parts: two modified brainwriting sessions [63] and a final discussion. In both modified brainwriting sessions, we allowed each participant to brainstorm and record their ideas on paper, but prevented written modifications based on external feedback. In total five HCI researchers (2 female, 3 male) from the same research institute who did not take part in the preceding online survey aged between 24 and 30 ($M = 27.8$, $SD = 2.28$) with an average professional working experience of five years participated in this focus group session.

In the first brainwriting session, participants were given cards with a first set of scenarios, where they were asked to brainstorm about awareness systems that provide them with information about their colleague(s) needed before starting an explicit communication with them. The goal was to establish a list of requirements for the systems by analyzing the participants' designs. We asked participants to describe in written form or sketch a system that provided them with some or all kinds of the information needs collected form the online survey. At the end of each scenario, participants had to answer two questions regard-

ing the features and information needs they found (un)important for such a system.

In the second brainwriting session, participants were given six cards with another set of scenarios describing concrete real life situations. Two examples of these situations are listed below:

Scenario #1: *Imagine that you are sitting in a cafe and drinking a coffee. Suddenly, a friend of yours enters the same café and goes to a free table. He does not notice you, because the place is crowded. However, you notice him and want to talk to him since you did not see each other for a long time. What sequence of actions are you going to perform to initiate a direct conversation with him?*

Scenario #4: *Imagine that you enter a store to buy a silicon case for your new smartphone. You find a suitable case for it, but you would like it in another color. You wonder whether they have the same case in another color and need a short answer "Yes"/"No" from the salesman as fast as possible, because your train is leaving in 10 minutes. However, the salesman is talking on the phone, and you really need to ask him, because you like this case. What sequence of actions are you going to perform before directly asking him this question?*

For each of the scenarios, participants were asked to describe a sequence of actions they would perform before initiating explicit face-to-face conversation. These scenarios were based on three communication factors that influence the sequence of actions before explicit communication: *urgency*, *availability* and *familiarity*. The first two factors we took from the online survey and to extend the list of possible non-working scenarios added the third one – *familiarity*, based on the work of Castella et al [14], where they showed the influence of familiarity on verbal interaction among group members. To ease the understandability of these communication factors for users, we translated each of them to polar values: urgent/non-urgent, free/busy and acquainted/unfamiliar. The combination of these polarities lead to eight different scenarios. However, we excluded the combinations free-unfamiliar and free-acquainted, because they lead to direct explicit communication.

In the final discussion we discussed the requirements and the prioritized information needs collected from the first part, and metaphors from the second part.

3.3 Co-Design Session

The co-design session consisted of two parts: (1) brainstorming about metaphors from a third angle different from working and non-working environments and (2) co-

design of awareness systems. In total five HCI experts (2 female, 3 male) from the same research institute who did not take part in the preceding online survey and the focus group session aged between 26 and 42 ($M = 31$, $SD = 6.78$) took part in the co-design session. The participants were experienced in designing and prototyping tangible awareness systems for workspace (3), ships (1) and medical units (1).

For the brainstorming part, we derived four tasks regarding the attention, presence, distance and visibility in the real world. For example, one of the tasks was the following:

Think of the things that indicate the presence, willingness to talk or availability of another person(s). For example: an opened door, light in the window, noise in a neighbor's flat, status in IM, eye contact.

The participants were asked to brainstorm together about each task scenario out loud for three minutes.

In the co-design part, participants were given a task to collaboratively design an awareness system, which provides the prioritized information needs and follows the system requirements from the focus group session. Participants were asked to use one or more of the metaphors derived in the previous steps to base their designs on. They were also provided with a prototyping material to build a quick prototype of their ideas.

3.4 Results

In total, we derived three prioritized information needs, established three requirements for awareness systems, and collected 20 distinct metaphors from the methodological process. In particular, we found out that *availability (free/busy)*, *amount of free time* and *location* were the most important information needs. As for the system requirements, we established that the awareness systems should be *informative*, i. e. provide the mentioned above information needs, *unobtrusive* and *social*, i. e. support multi-user interactions by encouraging people to engage in spontaneous communication. The additional stipulation regarding privacy was the possibility to turn off tracking or the whole system. The summary and descriptions of the derived metaphors is presented in Table 1.

As discussed earlier, tangible systems facilitate smooth transition of focus between background and foreground [36, 37], and have the ability to fully take advantage of natural 3D interaction. Given the derived information needs and system requirements, during the co-design session the experts suggested the system in the form of a house following the open door policy metaphor and a

Table 1: Distinct metaphors collected throughout the methodological process.

	Metaphor	Description
1	Knocking at the door	A person comes to a colleague's office, knocks at the door. If a colleague inside reacts to it, e. g., by saying "Come in!", a person understands that a colleague is free and an explicit face-to-face conversation can start.
2	Open door policy	Open door indicates the availability of a colleague, a closed – busyness.
3	Checking facial expression	Facial expression indicates how busy or how hardly concentrated a colleague is, e. g., an eye gaze concentrated for a long period of time on the screen indicates a high concentration, and therefore busyness.
4	Sound of activities	Sound indicates what a colleague is doing at the moment, e. g., noise of a coffee machine in the kitchen indicates someone's presence at that location.
5	Raise or waving one's hand	Raising/waiving a hand indicates a willingness to communicate, or grabbing someone's attention in the periphery of vision.
6	Tapping on the shoulder	Direct touch on the shoulder indicates a willingness to communicate, or grabbing someone's attention, and a direction where a touch came from.
7	Clearing one's throat/coughing	Clearing one's throat/coughing is used for grabbing someone's attention acoustically.
8	Directed speaking	A speech directed in the direction of the opponent (often with a referred name of a person) indicates a willingness to talk.
9	Honking	Honking indicates presence and a need to increase awareness of others.
10	Raising the voice	Increased volume of the voice makes it clearer and therefore makes another person more aware about a willingness for communication.
11	Throwing something on the person	Physical interaction with an object indicates a willingness to talk and a colleague's location, based on the direction where an object came from.
12	Body language/body postures	Particular gestures/postures indicate unwillingness to talk, e. g., crossed hands, turning a head aside.
13	Walking slower in front of another person	Perception of a potential collision with a person in front might increase awareness of presence and a willingness to talk.
14	Tin can telephone	A cup connected to another cup symbolyzes a telephone and indicates a possibility to communicate.
15	Cooking smell	It indicates the presence of a person, e. g., in the kitchen, and also what is being cooked.
16	Sunglasses/X-Ray/laser beam/binoculars	They allow to see more in difficult conditions or further away, especially in conditions with working colleagues over distance.
17	Closed/opened curtain	Light or shadows behind the closed curtains might indicate the presence and number of people.
18	Door hangers	Door hangers display a message, e. g., "Do not disturb.", like in a hotel or in particular office environments.
19	Eyes squinting	It indicates a person's higher concentration and a willingness to see more/know more.
20	Clearing/cleaning/scratching/warm blowing a surface	It helps cleaning the view, e. g., out the window, and indicates a presence and activities for a person on the other side of a surface.

portable tangible awareness systems following the tin can telephone metaphor.

Tin Can Telephone is a type of acoustic (non-electrical) speech-transmitting device that allows two people to explicitly talk to each other exploiting two wired cans, cups or other similarly shaped artifacts by bringing it to the ear as a telephone.[1]

Open Door Policy is a communication policy in which a worker leaves an office door "open" or "closed" to indicate his/her availability. When the door is opened, a person is free, when it is closed, a person is busy.[2]

This experts' suggestion was made on the following rational: (1) these two metaphors can be fully represented in a 3D volumetric way without losing an advantage of natural interaction methods, (2) both metaphors provide different aspects of communication: Tin can telephone conveys communication experience and Open door policy relies on social working behavior, (3) both metaphors employ system designs through different types of form factors which might cover awareness for different working situations, e. g., stationary and "on the go". Undoubtedly, one can find other metaphor candidates following the same requirements, however, our goal was to prove the concept of metaphors from people's social, behavioral and communication experiences for designing tangible awareness systems on the subset of derived metaphors.

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1 https://en.wikipedia.org/wiki/Tin_can_telephone
2 https://en.wikipedia.org/wiki/Open_door_policy_(business)

Another idea behind the design of the systems discussed during the co-design session was to convey information of availability's binary state (free/busy) unobtrusively and bring a detailed information regarding location and amount of free time via explicit interaction. With this, we aimed to distribute the information between foreground and background of attention via smooth transition [37, 36]. This led us to a design decision for supporting the shift from implicit to explicit via interaction with artifacts, i. e., a person notices the change of a state in the periphery of attention and listens to an audio message to receive more information by interacting with a system.

Due to these considerations and follow-up discussions with experts during the co-design session, we focus on design of metaphor-based tangible awareness systems based on Tin can telephone and Open door policy designed for a single person in a private environment and their effects on the potential increase of awareness among colleagues.

4 System Designs

A single metaphor often limits system's functionality and cannot fully represent complex communication [45, 27], while composite metaphors facilitate users to develop a more comprehensive understanding of a system [33]. We employ the Tin can telephone and the Open door policy metaphors as a basis for the design of two tangible awareness systems – *AwareHouse* and *AwareCups* – to enrich and avoid limitations of the system designs.

Given the derived and prioritized information needs from the previous steps, both prototypes provide information about current availability, location and amount of free time of specific colleagues. With the current system implementations, we restricted the number of colleagues that one can be aware of to four, but for future implementations we aim to make it flexible and change the mapping between artifacts and colleagues on the fly using a dedicated application.

4.1 Tangible Awareness System 1: AwareCups

4.1.1 Design

AwareCups is a wireless prototype that utilizes the tin can telephone metaphor. We implemented four AwareCups, where each cup conveys all three information needs about

one colleague, whose name is shown on the label sticker on the side of the cup. A person can write a name of a colleague using a marker similar to how coffee shops provide visitors with cups that have their names on them (e. g., Starbucks). Availability of a colleague is represented via a RGB LED light strip positioned around the cup; red indicates that a person is busy, green signifies a person is free, and the off state represents a lack of information about a person's availability. When a person wants to know more sensitive information about another colleague (e. g., amount of free time and location), she brings the cup to her ear and listens to a voice based recording (Figure 2b), such as, "In the lounge, free for the next 5 minutes." During every state change, such as busy to free or vice versa, the cup slowly blinks three times (with a duration and delay of 500 ms and brightness of 30) in the succeeding state. For example, in changing from the busy (Red) state to the free state, the cup would blink green three times and stay green. The cup can be turned on and off via a button and charged via a chord on the side (Figure 2a).
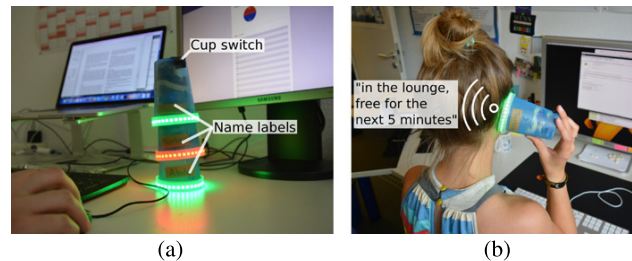

(a)   (b)

Figure 2: AwareCups: on the working desk (a) and interaction with cups (b).

Based on the system requirements collected from the focus group session, *AwareCups* were designed to be: (1) *unobtrusive*: they use ambient light on the periphery of human vision in a non-distracting manner; (2)*orientation independent*: the arrangement of LEDs around the cup allows seeing the cups from any direction; (3) *portable*: the cups can be easily carried out to a meeting or any other place; (4) *stackable*: the cups can be easily stacked on top of each other to save desk space; (5) *provide an overview*: the cups provide an availability overview about a group of colleagues at a glance; (6) *privacy-oriented*: the system provides sensitive information on demand in an interactive way; (7) *intuitive*: due to the familiarity with a tin can telephone.

Our design of *AwareCups* is further supported by the design of StaTube [28] and Lantern [2], which show that tangible artifacts are effective in increasing awareness between people.

4.1.2 Implementation

Our prototype is based on the Light Blue Bean board and an iOS application "Handy BLE" from the App Store that communicates with the board using integrated Bluetooth. We used a plastic cup container as housing for the hardware (11 cm height and 7 cm in diameter). The Light Blue Bean was connected to an MP3 module with a simplified output directly to a mini-speaker. Both boards are powered by a lithium ion 400 mAh (LiPo Akku) battery connected to a voltage booster (Adafruit PowerBoost 1000) to ensure consistent 5 V power. For the LED-strip around the cup, we used a Neopixel strip.

4.2 Tangible Awareness System 2: AwareHouse

4.2.1 Design

To fully implement an open door policy combined with including doorbells, we decided to build a wood prototype house that contains four doors on the front side with door bells next to each door. *AwareHouse* has the following measurements: 23 cm × 37 cm × 25 cm (Figure 3a). Each door is mapped to one colleague with a label to indicate the person's name. Following the open door policy metaphor, it shows the colleague's availability via an opened door (free) or a closed door (busy). On the right side of the door, a doorbell button can be pressed to receive more detailed information about a particular colleague. Each door contains an integrated 7-segment display that shows a number for the amount of free time in minutes. When the door is closed and the user presses the button, she hears a voice recording that conveys the location of the colleague along with the amount of free time. The display on the door indicates the minutes before a colleague is free from other commitments. For example, one possible recording would be, "In the office, free in 5 minutes." When the door is open and the button is pressed, the user hears a voice recording of the colleague's location with the amount of free time. The display indicates the amount of a person's free time (Figure 3b). The servo was used as auditory feedback for opening and closing the door.

Based on the system requirements collected from the focus group session, *AwareHouse* was designed to be: (1) *privacy-oriented*: it provides sensitive information on demand in an interactive way; (2) *provides an overview*: it provides an availability overview about a group of colleagues at a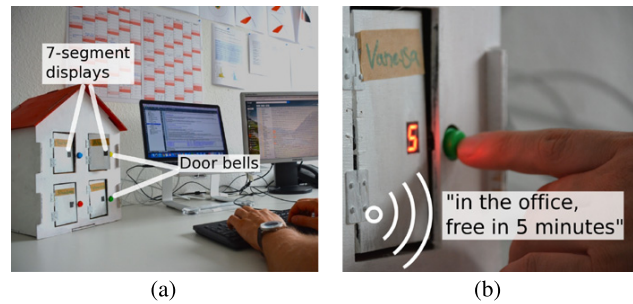 glance; (3) *unobtrusive*: opening and closing of the doors is done in an unobtrusive way and does not distract the user from their primary task; (4) *intuitive*: due to the fact that open door policy is well-known in the world, people understand how the system works based on their real life experiences.

Figure 3: AwareHouse: on the working desk (a) and interaction with the house (b).

4.2.2 Implementation

Each door of AwareHouse is labeled and mapped to a particular colleague. We used a servo (per door) connected to an Arduino Mega to track opening and closing of doors. The Arduino Mega also interfaces with the 7-segment display, the button and the BLE Bluetooth shield. For sound playback, we used the same mp3-player module as for *AwareCups*, to play files directly from an SD-card to a mini-speaker. For the communication part between *AwareHouse* and a smart phone, we used an iOS application "Adafruit Bluefruit LE Connect" from the iOS App Store.

For both system implementations the users do not have to record the voice messages themselves, since both systems contain two sets of pre-recorded audio messages related to locations and amount of free time. Location information can be extracted from the online calendaring systems and for the durations longer than 30 minutes, the systems will say: *"Free in more than half an hour"*. With both our implementations, we ensure that a person sees an overview of their colleagues' availability at a glance, and receives more sensitive and private information in a playful and intuitive manner. Moreover, both systems nicely integrate into the office environment in a compact and appealing fashion (Figures 2a and 3a). As for information sharing, users can specify what kind of information they want to share and with whom using a dedicated application.

5 Exploratory User Study

We conducted a short-term field study aiming to provide a proof of concept for designing metaphor-based ambient tangible artifacts to support workspace awareness.

5.1 Participants and Procedure

We recruited 22 participants (11 female) aged from 21 to 53 (M = 33.62, SD = 9.15) from a research institute. They all worked in the same building. For this study we did not provide real tracking data, because the purpose of this study was to investigate the derived metaphors and provide a proof of concept for conceptualizing user interfaces for ambient tangible artifacts through the idea of metaphors. The state changes for both systems were manipulated via Bluetooth by the experimenter in a Wizard of Oz manner [18]. None of the participants had vision impairments, color blindness or other color recognition and hearing impairments.

At the start of the experiment, each participant was given an explanation about how the prototype works and the metaphor behind it. Also, each participant was informed that information conveyed by the prototypes was simulated, and used only for exploring our concepts. Participants were also informed that they would be live videostreamed so that we are able to observe any behavioral patterns and usability issues. We placed a tablet in the office of each participant that constantly live-streamed video to the tablet of the experimenter. Participants were also informed that this video stream was not stored or shared anywhere, and was used for observation purposes only. Additionally, we asked participants to write their experiences and comments onto a provided paper diary while using both prototypes.

Participants were not given specific tasks for the duration of the study, and were asked to do their regular work. Each participant used each prototype in their normal working environment for one hour. The order of prototypes was counterbalanced. After each hour, each participant was asked to fill in a 10-item questionnaire based on the System Usability Scale (SUS) [11] to estimate the usability of the metaphor-based prototypes and 5-point Likert scale to assess prototypes' potential to increase the awareness of availability, location, amount of free time, and social connectedness via the following statements: *"I feel like I became more aware of my colleagues' availability/amount of free time/location"*. In total we collected 44 hours of observations (1 hour × 2 prototypes × 22 participants). Participants were also free to choose a location for where to place the prototype in their private working environment. At the end of each study, we interviewed participants and asked about the applicability of metaphors used in the design, the influence of the prototypes on their working hours, positioning of the prototypes, and general comments.

6 Results

6.1 Quantitative Results

6.1.1 Usability

We gave participants a 10-item System Usability Scale (SUS) [11] questionnaire after a trial with each prototype to estimate their usability. SUS scores for *AwareHouse* and *AwareCups* are 81.36 and 81.48 accordingly. Any SUS score greater than 70 is considered as usable.

6.1.2 Awareness and Social Connectedness

The quantitative self-report measures using Likert-scale items regarding awareness of availability, location, amount of free time and social connectedness showed high scores for both *AwareCups* and *AwareHouse* without significant differences between prototypes (Table 2).

Table 2: Likert-scale item results: 5 – strongly agree, 1 – strongly disagree.

Awareness System	Availability awareness		Location awareness		Time awareness		Social connected-ness	
	Md	*IQR*	*Md*	*IQR*	*Md*	*IQR*	*Md*	*IQR*
AwareHouse	4.5	1	4	2	3.5	2.5	3	1.75
AwareCups	4	1	3	2	3	2	3	1

6.2 Qualitative Results

For the analysis of diaries, interviews and video observations, we structured the data and categorized the interpretations of participants according to a method of structuring and deductive category assignment which aims to bear on the material in the form of a category system, described by Mayring [49]. It operates in three stages: (1) definition

of the categories: determining which text components belong in a given category; (2) anchor samples: concrete passages belonging in particular categories are cited as typical examples to illustrate the character of those categories; (3) coding rules: rules are formulated for the purpose of unambiguous assignment to a particular category.

The definitions of the categories evolved during the analysis of the feedback collected from the video observation and the diaries by grouping the quotes that represent different aspects of experience with the prototypes. For example, multiple participants mentioned the privacy concerns while interacting with the prototypes, which led to a category of *privacy* at the workspace. In the end of the process we derived the following six categories: *awareness*, *obtrusiveness*, *location*, *interaction and playfulness*, *novelty effect*, and *privacy*. This process was used to distil a set of distinct themes, and was stopped when any further quote could be unambiguously assigned to an existing category. The data from the post-study interview was transcribed verbatim and analyzed by one researcher. The live video-streaming was not used for transcription, but to observe behavioral patterns and usability issues with the prototypes.

6.2.1 AwareCups and AwareHouse as Metaphor-Based Artifacts

Overall, none of the participants had problems understanding the design of the systems, since all of them were familiar with the presented metaphors. They reported that they liked the idea and design of the systems. *"I find them [AwareCups and AwareHouse] very good. They are very intuitive and easy to use."* [P3]. *"Both [metaphors] are quiet interesting and easy to understand"* [P6]. The participants were satisfied with the information they received about their colleagues and liked the "on demand" option to receive more information. Almost all participants (91 %) mentioned that they could imagine using the prototypes and relying on them during working hours.

Twelve participants found the metaphor behind *AwareCups* intuitive, easy to use and understand. *"The cups are more likely to get attention and are more intuitive because of the lights."* [P13]. *"I liked the cups metaphor because I can bring a cup to my ear and the sound is not as public as the sound of the house."* [P14]. All participants perceived *AwareCups* as an unobtrusive and peripheral artifact. *"I glance at AwareCups and see what my colleagues are up to."* [P9]. *"I see them [AwareCups] easily in the periphery of my vision"* [P6].

Other ten participants reported that *AwareHouse* is an aesthetic prototype and undemanding from an interaction perspective. *"House is less demanding to interact with. I also find it as more beautiful decoration for my office."* [P8]. *"The metaphor with the doors is fine. I like it."* [P15]. *AwareHouse* was perceived as unobtrusive by 15 out of 22 participants. The opening/closing sound of the doors in *AwareHouse* for 15 participants was perceived positively, because they could become aware of changes in the states of their colleagues. *"Opening/closing noise for doors was more informative and I knew when there was a change."* [P10]. P16 suggested another implementation for an open door policy metaphor: *"The metaphor by itself is funny, but an abstraction would be enough, for example, a picture with red or green doors. They do not have to be physically closed and opened."*.

6.2.2 Awareness

All participants mentioned that the systems made them think more of other colleagues than before using *Aware-Cups* or *AwareHouse*. *"I was checking over time when it [AwareHouse] switched the state. Maybe I don't wanna know where they are, but I was just curious what they are up to."* [P6]. One participant reported that she felt excluded from the group when she saw two of her close colleagues being free at a specific location. *"Sometimes I was feeling excluded when two of my close colleagues were free at some location. I wanted to be invited by them somehow."* [P3].

6.2.3 Obtrusiveness

All participants perceived *AwareCups* as an unobtrusive artifact. *AwareHouse* was perceived as unobtrusive by 15 out of 22 participants. By comparison, 19 participants reported that *AwareCups* were less obtrusive than *Aware-House*. However, the opening/closing sound of the doors in *AwareHouse* for 15 participants was perceived positively, because they could become aware of changes in the states of their colleagues. *"Opening/closing noise for doors was more informative and I knew when there was a change."* [P10]. *"House is not as distracting because nothing is shining."* [P21].

6.2.4 Interaction and Playfulness

Two participants mentioned that they like how playful and interactive both of prototypes were. *"I liked that I could just*

press a button, turn back to my monitor and listen to information without looking at the House." [P4]. Two other participants said that they would feel comfortable to bring one of *AwareCups* with them to another place within the building. *"I would also bring Cups outside when they would be also possible to drink from them."* [P5]. *"If a cup would be a bit smaller (with a size of a shot), I would carry it with outside the office."* [P2]

6.2.5 Location

From the video observations we have seen that participants were placing both prototypes in close proximity to their laptops and monitors in order to keep them in the periphery of vision and within reachability to press a button or grab a cup. For example: *"Cups are also easy to separate and put on different sides from my laptop."* [P5]. *"With the cups it is good that you can place less important colleagues at less important locations."* [P17]. *"I placed House on the side from my laptop to reach the buttons and to keep it less obtrusive."* [P5]. None of the participants positioned a system behind the back, neither out of reachability nor periphery of vision.

6.2.6 Novelty Effect

From the video observations, we saw that participants paid attention to the systems for the first half an hour regularly to see what the system does. *"I was glancing at the House in the beginning more often than later, because firstly I was curious what this thing does and then I just got used to it."* [P3]. We observed that participants were interacting with systems when there was a change of the state happening, i. e. six-seven times during an hour. Participants were also checking the information about multiple colleagues by interacting with multiple doors or cups to build a full picture of the current state of the team.

6.2.7 Privacy

AwareCups ensure that only a person who holds a cup next to his/her ear can hear more sensitive information. *"I had a colleague standing in my office. When I checked the status of another colleague using the cups, I could hear the sound, but he could not."* [P8]. One participant (53 years old) expressed concerns over the automated tracking and preferred using existing communication needs: *"Availabil-*

ity is interesting, but the location can lead to surveillance. It is easier to use the phone." [P19].

7 Discussion

7.1 Awareness, Interruptions and Social Connectedness

In our work, we addressed the problem of workspace awareness [24] by exploring the design space for tangible awareness artifacts based on metaphors (RQ). Based on both quantitative (SUS) and qualitative data, we showed that both systems are highly usable, intuitive and easy to use likely due to their metaphor-based design. Results from the self-assessment Likert-scale items (see Table 2) and the exit-interviews showed the potential for increase of awareness for availability, location and amount of free time among colleagues, which has to be further investigated in the long-term studies.

Awareness often comes with the price of disruption from the task in focus [32]. Both systems helped participants to enhance an interaction experience through the notion of metaphors and enabled them to be aware of background information at the periphery. This is in line with the findings of Ishii et al. [37, 36], who showed that tangible artifacts can increase awareness at the periphery of human attention. Type of awareness or notification is highly dependent on the urgency of notification. It might be a situation when a worker is waiting for a boss to become available, or his colleague to have a cup of coffee together. Such choice of notification should be given to a user depending on the situation.

Ideally, such results uncover the social trends between colleagues, but as far as the tracking data was simulated and constrained under an allotted timespan, it was hard for participants to say whether they could feel more socially connected, because there was no explicit social interaction happening. However, given the current metaphor-based design of the system and the ways they represent information, during the interview all participants mentioned that they could imagine using the systems and that it can increase awareness.

7.2 Metaphors as Design Base

Marcus [45], Carroll and Thomas [13] consider metaphors to be a fundamental component in user interfaces and an essential concept in computer-mediated communica-

tion that substitute the underlying code, terminology, applications and data. The desktop metaphor, for example, represents a desktop covered with documents and folders mapped to real data, functions, and interaction paradigms. In our work, we brought a set of metaphors to design tangible ambient artifacts and covered availability information of others with tangible awareness artifacts based on metaphors from people's social, behavioral and communication experiences. From the SUS scores and qualitative analyses, we observed the high usability of both systems due to the metaphor-based designs, since the participants were already familiar with them as they reported during the interviews.

Donald Schön [60] refers to "metaphor" as "to a certain kind of product – a perspective or frame, a way of looking at things – and to a certain kind of process – a process by which new perspectives on the world come into existence." In our work, we demonstrated how a thorough methodological process can help designers to bring metaphorical perspectives into real tangible awareness systems. We also derived a set of metaphors (Table 1) to assist future designers for building new awareness artifacts. For example, similar to the cooking smell metaphor, Amores and Maes [5] showed that the scent can increase awareness in the private spaces. This finding can be further used to design tangible awareness artifacts.

Despite breaking/combining metaphors, we showed that composite metaphors [33] can simplify understanding of a systems' functionality and interaction paradigms [13, 45]. For example, *AwareCups* caught participants' attention due to the ambient light and not due to the used metaphor. However, the follow-up interaction of bringing up a cup to the ear was based on the Tin can telephone metaphor. Additionally, we showed that composite metaphors can enrich user interface design without affecting a user's understanding of a system, such as combination of the open door policy and ringing the door bell. This supports earlier work regarding the understandability and user expectations of metaphors in virtual environments [53]. We showed that metaphors assist in conceptualizing the design of tangible awareness systems and promote easy learning as mentioned by participants, who became used to the system within a short period of usage. As in the example of *AwareHouse*, when users had to ring the door bell to get more information about a colleague instead of calling.

Tangible artifacts can provide a sense of intimacy that is often hard to achieve with screen-based interfaces. Physical devices have the advantage of full representation of metaphors without misleading interaction and affordances. As we saw from our findings, designing metaphor-based ambient tangible artifacts support the peripheral interaction and has a potential to support workspace awareness. This idea is supported by prior work by Schneider et al. [59] about the benefits of tangible interfaces for collaborative interaction.

Even though we did not investigate all of the metaphors derived in the methodology phase and showed only the feasibility for two of them for tangible systems, we demonstrated that this design approach can be applicable for future designs of awareness systems, since the prototypes are easy to use and understand, and offer peripheral awareness. Moreover, since the collected metaphors were derived from people's social and communication behavior in both working and non-working environments and actions focused on the increase of attention, presence representation, dealing with a distance and the increase of visibility, they cover a wide space of possible application areas and can facilitate design, interaction and communication with them accordingly. For example, the metaphors of closed/opened curtain or clearing the icy and steamy surfaces can be used for preserving privacy on the public displays, similar to the work of Häkkilä et al.[26].

7.3 Working Environment and Privacy

Both prototypes have their advantages and disadvantages with regard to privacy and working environment. While both are suitable for a single person in a private environment, *AwareCups* are a more suitable awareness system for a shared working environment than *AwareHouse*. *AwareCups* ensured both unobtrusiveness and privacy with regard to co-located colleagues. One can still check the status of other colleagues by bringing the cup to their ear without disturbing colleagues near-by and sharing such sensitive information. On the other hand, *AwareHouse* keeps an abstract representation of availability following the open door policy metaphor and conveys more sensitive information on user demand, which makes it more suitable for a one-person office space.

During the process of information needs acquisition, we derived and prioritized the list of information needs for awareness systems, such as availability, amount of free time and location. Current design and implementation of the systems assumes that all three information needs are available at the same time. The scenario, where participants have a control over what information to share, when and with who, raises a point of possible exclusion for some of the information needs due to surveillance issues. One of the participants in the study did not mind sharing his availability, but location is sensitive information [62],

which one does not want to share with everyone all the time, if at all.

7.4 Design Considerations

We observed that ambient light of *AwareCups* is an effective medium to convey information unobtrusively and facilitate an increase of awareness, which supports the previous work concerning unobtrusive reminders of upcoming tasks [50, 28, 48], and has to be considered by future designers of awareness systems. We also showed that the ambient sound can be used to indicate the change of users' state with sound of opening/closing doors on *AwareHouse*, what supports the previous works regarding the sonification in the periphery of human attention [21, 8].

We experienced the importance of easily accommodative form factors and modular implementation of the prototypes. For example, participants freely and easily rearranged *AwareCups*, stacked them on top of each other or even were ready to bring a cup with them. Each door of *AwareHouse* and each cup of *AwareCups* was designed as an autonomous part. Even if one door or cup stops working, the prototype still remains functional, which eases the maintenance of prototypes and conducting experiments. This indicates the importance and benefit of keeping the modularity and portability of the complex tangible systems.

With both *AwareCups* and *AwareHouse* we focused on information needs related to the present moment. However, designers of future ambient systems might consider integrating an "on-demand" calendar-like functionality (cf., CubeLendar [48], AwareKit [47]) to provide an additional information about availability in the future. This will enrich availability information about others and help planning future meetings.

To avoid privacy concerns and any increase in obtrusiveness, future designers have to take into consideration the context of working environments, such that participants feel comfortable using the systems in a shared environment without disturbing others. Additionally, while designing systems for increasing awareness and social connectedness, future designers have to be also aware of possible exclusions of others and provide invitational mechanisms for people who are close.

7.5 Limitations

Within the scope of this field study, we did not provide real tracking data for the participants and the duration of in-

teraction with each prototype was one hour. Undoubtedly, it is inherently impossible to observe effects of the presented systems during such a short period of time. However, our aim was to fill in the gap in conceptualizing user interfaces for ambient tangible artifacts through the idea of metaphors. Therefore, we ran the study to prove the concept of metaphors from people's social, behavioral and communication experiences for designing tangible awareness systems. We did not investigate all possible metaphors, but we showed on the example of two distinct metaphors that such design approach can ease the understanding and usage of the systems. Since HCI experts and researchers took part in both focus group and co-design sessions, it might bias the system designs due to the technical background and expertise of the participants. Both systems are physically limited to four persons at the moment, but one can easily remap the doors/cups to other colleagues using a dedicated application. The portability of *AwareCups* might be an issue due to their social acceptability, which needs to be further explored in the future. The display of *AwareHouse* is limited to the timespan of maximum nine minutes. However, our design solutions were meant to increase awareness among colleagues without planning meetings in advance unlike calendaring systems. The presented systems are not meant to be used for planning of meetings or collaborations similar to calendaring systems, but rather show the up-to-the-moment knowledge about another person's availability, location and amount of free time to build closer relationships among colleagues. We evaluated both prototypes in a research institute with researchers as main subjects, which limits the generalizability of our results. Additionally, within the scope of this paper we focused only on the prioritized information needs, such as availability, amount of free time, and location, derived during the design process. However, depending on the situation every person would like to access more information and individualize the system designs [4], what we aim to observe during a longer field study.

8 Conclusion and Future Work

In this paper, we provide a deeper understanding of awareness needs and the solution space through a systematic methodological process which consists of online survey, focus group and co-design sessions. During this process we derived an extensive list of metaphors, scenarios, information needs and system requirements for conceptualizing the future development of tangible aware-

ness systems. Based on our findings, we designed two awareness systems and evaluated them in the workspace as a proof of concept. Due to the high understandability of metaphors, we showed that such systems are easy to understand and use. Both systems showed the potential to increase awareness of availability, location and amount of free time among colleagues. With this, we expanded the design space for future awareness systems and demonstrated a feasibility of our approach based on metaphors.

In future work, we aim to improve the implementation of our designed tangible artifacts and conduct a longer field study with real tracking data, to validate further whether such systems increase awareness, and to what extent they can increase social connectedness. Further, we aim to investigate this approach based on metaphors and investigate other metaphors for working groups of colleagues in public workspaces.

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Bionotes

Andrii Matviienko
University of Oldenburg, Oldeburg, Germany
andrii.matviienko@uni-oldenburg.de

Andrii Matviienko is a PhD researcher in the Media Informatics and Multimedia Systems Group at the Department of Computer Science at the University of Oldenburg. His current research focuses on tangible user interfaces and multimodal assistance systems for child cyclists.

Abdallah El Ali
University of Oldenburg, Oldeburg, Germany
CWI (Centrum Wiskunde & Informatica), Amsterdam, The Netherlands
a.elali@cwi.nl

Dr. Abdallah El Ali is a human-computer interaction (HCI) researcher with a background in Cognitive Science. His research focuses on people-centric pervasive sensing for urban mobility and mobile interaction.

Christin Hilmer
University of Oldenburg, Oldeburg, Germany
info@christin-hilmer.de

Christin Hilmer is a computer science student at the University of Oldenburg.

Yannick Feld
University of Oldenburg, Oldeburg, Germany
yannick.feld@uni-oldenburg.de

Yannick Feld is a physics student at the University of Oldenburg.

Wilko Heuten
OFFIS – Institute for Information
Technology, Oldeburg, Germany
wilko.heuten@offis.de

Susanne Boll
University of Oldenburg, Oldeburg,
Germany
susanne.boll@uni-oldenburg.de

Dr. Ing. Wilko Heuten is senior principal scientist at OFFIS – Institute for Information Technology in Oldenburg, Germany. His research interests are the design and development of pervasive and multi-modal interactive technologies to support everyday life activities. Since 2008 Wilko Heuten leads the group Interactive Systems in the health department at OFFIS.

Susanne Boll is a Professor of Media Informatics and Multimedia Systems in the Department of Computing Science at the University of Oldenburg, Germany. Her research interests lie in the field of multimedia and intelligent user interfaces.