Report from Dagstuhl Seminar 17161

Ambient Notification Environments

Edited by

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Abstract

Direct notifications are on the exponential rise. In our time, numerous personal computing devices and applications vie for limited attention, racing to deliver large amounts of information to us. This often results in users being overwhelmed by notifications and interruptions to their regular schedule, to whom a complete avoidance of technology seems to be the only viable option. In other words, the current approach for notification delivery is unsustainable and will not scale. In the Dagstuhl Seminar 17161 "Ambient Notification Environments" we brought together experts from different fields related to smart homes, ambient intelligence, human-computer interaction, activity recognition, and psychology to discuss a potential alternative approach: ambient notifications. We explored how ambient notifications can support people in their daily activities, by providing relevant information that are contextually embedded in the environment. The objective is to facilitate unobtrusive access to information at the right time and in the right place, hence reducing the disruptions and annoyances that are commonly associated with direct notifications. In this report, we present the numerous ideas and concepts of how the research community could strive toward towards realising ambient notifications. This is based on the presentations and activities conducted during the seminar. Overall, the community is in agreement that current approaches to notifications will not scale and that ambient notifications are a potential solution.

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1 Executive Summary

Albrecht Schmidt (University of Stuttgart, DE, albrecht.schmidt@acm.org)

Reports indicate that many users interact with their smartphone and wearable devices more than 100 times per day. Oftentimes, these interactions result from direct notifications, presented on the screen or via sounds. New communication applications (e.g. from email to WhatsApp) has increased the frequency of notifications, while social media applications are

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inherently motivated to entice repeat visits and interactions. The end result is that more and more systems as well as applications compete for the user's attention using notifications. Projecting this into the future, it is apparent that current implementation schemes that rely on direct notifications will not scale. A simple extrapolation of the rate in notifications suggests that a near future whereby users will only attend to notifications with no time leftover for productive work. Therefore, a radical restructure of notification delivery is necessary – specifically, one that keeps the user in-the-loop without consuming all of the user's attention. This is a key challenge. If no alternatives to direct notifications can be realized, current visions of ubiquitous computing and smart environments are likely to be unrealistic, given their anticipated undesirability to the end-user. In the Dagstuhl Seminar 17161 "Ambient Notification Environments", we looked at how novel approaches to notification delivery can address the above issue. We brought together researchers and experts that understand the technical, psychological, and social aspects of notification systems. This facilitated a broad discussion that was fuelled by the discussants' joint expertise in mobile and smart home technologies, in ambient sensing and presentation, and psychological models of human attention, to name a few. This discussion brought to the foreground, many of the underlying challenges that deserves further research. On the hand, a technological push in novel communication and smart devices drives an immediacy in user interaction. On the other hand, this will result in a higher demand on human attention. In the current report, we document the diverse approaches that were proposed as an alternative means towards notifications that are more personalized and contextualized, with the express purpose of reducing user effort. The central aim of the seminar was to understand the challenges and questions that we face when designing future interactive systems and to overcome the mounting notification problem. In addition to the ideas raised in the individual presentations and the group sessions, we jointly identified the following research questions and challenges:

1. How can notifications be designed to be simultaneously non-intrusive and yet noticeable?
2. How can artificial intelligence be designed to provide effective context-aware notifications?
3. What is a suitable notification architecture for integrating user devices, smart (shared) environments, and personal data without compromising personal privacy?
4. What is a suitable conceptualization for notification systems and how will a taxonomy for classifying notification delivery that is centered on user preferences and privacy look like?

Overall, the seminar contributed to a common vision of how interactions between human and systems can and ought to progress – one where technological progress does not necessitate an ever growing burden on the user's attention. In this report, we balance an analysis of the underlying drivers and problems, ideas for novel conceptual and technical approach, and most importantly a set of questions and research challenges in this domain that merit the attention of like-minded researchers.

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3 Overview of Pecha Kucha Presentations

3.1 Ambient Notification Techniques to Display Changes of the Ecosystem

Aaron Quigley (University of St. Andrews, GB, aquigley@st-andrews.ac.uk)

Our work has explored a variety of screen, widget and pixel level ambient notification techniques for visualizing display changes in ecosystem of display environments [3]. In such environments, users can easily become overloaded and become unaware of display changes as they alternate their attention towards different displays. We have explored and patented subtle gaze-dependent techniques for visualizing change on unattended displays with techniques including FreezeFrame, PixMap, WindowMap and Aura [1]. We have extended this to explore a range of four notification levels unnoticeable, subtle, intrusive and disruptive. These range from an almost imperceptible visual change to a clear and visually saliant change. We explored such ambient notifications in AwToolkit, a novel widget set for developers that supports users in maintaining awareness in multi-display systems [2]. The first set of techniques were studied over consecutive days and the results of the study show that the participant found the system and the techniques useful, subtle, calm and non-intrusive. With AwToolkit the evaluation results reveal a marked increase in user awareness in comparison to the same application implemented without AwToolkit.

Our work indicates that subtle visualization techniques can indeed positively change the display attendance behavior of a working professional who used these techniques as part of their regular work activities. However, many opportunities still exist for taking the technology further, both in terms of refining the techniques, and in terms of identifying cost-effective means of evaluating the efficacy of such techniques. The subtle display of visual change information from unattended displays can alter our interactions and expectations of interfaces. Out of sight no longer means out of mind, when inattention is no longer an inherent cost but a new research and development opportunity.

Finally, our work suggests a visual continuum from effectively invisible ambient notifications to highly disruptive notifications which demand attention. Context-aware systems need to understand when notifications have been perceived and acted upon as required before promoting them through a chain from unnoticeable, to subtle, then intrusive and finally disruptive. Today, too many notifications systems begin with disruptive action, rather than resorting to that as a means of notification as last resort.

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3.2 Notifications will not scale with Internet of Things

Albrecht Schmidt (Universität Stuttgart, DE, albrecht.schmidt@acm.org)

With the Internet of Things more and more devices and systems will want to get the attention of the user [1]. Potentially hundreds of devices, sensors, and communication endpoints will create notifications that should be brought to the user's attention. Looking at the current volume of notification users receive and at the expected number of internet enabled devices it becomes clear that classical notifications will not work anymore in the near future.

To empower users to live and interact in a world of ubiquitous computing and making good use of many potentially useful interconnected things, we need to re-think how we do notifications. The key criteria for future ambient notification systems are:

1. **Transient notifications**: the large majority of notifications are transient and do not require user attention. If users do not see them or chose not to interact with them, they will disappear not requiring any interaction or attention by the user. An example for this are ephemeral interfaces [2].
2. **Natural attention management**: notifications are designed that humans can use their natural ability to filter and focus. In a forest we are not overwhelmed by the amount of things we see, even though there may be hundreds of leaves, mushrooms, plants, and insects. Humans are good at directing their attentions to things of important or aspects they are primed for.
3. **Situating information and notifications**: by contextualizing notifications to the current situation, by putting information into context, and by making data and notification available in points where humans need to make decisions [1]. Embedding information and interaction into objects reduces the overall complexity in dealing with the information as it is anchored in the real world and it hopefully reduces the demand on the user's attention.
4. **Ambient, peripheral, and aesthetic presentation**: the notifications should be designed that they can blend in with the environment and that the rather aesthetically enhance an environment than making it cluttered [3]. By these means environments can be made more pleasant and at the same time have them communicate information that can be peripherally perceived.

The long term vision is that we create technologies that make us peripherally aware of things we need to know through technologies that augment and amplify [4] our perception. This can help to overcome temporal and spatial limitations of our perception [5]. Similar to human senses, we are not required to actively seek and process information, we will just know it.

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3.3 Notification Strategies for Mobile and Smart Home Notifications

Alexandra Voit (University of Stuttgart, DE, alexandra.voit@vis.uni-stuttgat.de)

My research aims to investigate notification strategies for various kind of information as mobile or smart home notifications. Today, many users own different kinds of smart devices such as laptops, smartphones, smartwatches or tablets. Displaying notifications is an important feature that all these devices support. The smart devices inform users proactively about incoming messages, upcoming appointments or device specific information, e.g. updates. On the one hand, users appreciate notifications because they do not want to miss such information and they do not have to check the different applications manually. On the other hand, many applications use notifications to keep the user in the loop or to catch the user's attention. In addition, receiving notifications can lead to interruptions and therefore lower the task performance of the user's current primary task.

In most cases, different devices are not aware of each other. If a user uses a laptop, a smartphone, a smartwatch and a tablet, and he receives an email, all devices with an email client installed will try to notify the user. I argue that, in order to respect the user's attention, selecting a specific device to notify the user is a better approach. To gain information about on which device the users want to receive notifications in their current context, we conducted a study using the Experience Sampling Method [1], the user's proximity to the device, whether the user currently uses a device, as well as the user's current location can indicate if the user wants to receive notifications on a specific device. In addition, we investigated notification strategies to display mobile notifications, such as incoming messages or upcoming appointments, within the user's environment. With this approach, the users do not have to check their smartphones anymore. For example, we developed guidelines for displaying notifications on smart TVs [2]. Also, we developed a system to display the user's personal notifications on displays, using ambient lightning, using sounds or speech output [3]. Furthermore, smart wall calendars can be used as ambient display in the users' home to increase the attention regarding upcoming appointments or tasks and to support aging in place [4].

With the raise of the Internet of Things (IoT), smart devices in the user's environment will be able to notify the user as well. For example, current automatic vacuum cleaners notify users on their smartphones about their current state (e.g., when the cleaning process is finished). My work investigates new notification strategies to display smart home notifications [5, 6]. In an online survey, I investigated four notification strategies for four scenarios with different urgencies. The results indicate using ambient notifications at the notifying object itself as well as an ambient notification display can display for non-urgent smart home notifications as e.g., watering plants, feed animals or remind the medication intake. My future work focuses ambient notifications and their representation in the user's home.

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3.4 Peripheral Interaction

Andreas Butz (LMU Munich, DE, andreas.butz@ifi.lmu.de)

The focus of the Dagstuhl Seminar 17161 – Ambient Notification Environments obviously is on ambient notifications. This means, that some computing system (or some human via a computing system) is sending us a certain bit of information in an ambient way. There is work from the last century on these concepts, but already several years ago, this situation struck me a somewhat unbalanced: It seemed nice that systems would notify me in unobtrusive and peripheral ways, but how about the other direction? How about interaction in a similarly lightweight and peripheral way? Tis idea of peripheral interaction was investigated by my former PhD student Doris Hausen at LMU and simultaneously by her colleague Saskia Bakker at TU Eindhoven. The two of them edited a book on peripheral interaction [1], and in its introductory chapter they write: "In everyday life, we perform several activities in our periphery of attention. For example, we are aware of what the weather is like and we can routinely wash our hands without actively thinking about it. However, we can also easily focus on these activities when desired. Contrarily, interactions with computing devices, such as smartphones and tablet computers, usually require focused attention, or even demand it through flashing displays, beeping sounds, and vibrations used to alert people. Hence, these interactions move more unpredictably between periphery and center of attention compared to non- computer-mediated activities. With the number of computers embedded in our everyday environment increasing, inevitably interaction with these computers will move to the periphery of attention. Inspired by the way we fluently divide our attentional resources over various activities in everyday life, we call this type of interaction "peripheral interaction."

We believe that considering and enabling peripheral interaction with computing technology contributes to more seamlessly embedding of such technology in everyday routines. This chapter briefly explores the history of peripheral interaction as a field of research and lays out how peripheral interaction, in our view, fits into the larger domain of interactive systems and HCI." My aim when coming to the Dagstuhl Seminar 17161 – Ambient Notification Environments, was to pick up the topic where Doris Hausen had stopped. I was curious to see how others felt about the input direction. However, during the course of the seminar I realized that there are still far more open issues on the output side than I had anticipated. Some of them have only come into life recently because of the scalability issues of notifications in our daily lives. These scalability issues will certainly also apply (probably even stronger) to the input direction, which means that there will be ample research opportunities in that field for years to come.

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3.5 Notifications and their Impact on the Awareness for Activities

Aurélien Tabard (University Claude Bernard, FR, aurelien@tabard.fr)

My research focuses on supporting reflection on individual and group activity. It is structured around two broad questions:

- How can visualization be made more relevant to people's context in order to better support reflection in-action [4], and
- How Activity Based Computing can accommodate ill defined activities, scaffolded activities and activities spanning across various people, places, devices and time, so that users have better means of reflecting on their past activity [1].

Self- and group-reflection are tightly connected to awareness of personal and group activities. Notifications are an interesting way to increase awareness, however they can also be highly distracting. Recently, I have been exploring how to design slow or calm notifications. These notifications can take the form of physical objects representing data, such as a run [4]. Making notifications physical and passive means that they can be always on, but won't distract and can blend in the environment. Another strategy we explored was to integrate notification and awareness tools directly into the objects of interest. For instance in a card sorting activity the participation of each user would be integrated into the cards. Rather than prompting one person to participate more or less with an explicit notification, the UI changes smoothly to notify the group of each others participation.

Finally at a larger scale we are currently exploring how to notify people of activities taking place in libraries, a place where calmness and focus are particularly valued, but in which people are increasingly coming to participate to public events. We are exploring by broadcasting notifications through pervasive displays, mobile devices, and dynamic signage.

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3.6 Embedded device use

Barry Brown (University of Stockholm, SE barry@dsv.su.se)

In this talk I discuss my interest in the 'embeddedness' of device use in everyday life. By this I mean the way in which devices are in state of 'incipient use' where a individual can start using a device almost at any time without the need to account for this to others. The question of when and where a device is used - before and after, as well as the question of the impact of usage on non-usage time are interesting directions for research. In my own work I have been drawing on video recordings of the use of smartwatches and mobile phones to try and understand this 'embedded' relationship - in particular how notifications work to incite usage from a situation of non use, and in contrast how usage can be 'occasioned' by the situation - such as waiting for a bus can occasion the use of a device.

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3.7 Smart Notification Management for Personal Assistants

Benjamin Poppinga (AUDI AG, DE, bp@benjaminpoppinga.de)

In my opinion, a smart user experience will be the key differentiator in a connected world. Nowadays, more and more smart devices enter the market. They are all connected, mutually notifying each other and the users about, e.g., air quality, strong winds, number of people in the house or whether the washing machine is finished. The increasing number of notifications is leading to information overload. Users who need to deal with that many information simply cannot stay in the loop on everything, and start to miss information or perform worse on their actual tasks. As a result, users feel annoyed or disconnected, which results into a bad reputation for the related products and brands. I started to work on smart notification management for mobiles during my PhD. Now, I am working with Audi and have the vision that the users will have a smart and highly adaptive user experience within our vehicles. To achieve this, I am working on two large research and development areas: driver monitoring and intelligent personal assistants. Driver monitoring is important to understand how busy the driver is with the primary task, e.g., to safely drive the vehicle. Here, deep learning is a breakthrough technology, which allows to have a very detailed impression on what the driver does or which additional information might be helpful in the current situation. Intelligent personal assistants, like Apple's Siri, will be a key user touch point in many digital environments. They have the role to assist us and, thereby, take some burden off the users. In my opinion, an intelligent personal assistant will be the central entity for all highly connected and smart experiences. My impression is that research and development teams worldwide have identified smart and intelligent user experiences as one of the key working streams for the next decades. Consequently, I am not only looking forward to smart devices and smart eco systems. I look forward to a seamless, adaptive, and truly immersive user experience, which feels convenient in all aspects and supports all humans to achieve whatever are their goals or dreams.

3.8 Intelligent Messages

Christoph Gebhardt (ETH Zurich, CH, christoph.gebhardt@inf.ethz.ch)

Optimizing the User Experience of Mobile Instant Messengers Mobile instant messages are a huge contributor to the problem of constant interruptions through notifications as perceived by a large number of smartphone users today. To tackle this issue, we work on a system which predicts opportune moments to notify users on received messages in order to maximize receptivity. Receptivity anticipates users' subjective overall reaction to an interruption, encompassing users' interruptability (depending on context) and their experience of interruption (depending on the content and sender of a message) [1]. For that reason, we want to find a model which predicts whether a user wants to be notified about an incoming message with respect to a user's context as well as the sender and the content of the message. Within that task, we are focusing on three particular problems of intelligent notification systems: Due to habit [2] or social pressure [3] users react on messages even if send at interrupting moments, making it impossible to build models solely by observing user reaction times. Related work solves this problem by randomly polling users on the perceived receptivity of a message. This has the disadvantage that the same or similar instances could be requested to be labeled several times, causing an unnecessary burden on users. In contrast, we intend to employ Active Learning to minimize user polling. In this framework, a certain property of a model is exploited to only poll users for messages where the model's prediction is uncertain subject to that property. Research has proven that in the context of notification management personalized models perform better then general models [4]. One consequence of using these individual models is that each new user will experience a "cold start", meaning that because of lacking data no proper predictions can be given. The standard approach to overcome this problem is to personalize a general model: a new user starts with a model learned on all existing users which gets individualized online with data collected from that user. To accelerate personalized model learning, we intend to explore user similarities. One conceivable approach could be to find a vector space which describes user preferences, enabling the retrieval of similar users. Related work has shown that content has a significant effect on the receptivity of messages [1, 5]. Nevertheless, nowadays systems do not consider the content of a message when predicting a user's receptivity. For this reason, we intent to apply semantic clustering on mobile instant messages and use these topic clusters to improve the prediction of receptivity models. Currently, we are collecting data in order to better understand the problem domain and be able to experiment with different models. Therefore, we implemented a smartphone app called MSGSTAZ which is available on Google Play. The application provides statistics and other features centered on mobile messaging. In the background, the app collects sensor data as well as sender and message content for each incoming mobile instant message. In addition, we sample users' receptivity for random messages.

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3.9 Unobtrusive Interaction for Wearable Computing

David Dobbelstein (Ulm University, DE, david.dobbelstein@uni-ulm.de)

Head-worn displays (such as Google Glass) allow for a quick access time to information and by that can serve to augment the user's memory.

Interaction with such a display, however, is yet a problem. While the input space is limited, the interaction itself can have strong social implications in public spaces. Missing social conventions and technology apprehension can affect the users' willingness to perform interaction in public. One possible way to address this, is to reach for preferably unobtrusive interactions that do not cast a lot of attention upon the user. Social acceptance may then rise due to continued exposure with the technology.

In our work, we focus on wearable touch input utilizing the user's clothes. In user studies on where participants would potentially accept wearable touch input, the spatial area at the upper thighs is often mentioned, because it allows for a quick access time from the resting position of a user's hand with little movement involved. We introduced a touch-enabled belt, allowing the user to rest their hand within the pocket while reaching for the belt with their thumb for touch interaction. In a user study in public we found that users feel comfortable to interact as long as the interaction is short and thus isn't perceived as interaction but rather random hand movement. For longer interaction, they preferred the area above the trouser pockets for the close proximity to the resting hand. In following work, we integrated touch functionality into the pocket fabric itself. This allows to reach the interface from inside and outside the pocket, which is utilized for dual-sided touch interaction. Most wearable touch interaction systems provide only very limited basic touch gestures such as dimensional swiping, due to a lack of available input space and difficulties providing hand stabilization in mobile scenarios. With our dual-sided touch interaction at the pocket, the hand can be stabilized into position enabling a cursor-based control with a high input expressiveness. In a target selection study, we found that dual-sided interaction utilizing both sided by sliding the thumb into the pocket and using the index finger to tap for selection from outside is significantly faster than familiar single-sided touch interaction using only the index finger to control a cursor (as familiar from laptop computers). This effect was largest when walking.

The dual-sided interaction furthermore allows to use the thumb as a spatial point of reference for the remaining hand which can be used for jointly performed gestures.

3.10 Augmenting Social Interactions: Realtime Behavioural Feedback using Social Signal Processing Techniques

Elisabeth André (University of Augsburg, DE, andre@hcm-lab.de)

In our research, we focus on a specific form of ambient notifications that augment social interactions by combining ideas from Augmented Reality with recent advances in Social Signal Processing. The resulting concept called Social Augmentation offers great promise for social skill training. It may be in particular beneficial to people experiencing social phobia or stage fright. By exposing people in-situ to selected stimuli, they may learn cope with negative emotions associated with socially-challenging situations, such as job interviews or group discussions. In [2], we illustrate the idea of Social Augmentation using public speeches as an example. While people engage with a staged or real audience, social cues, such as body posture and movement energy, are analyzed to provide immediate feedback on their behavior and thus help them adapt (see Fig. 1). A particular challenge is to provide feedback in a way that does not interfere with the main task, namely the social interaction with the interlocutor(s). To this end, we have analyzed and evaluated various options, such as visual feedback using head-mounted displays, haptic feedback using a vibrating arm band [1] and acoustic feedback. Social augmentation may also be of benefit to people being able to perceive their social context to a limited extent only due to physical handicaps. In [3], we show how blind and visually impaired users may profit from Social Augmentation by receiving information on their social context via sonification techniques (see Fig. 2).

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Figure 1 A user wearing an HMD while giving a lecture (left). Using various sensors and social signal processing techniques, the user receives real-time feedback on his behavior superimposed on his field of view (right)

Figure 2 A blind user wearing eye tracking glasses (left). Sonification techniques are used to communicate the facial expression of the person the blind user is directing her attention to (right).

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3.11 Ambient Episodic Memory Augmentation with Context

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Today's technology is radically altering the nature and scale of information that we can draw on for remembering. Digital photo albums, progress tracking applications, and e-mail archives are only a few examples of technological artefacts that improve our "episodic memory" – our ability to remember past experiences. However, despite this technological proliferation, people still struggle to remember past experiences. In fact, a surprisingly high amount of failing memories concerns one's daily encounters. This might be due to the today's hectic lifestyle that divides one's daily routine in numerous small segments, while often blurring the border between work and personal life. Inevitably, attention, which is important for creating high quality memories, spans over a large number of often simultaneous tasks. The episodic memory holds contextual information regarding who, what, where, and when of past experiences [3] – a summary of records of our life [1]. Once an episodic memory is formed, its information is said to be "differentially accessible", i.e., different sensory stimuli have different potential in triggering us recalling a particular personal past event. This is called "episodic activation" and describes the idea that in any episodic memory there is a pattern of activation that determines how its details are accessed [2]. Information stored in the episodic memory (i.e., episodic memories) is dominated by visual imagery that can have a “field” or an “observer” perspective, and are usually recalled in a temporal order. For successfully recalling an episodic memory, our memory system utilizes memory traces and encoded contextual information that arrives as input through our five senses. This contextual information is the basis of what is known in Psychology as memory cue, that when replayed help one remember about a past experience, a practise known as “cued recall”. Memory cues can come in a wide variety of forms, as long as they help trigger the memory of a certain past event. Memory cues are per definition never "complete" – they do not comprise the entire experience but merely a related context, e.g., a visual capture (picture), a sound (a song), or a smell. A memory cue can also be textual or an abstract visual, hinting at one’s activity, location, or social interaction at a certain time (e.g., device and application usage, GPS logs, Facebook posts) – a "personal context" of an episodic memory. Modern technology and trends such as lifelogging and the quantified-self movement, allow us to capture such personal contexts unobtrusively. Personal mobile devices such as laptops, smartphones, digital and wearable cameras (e.g., Narrative Clip), wristbands (e.g., Fitbit) or smart watches can all record – both implicitly and explicitly – a large range of contextual information about one’s daily routine. The ambient presentation of memory cues throughout one’s daily life hold the potential to significantly improve one’s ability to recall past experiences, while sharing many common aspects with ambient notifications. For example, memory cues – same as notifications – can be delivered via a plethora of daily encountered devices such as, smartphones, displays, wearables that utilize visual, audible, tactile or even olfactory modalities, while raising challenges about privacy and one’s attention and cognitive reserves in general.

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3.12 Ambient Notifications Environments as a Support for Daily Activities

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Currently, I am a PhD student in computer science working at the German Research Center for Artificial Intelligence, Saarbrücken in the field of human computer interaction, human factors, activity recognition, and wearables. In my research I explore how to build technology that assists in overcoming physiological and cognitive restrictions. I do so by trying to extract higher-level information from sensors in the environment and on body worn devices that helps to understand the users' current activities and ongoing mental processes. I am further investigating systems that take such information into account and enable individual meaningful assistance enhancing learning and improving social interaction.

More specifically, a current focus of my resarch are ambient notifications environments that can support people in their daily activities, providing courses of action and relevant information in context. A key aspect of ambient notifications is the unobtrusive provision of information, embedded into the users' environment. The number of services which are providing notifications on numerous devices, both mobile and embedded into the environment, is increasing. Therefore, is important to find unobtrusive ways for notification, avoiding redundancy, and the appropriate detail of information and alert level.

Another aspect of ambient notification environments is its spatial aspect. Kevin A. Lynch describes the 'need to reorganize and pattern our surroundings' driven by the fear of disorientation, or, positively speaking, by the wish for emotional security, which can arise from a harmonious relationship between the self and the outside world [1]. The intrinsic need for emotional security or respectively the fear to get lost stays in contrast with the design of current assistive systems. These momentarily ease our life but holds us back from learning and may also have an effect on general planning and problem-solving capabilities over longer terms. Spatial knowledge acquisition generally enables us to plan and take actions. The spatial relationships of the apprehended environment, as for example patterns, shape, connection, and separation, remain unchanged regardless of the scale at which it is viewed. Montello introduced the classification of psychological spaces in figural, vista, environmental and geographical space [2]. Effectively, the projective size of the spaces in relation the size of the human body serves as a basis for this classification. In terms of ambient notification environments, I investigate modalities and interaction designs that foster spatial skills and competencies while still maintaining an appropriate level of support.

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3.13 Blended Interaction and Ambient Notification Environments

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The goal of my research vision Blended Interaction[3] is to enable a user-centered design of natural interactions in interactive spaces. The framework tries to advance Mark Weiser's vision [4] to create an "invisible" ubiquitous computing "that provides us with the great powers of digital computation in an unobtrusive manner, so that we are freed to use them without thinking and 'mental gymnastics' and to focus beyond computers on new goals". For that purpose, it draws on the principles of Reality-based Interaction [2] and of Conceptual Blending [1]. Reality-based Interaction attempts to make human-computer interaction similar to the interaction with the real world. By drawing on humans' pre-existing knowledge and skills, the mental effort required to operate a system is reduced and users are free to focus on the actual task without their cognitive flow being interrupted by cumbersome interactions. In contrast to Reality-based Interaction, Blended Interaction not only applies users' natural skills and pre-existing knowledge of the real world but also considers digital well-established concepts in the design of new user interfaces. As humans spend more and more time in the digital world, we cannot consider human thinking free from digital influences anymore and need to take them into account when designing new interaction concepts. Conceptual Blending theoretically explains how human thinking subconsciously creates a new concept through projection from two existing input concepts. Therefore, human mind connects the two input concepts on the base of a generic space. The generic space contains basic level concepts which are com- mon to both inputs (e.g. both inputs are containers). On base of these commonalities, human mind blends both input concepts in an output concept that has a new and emergent structure which is not available from the inputs alone. Blended Interaction uses this process of indirect projection to theoretically explain that user interfaces only need to share selected aspects of reality for users to be able to understand and operate a new interaction design. This enables us to use computational power to go beyond what is possible in the real world by keeping a natural and intuitive interaction. During the Dagstuhl Seminar I had the opportunity to discuss how our Blended Interaction Framework could be used to design Ambient Notification Environments. The following questions lead my discussions: What are right blends for this kind of environments? What would we call a natural notification? What are typical design tradeoffs that have to been solved? The very fruitful discussions in different break out groups have shown that Blending Interaction has the potential to support designers of ambient notification environments to find novel design solutions for ambient notifications.

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3.14 Ubiquitous Sensing

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My research has in recent years focussed on ways in which ubiquitous sensing and actuation can connect to people in different ways. At Dagstuhl this year, I presented ways in which this melds onto what can be considered 'notification' - in some sense, ambient notification is what we see happening now, but this will eventually be considered to be augmented perception once users gracefully graft onto ubiquitous sensing now deploying under IoT. My team and I have outlined this via high-level review articles [1, 2] outlining the future of perception in the world of dense sensing. More detail has been presented on research projects that focus onto pieces of this - for example, our 'Tidmarsh' project [3], where we are building what we call an 'attention-driven sensory prosthetic', which funnels information into user perception that is derived from elements of the users' environment that he or she is focussing on. We have also designed ambient displays [4] that track user location, state, and gesture, providing relevant information accordingly in a fashion relating to ambient notification. My team has also recently explored personal lighting systems as a way to signal others [5], as well as rooms with ambient projection and lighting that can change with user state, context, and potential 'notification'. There are many other projects running in my group that overlap with the notification theme in interesting and productive ways, hence I was delighted to take part this year.

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3.15 Lifelong Learning

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My research aims to support lifelong and lifewide learning, by harnessing people's digital footprints, the data collected by diverse sensors on devices [1]. There are many ways that this links to ambient notification environments both in formal learning settings and more broadly.

Broadly, my work aims to transform raw sensor data into a user controlled, scrutable user model. The data ranges from activity tracks, to personal loggers, to interfaces for group work. The user model provides an interpretation of the user available data to represent aspects that are important for a person's goals for learning. Then interfaces, often called Open Learner Models, OLMs, [2] make this information available in useful forms, to support long term metacognitive processes, of self-reflection, self-monitoring and planning. There are two important roles for notifications associated with OLMs: prompts to remind the user to attend to the interface at appropriate times; and scaffolding to help people pay attention to the relevant aspects. An alternative approach we have been exploring is to create ambient interfaces that are carefully situated at the precise places that the user should consider their OLM.

For example, in our tabletop classroom, we created an environment where students worked in 5 groups, each with 4-6 students, at an enhanced tabletop system that tracked each student's work on the class activity [3]. Then, harnessing the data collected by the tabletops, we created a teacher's dashboard that provided real-time, continuously updated information about the progress of each group and each student in the group. In this context, notifications proved valuable for ensuring teachers gave more attention to the groups that most needed intervention [4]. So this is one example of an environment where active notifications seems valuable for enabling a teacher to manage complexity.

At a quite different level, we have explored how to help people with challenging behaviour change, in trying to meet the recommended levels of vegetable intake. So we maintain daily OLM of the number of serves consumed. One approach we have explored takes over the lock screen so that the 30-80 times a day many people unlock their mobile phone, they see a "subtle notification" that they intended to eat vegetables and they can easily see their progress on a gamified, pleasing display and very easily log each serve of vegetables.

Continuing this theme, we have been exploring how a SAL logger (Simple, Situated Ambient Logger) can help people use a simple OLM plus logging interface in diverse ways. For example, we have studied people configure their SAL to support behaviour change and maintenance by tracking intake of each food group [5] and to build new tiny habits, such a target number of pauses from desktop computer use for relaxed breathing, eye exercises or drinking water. We have also experimented with deployed use of SAL loggers for medication taking.

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3.16 Exploring the role of notifications relating to Group QoS and proactive behaviour in IoT environments.

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My research has considered notification issues across a range of areas including notifications to support users of distributed mobile groupware and notifications relating to proactive behaviour in an IoT environment.

In relation to distributed mobile groupware I was interested in the investigating the usefulness (and the required underlying middleware support) for enabling the specification of Group QoS and the use of notifications signifying Group QoS violations. For example, one might specify a Group QoS relating to the timely delivery of a message to all members of a given group. Assuming that one or more of the group members failed to receive the message in a timely manner, (e.g. because of a network disconnection) then the message sender would receive a visual notification that the specified Group QoS had been violated enabling her to act accordingly. The requirement for supporting Group QoS came from our work with a regional electricity board carried out under the EPSRC funded MOST project. A key requirement was for field engineers to be provided with appropriate 'Mobile Awareness' [1] when making changes to the switched power network in a distributed fashion rather than the more traditional centralized approach. The distributed approach required engineers to communicate updates to the state of the power network to the group of other field engineers who might be making their own changes/switches concurrently. Given the safety critical nature of the domain (e.g. ensuring that all engineers held an up-up-date view on which parts of the power network were currently switched to 'live') the use of appropriate notifications was critical in ensuring that engineers were made aware of when other field engineers were not receiving updates to the state of the power network in a timely manner, e.g. because of problems of poor wireless connectivity.

The potential role of notifications associated with IoT was studied as part of our research that explored the user experience issues associated with a system known as the Intelligent Office [2]. This system supported the proactive behavior of devices (e.g. the office fan) based on rules inferred from user behavior (e.g. under what contextual conditions the user would turn on their office fan to cool reduce the temperature rather than opening a window). In the developed system a notification would appear prior to the system actuating the given device in order to enable the user to either reject the suggested actuation, view the 'if-then' rule used to trigger the actuation, or even to inspect the learn behavior and associated context history used to infer the rule (and so support the user in scrutinizing the user modeling aspect of the system).

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3.17 Updating without interrupting

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Ambient notifications are designed to update the receiver without interruption. Can this work? This depends on the perceptual or cognitive resources that a notification would demand of the receiver in order to be effectively noticed. After all, a notification is not a notification if it is not noticed. Nonetheless, a receiver can certainly be updated without be behaviourally disrupted. My research has consistently demonstrated that task-irrelevant environmental sounds can elicit brain responses that underlie working memory updating without compromising steering itself [1]. This response weakens as the steering task becomes more difficult. In other words, it is noticed but less so when the receiver is occupied. It requires resources but it does not demand them. Ambient notifications are designed to operate in a similar way. In this seminar, we heard of light environments that change hue according to the user activity [2], of worn clothing that constricted instead vibrating upon receiving notifications [3], of wall panels that created new environments in response to the user's brain state, and more. The brain responds to these changes in the environment (hopefully in positive and the intended way) without stealing from the current task.

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3.18 Ambient Notifications for Dementia Care

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Age-related health issues, such as dementia, will become a major cost factor in Denmark as well as many other western countries. The Danish National Research Centre for Dementia (2015) estimates that the number of people with dementia in Denmark today is 84.000 and will increase to 151.000 in 2040. People with dementia have a tendency to wander which includes going to places they should not, night-time wandering, trailing others and attempts to leave the house or care facility [4]. Especially the latter is a big concern for relatives and caregivers. As people with dementia are often unable to take care of themselves there is a serious risk that their straying can lead to dehydration, hypothermia and in the worst-case fatality [1]. The tendency to wander is often paired with previous life routines, e.g., going to work each day. These types of wandering behaviour occur for different reasons and is not always obvious why. Cognitive impairment is often a causative factor for wandering and a correlation between the severity of the impairment and the behaviour has been shown [1]. Other factors such as stress, boredom and environmental influence also affect when, and how often, the wandering behaviour is triggered (e.g., too busy, too much noise) [1, 2]. We want to increase security and reduce the concerns of residents, caregivers and relatives without limiting residents' sense of autonomy, and their opportunities for daily activities. Therefore, electronic tracking and tagging solutions have been suggested and implemented to ensure the safety of the residents. Tracking devices are often used to preserve the independence of a person with dementia and to provide the caregivers with reassurance One of the most important parts to ensure the effectiveness of such as system is the user interface. It is important that the caregiver receives the right information at the right time in the right manner so the caregivers can take the necessary actions e.g. to avoid that a resident leaves the facility. Especially, as we want to avoid additional temporal or mental demand for the caregivers the user interface needs to blend into their workflow. We will develop novel notification techniques that are embedded into the environment and its architecture. For example, instead of just using mobile devices that the care giver carries around or public displays in the facility, different elements in the environment such as color of the lighting could notify the caregivers of potential danger in an ambient manner.

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3.19 Notifications through Indirect Illumination and Pneumatic Compression

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We investigated two different notification approaches for wearable devices that aim at less intrusive notification experiences. The first is based on visible light that is scattered through the skin. The second is based on pneumatic compression feedback. This work was done in the HCI group of the University of Hannover and is mostly by Henning Pohl, who just completed his PhD thesis and is now with the University of Copenhagen.

The first approach to mobile notifications uses the underside of a smartwatch for indirect light feedback. A main function of smartwatches is to notify the user. Typically notifications that arrive on the mobile phone are dispatched to the smartwatch and played there as vibration feedback. However, vibration feedback can quickly become annoying as it is quite attention grabbing. This is the reason for some wearers of smartwatches to disable this functionality. We propose an alternative in which eight LEDs on the backside of the watch illuminate the skin surrounding the watch. Human skin transmits light. Only about 5% of the light is directly reflected from the skin's surface. The rest is scattered and subject to dermal and epidermal remittance as well as absorption. This effect becomes stronger near the infrared range. This is the reason we used red LEDs with a wavelength of 623 nm. For manufacturing reasons the SMD-LEDs are soldered on a PCB, embedded in a thin silicone layer and face down.

We performed an in-the-wild user study in which 13 participants wore our watch prototype with indirect light feedback for 24 hours on a weekday. They only took off the watch at night. The light stimuli were played at random times every couple of minutes. The study took part in the summer of 2015 with 6 hours of sunshine per day on average. Participants reacted to 80.3% of the light stimuli and took 16.6 seconds to react to the stimuli. The reaction time distribution has a long tail, so some of the notifications took much longer to be noticed. The participants generally liked the light feedback, but were concerned about others noticing the light feedback in public. Moreover we designed and tested different light patterns, like rotations and oscillations. Participants were generally able to distinguish most of the light patterns. There were no large differences in terms of reaction rate and reaction time.

The second approach to mobile notifications uses pneumatic compression feedback. A repurposed blood pressure meter is used at very low pressure levels to create uniform compression around a limb without generating shear forces. A unique characteristic of this approach is the wide range of haptic feedback that can be generated, from very subtle to very strong, so strong that it inhibits movement. Low pressure levels can be used for continuous background feedback. We conducted an absolute detection threshold experiment and found threshold levels of 0.7 kPa in the lab and 2.3 kPa in the wild. In comparison, blood pressure cuffs are inflated to 16.0 kPa (120 mmHg) for systolic and 10.7 kPa (80 mmHg) for diastolic blood pressure, i.e., 15x-23x the lab detection threshold and 5x-7x times the in-the-wild detection threshold. We did a 1-hour experiment with 9 participants, in which they wore a cuff inflated to 1.3 kPa for during deskwork. They did not report any feeling of annoyance or inhibition.

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3.20 Towards Holistic Notification Management

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We currently witness a steadily increasing number of notifications that are delivered to users through a similarly increasing number of notification channels. Today, users can be notified through their smartphones, tablets, PCs, and smart watches. In the near future, Internet-of-Things devices will not only generate additional notifications but will also be able to notify users themselves. In our work, we investigate how users interact with notifications today [1], study users preferences when they have multiple devices that can notify them [2], and explore notifications in smart home environments [3]. As we assume that current approaches for notification management do not scale, we envision a holistic notification system that manages incoming notifications across device boundaries.

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3.21 Notifications in Mixed Reality

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We already face a vast amount of notifications delivered to our smartphones and tablets, and nowadays to smart TVs and watches, too. This trend is further fueled by more and more Internet of things (IoT) devices. Further, due to the advances in the field of mixed reality, notification output systems will move closer to our eyes to catch our visual attention.

Head mounted displays such as the Google Glass already offer limited input and output space to display notifications and are always in the field of view of the user. New augmented reality (AR) glasses allow displaying high-resolution three-dimensional content located in the real world. There is a potential need for a notification system which is aware of the user's current context and location. Instead of using levitating physical tokens [2] to visualize digital information, AR-glasses in combination with context aware notification systems could reduce the notification overload we currently face [3]. Several virtual reality headsets are now available for end users. Users immersed in a virtual world are not penetrated by notifications since they are currently not forwarded into the virtual world. However, we assume that systems will support notifications in VR shortly. Possible concepts to notify the user include well-known visual and auditory, but also haptic notifications [1] methods are imaginable. In all instances of the mixed reality spectrum, we need to investigate new techniques to manage the increasing amount of notifications to unburden the user.

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3.22 Towards Visual Notifications in Multi-User Large-Display-Environments

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Towards Visual Notifications in Multi-User Large-Display-Environments In our research at the Interactive Media Lab Dresden we are concerned in particular with using several interaction modalities – such as multitouch, pen, gaze, gestural, and tangible input – for the interaction of one or multiple people in environments with interactive surfaces. Typically, input modalities can be synergistically combined, like gaze input with multitouch input [6], or offered in parallel for a seamless transition, like body movements, hand gestures, and touch input in BodyLenses [2]. In addition, multiple interactive surfaces of different sizes can be combined to provide effective multi-display environments (MDE), like handhelds with large wall displays [8, 4]. Naturally, such environments are well suited for multi-user interaction and collaboration.

Our research in multi-user multi-display environments illustrates that notifications are no longer limited to personal settings, but need to be managed for multiple users simultaneously. What is the best notification place and technology? Where can people be notified during collaborative work in MDE? In our SleeD approach [8] we for example use personal body-worn devices to provide visual feedback and notifications to users at a large display wall. With BodyLenses [2] we contributed personal territories for individual users at interactive wall-sized displays, which, like a personal lens, can be moved around by just moving the body or interacted with by means of hand gestures and touch input. Another related question is who is actually interacting in an MDE and how to assign both interactions and notifications to individual users. With YouTouch! [7] we developed an approach using depth-cameras and color histograms to identify users even under difficult conditions. Knowledge about the user's current attention using eye gaze [6] can also help supporting the display of appropriate peripheral notifications depending on the user's point of regard.

Another research avenue of the Interactive Media Lab is interactive information visualization using natural user interfaces. In our visualization research, we raise the question how visualization knowledge can help us in designing effective notifications and which modality in general is most appropriate for ambient notifications. The question where to present feedback and notifications has been addressed by our lab in several ways. Examples include tangible everyday objects [1], smart projections in everyday environments [5], and even normal paper being illuminated using electroluminescence in digital pen and paper applications [3].

For the future, we are not only interested in the "how" of ambient notifications – which often is the focus of current research, but increasingly in the question "how much" and the degree of user control. We call for more mindfulness in ambient notifications and a rigorous revealing of dark patterns.

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3.23 Multimodal Notifications

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My research focuses on multimodal feedback and using the range of capabilities that humans have to enable rich interaction with technology. These different feedback modalities can be used to create ambient notifications for users in different settings.

We have developed notifications in several different modalities. For non-speech audio, Earcons can be used to create messages for ambient feedback [1]. By changing auditory parameters such as timbre, rhythm, pitch, spatial location or tempo, different messages can be built up. These can be composed by concatenation or by hierarchically by changing parameters in turn [2].

Tactons are the touch-based equivalent of Earcons. By manipulating parameters of tactual perception, different messages can be created for ambient notifications, for example, waveform, rhythm and body location [3]. Tactons have been used in many different applications including as messages for mobile phones and for in-car feedback. Other types of notifications we have tested have included smell-based [4], ambient visual and thermal notifications [5]. The general process in all of the different modalities is to use an applied psychophysical approach: we first look at the range of human perception to establish human limits and we then develop and test a range of cues within that to see what is perceivable and usable.

Two specific areas of application are in homecare setting and user interfaces for cars. Caring for people in their own homes is a growing area for research due to ageing populations and decreasing healthcare budgets. Due to the wide range of sensory loss that can occur in old age, different forms of feedback and interaction are needed for homecare systems. A user with poor eyesight may need a very different system to someone who has poor hearing. Multimodal notifications can play a significant role as the same messages can be configured to display in different modalities. This makes them accessible for a wide range of users [6].

The key issue for notifications in cars is that they should not distract the driver. As driving requires visual attention on the road ahead, multimodal notifications can be used to inform the driver of information without needing visual attention. We have tested a range of different modality types in the car, from ambient visual, audio, tactile and thermal, plus many different combinations. The results from the studies suggest that more modalities are more attention grabbing [7]. If you want to get a driver's attention for important information then use multiple modalities. If the message is of lower importance then a single modality may be more appropriate.

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3.24 Guiding Attention in Cyber-Physical Environments

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Cyber-physical systems technology blends human attention with intelligent digital systems. Even with greatly increased automation in the future, the human will need to be in the loop for monitoring. However, interaction with cyber-physical systems like cars, ships, robots, smart homes, or emergency rooms will change dramatically: (1) humans will interact much less frequently with the larger automated cyber-physical systems than with today's simpler automated systems; (2) human interaction will be needed to a much greater extent for tasks in which the human is superior to the machine and where automation finds its limitations; (3) humans will be free to dedicate more and more of their cognitive resources to other tasks, with their attention shifting only when needed to interact with the automated Cyber-Physical environments such as Vehicles [1], Intensive Care Units or Ship Bridges.

Interfaces currently addressing these requirements for decision making in complex cyber-physical systems are rather primitive, mostly limited to single, unspecific alerts and auditory cues for gaining and dragging the attention to information and entities. Frequent, often unspecific alerts are leaving the human with the demanding task of identifying and localizing the problem. Different alarms, color changing displays, and sounds are even competing for the individual's attention, leading to irritation, alarm fatigue, and potentially dangerous human errors. While existing research in psychology shows that attention can be cued and that the quality of arousal, notification and attention shift influences the quality of task performance, a translation into human-computer interaction technology is fundamentally lacking.

In our ongoing work, we develop and evaluate pervasive displays for guiding human attention in cyber-physical environments by arousing an individual or several people and directing their attention and cognitive resources to a task or task sequence as they interact with an automated cyber-physical system. Starting out with work with pervasive display for notifications for example in the field of task switching [2] we moved into the domain of increasingly automated cyber-physical systems. With head-mounted peripheral display technology we are notifying nurses in intensive care units about alarms while reducing acoustic noise [3]. In the maritime domain, we are visualizing critical situations and off-screen objects by peripheral head-mounted displays to increase situation awareness in maritime navigation [4]. We are designing ambient notifications for take-over of a human after a phase of automated driving [5]. Our overall goal is to develop digital technology for guiding and shifting attention by an egocentric display, which is formed by an ensemble of embodied, peripheral, and ambient displays. Our research will result in a fundamental understanding about effectively supporting of human-machine cooperation of tomorrow in which human and machine cooperate as a team supported by digital technology in increasingly automated cyber-physical systems.

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3.25 Notification Management is Important to Avoid Information Overload

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Digital devices that are capable of providing notifications to their users have become ubiquitous over the last decade. We encounter and interact with such digital systems in our daily lives in different shapes. In our smart homes we have multiple interactive devices providing notifications on the status of the house's infrastructure, such as the heating system, doorbell, blinds, etc.. It is common that the notifications are provided by a smartphone application. However, smart home sensors of different vendors usually come with different dedicated apps, increasing the number of sources for notifications. Additionally, many of today's household appliances also communicate their current status through notifications having different modalities. For example, dishwashers project the information onto the floor or washing machines beep or send a message to a phone. This already results in a huge amount of – often distracting – notifications in our daily lives. Regarding smartphones, the situation becomes even worse [1, 2]. It is quite common to have more than 100 different applications installed on the smartphone. Most of the are displaying notifications to inform the user about new content, incoming messages, or they simple crave for his attention to open the app. If you have multiple smart devices (e.g., smartphone, tablet, smartwatch, notebook, smart TV, etc.), you usually receive the same notifications on each of the devices, causing an information overload that may lead to a notification blindness, where the user either ignores incoming notifications or just turns them off. A similar effect could be observed with public displays, that flood public spaces with digital advertisements [3]. We need to develop smart notification management systems that handle incoming notifications and provide them to the user in an appropriate situation, modality and frequency. If you acknowledged a notification on one device, it should also be acknowledged on all other devices. Another example could be that notifications are only displayed on the device that is the closest to the user. Ideally, in the future, notifications will detached from particular digital devices such as smartphones, tablets or wearables. Notifications should be displayed at the right time, in the right modality and in the right place. They should be ambiently embedded into our environment, which is a challenging task [4]. For example, a water dispenser in a living room could be illuminated to notify a person of drinking more. A further issue that needs to be addressed when developing smart notification management systems is the demographic change. In the future, the number elderly people compared young people will drastically increase. In order to develop usable notification management systems and in order to achieve a good user acceptance, systems need to be designed with elderly users in mind.

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3.26 Towards Attention-Aware Adaptive Notification in Advanced Ubiquitous Computing

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There has been an explosion of information available for people to read and act on. However, the amount of attention that can apply to this growing amount of information, has remained constant. Approaches for dealing with this include multitasking or dividing attention among a number of sources, and relying on push notifications to bring information to the forefront of their attention. However, notifications are responsible for an even greater number of interruptions. This is exacerbated by the fact that users are carrying, wearing and using a growing number of mobile and wearable computing devices including notebooks, tablets, smart phones, smart watches or wearable sensors, all of which can deliver interruptive notifications. Making the problem even worse are the growing number of installed applications on each device, each of which can also interrupt the mobile device owner. In particular, communication-based applications that support phone calls, texts chats, and social networking particularly suffer from this. But, games, news and other applications have similar issues as well, leading to a setting where people's everyday lives are significantly impacted from a feeling that they are being constantly interrupted by their computing systems.

Given the ever-increasing degree of information overload, the limited resource of human attention is the new bottleneck in interactive computing. In our research, we particularly focus on interruption overload, a form of distraction caused by the excessive number and inappropriate delivery of notifications from computing systems. All widely-used notification systems deliver notifications as soon as they are received, and this has been shown to negatively affect users' work productivity. Users experience notifications at "random" timings; that is, as they arrive on her devices. In other words, notifications from a variety of applications and services reach Melissa without any consideration of whether she is actually interruptible, causing divided attention and possible having negative impacts on her work productivity. In ubiquitous computing where computer systems promote calmness, they need to behave adaptively with regard to the user's current attention and interruptibility status. To address this problem, we follow the proposal of past literatures, to defer notifications until the user is experiencing a natural "breakpoint", defined as the boundary between two adjacent units of a user's activity. Deferring the interruptive notifications to this point can lower the impact of the interruption on users' cognitive load. Our research software Attelia successfully detected mobile user's breakpoints both during her physical activities and device interactions, in-real-time, by using mobile sensing on the smartphone and smartwatch and machine learning classification technique. Our current significant research challenges firstly include evaluation of our software in the real-world. We integrated the Attelia logic into Yahoo! Japan Android app. Our extensive in-the-wild user study with more than 680,000 users revealed that notifications in breakpoint timings surely improve users' experiences with reduced response time, increased click and engagement level. The second challenge is integration with smart city research. To review citizen's subjective experiences in a designed smart city, we plotted user's affective status (including interruptibility) onto a geographical map called "Affective Map". Our initial evaluation with the map revealed different types of breakpoints and interruptibility are observed in different locations and situations, such as rides in the train and buses.

3.27 Interactive Assistance in Working and Teaching Facilities

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Disturbances at work and learning environments by external factors interrupt the workflow in which the person was. Besides of decreasing the concentration on the current task, a refocus on the task is required to enter a flow state again. Distributing the current physiologoical or cognitive states helps to avoid unnecessary interruptions by others. Within the course of our research, we investigate how physiological parameters can be measured effectively and visualized ambiently to notify the person itself and their social environment. Informing social contacts about the current state avoids unnecessary interruptions when doing intensive tasks.

Generally, our work encompasses the measurement of physiological conditions to provide interactive assistance in working and teaching facilities with embedded cognition-awareness. We focus on the analysis of eye movements, brain activity, facial parameters, galvanic skin response, and musculuar activity. This is complemented by the training of models, which are suited to individual physiological responses. Such metrics can be used in a variety of use cases: reflecting physiological conditions over a timespan or adapting visualizations are just a few areas of interest. Within this, we investigate how physiological states can be used collaboratively, for instance, when it comes to notify other people or the person itself about his state.

It is important to be aware how to communicate this without drawing too much attention at the same time. A visual approach is to slowly increase the brightness of a lamp according to the stress and mental level of an individual. Heating up the door handle to a reasonable temperature provides a haptic solution. Finding the optimal representation modality states another challenge during the course of this research.

On a visual level, we have looked into how brain activation can be represented in an understandable way [1, 2]. Demanded brain parts are visualized in a color coded way, making the overall cognitive load visible the individual. Transferring these insights ambiently is our scope for future work. This is complemented by a feedback study [3], where we investigate the suitability of ambient tactile, visual, and auditory feedback. The results show a high preference for visual feedback.

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3.28 Awareness in Computer Supported Cooperative Work

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Ambient notification environments are an exciting research topic with many unsolved research questions and challenges. At the same time they have some predecessors and related areas that can provide great input. Particularly context-aware systems and event-notification infrastructures have a lot of similar challenges. Also the whole body of research in Computer-Supported Cooperative Work (CSCW) on awareness, which in general addresses questions around providing users with important information of their environment including other team members, has a lot to offer. Great concepts and systems have been developed and ethnomethodologically-informed ethnographic studies have a lot to offer towards a better understanding of how users manage to perform their own tasks and at the same time capturing what is going on around them.

At the Dagstuhl Seminar 17161 on Ambient Notification Environments I gave an overview along my historic survey paper on 25 years of awareness research in CSCW [1], where I characterised the origins of awareness in CSCW both in terms of ethnographic findings as well as in early concepts and technologies. Great concepts and technology have been supporting coexistence awareness with mutual information on users' presence and cooperation awareness with mutual information on users' activities in shared editors and other environments. Base technologies for sensing data and for presenting awareness information have been reported as well as various approaches on modelling awareness information.

In my own work related to ambient notification environments we have been doing surveys on awareness in in recent [1] as well as early [2] works. We have also developed our own event notification environments. For instance, in Gross and Prinz [3], we have presented an early approach that addressed challenges that are still relevant today concerning the capturing of data in their context of origin, modelling work contexts of users and keeping those models up-to-date, and presenting in-situ relevant awareness information on the users' computer screens as well as in their physical environment with ambient displays.

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3.29 The Role of Task Engagement in Mobile Attention Management

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Interruptions following mobile notifications are a complex phenomenon stemming from the message arriving at an inappropriate time, when the user is commuting on a bicycle, sleeping, or in a meeting, to name a few such situations. In addition, messages can be inappropriate due to their content or the nature of the sender-receiver relationship. In our work we have built models and practical systems that take the above factors into account and try to predict a user's interruptibility [1, 2, 3]. However, anther important aspect that impacts a user's interruptibility is the current task engagement, yet, this has been overlooked in mobile notification management systems. The knowledge of a user's task engagement or the cognitive load, opens up an array of possibilities for a seamless mobile computing device – human interaction, beyond just mobile notification management. Today's most ubiquitous personal sensing devices, such as smartphones, are equipped with an array of sensors that may be used to infer different aspects of human behavior. Still, inferring task engagement using smartphone sensors has not been explored. In our research we investigated the automated task engagement inference using only smartphone sensors [4]. We designed, developed and deployed a mobile sensing application TaskyApp, and collected sensor readings and task engagement labels from eight users in an office setting. Using machine learning we demonstrated that there is weak link between the smartphone sensor data and the task engagement. The most promising are the movement features, sensed by the built-in accelerometers, that show a significant correlation with the task engagement labels provided by the user. However, for full inference, the smartphone is not sufficient. In our future research we plan to use wearable devices, predominantly smartwatches and wristbands, in order to get physiological data pertaining to the user. Information such as heart rate variability, electrodermal activity and skin temperature have been shown to correlate with the user's cognitive load. Yet, these correlations have been shown only in well controlled laboratory settings with specialised equipment. Our research, on the other hand, aims to recognise task engagement using commodity wearable sensors.

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4 Sessions

4.1 Notifications vs. Augmentation

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URL https://www.media.mit.edu/people/joep/overview/

Currently, sensors are embedded in everyday devices. Joe Paradiso presented their developed general decentralized web based sensor framework (CHAIN API) to describe sensors (real sensors, virtual sensors) as RESTful resources. This is a a lightweight, adaptive way to describe sensors and to define relations between different services with a shared vocabulary. Combining different sensors with Amazon Echo or Google Home is anticipated to give rise to the "Digital Butler". These devices are expected to inform the users proactively about their own needs. After a transition phase to ubiquitious computing, smart environments will become an extension of the self.

In addition, Joe Paradiso described a need to redefine the user's presence in physical environments. In the future, sensors will be able to deliver different information directly into the user's perception. In this regard, Joe Paradiso presented built environments that affords extra-sensory perception. For example, sensors that are embedded through the MIT building collects multi-modal sensor data that is produced by the building itself or its inhabitants that are invisible to natural percepion. To communicate this data, real-time visualization are engineered that presents aggregated information to whoever might require it, e.g. the temperature in different areas (cf. DoppelLab [1]). While natural human perception is incapable of 'seeing' temperature and is limited of seeing people hidden behind walls, such visualizations will allow us to do so.

Another offered example was the Living laboratory [2] near Plymouth, Massachusetts with a size of 600 acres. In this area, many sensors were deployed to document the ecological processes of the restoration to natural wetland. In total, four key locations were set up as base-stations (running on solar cells) as well as numerous and varied sensors, e.g. The Mayton 2.0 Tidmarsh Wireless Sensor. Thus, information about the environment could be collected and transmitted in many different ways. For instance, they have set up a website that visualizes real-time aggregated data from the various sensors to allow people to explore the environment from the comfort of their own homes. Besides this, they have developed a DoppelMarsh VR sensor visualization to display the living observatory at the same time as the aggregated sensor information, e.g. temperature. Another VR instantiation provides a holistic view of the living observatory from a high altitude view together with real time sensor visualization. All of these instances afford humans the ability to access and process information about remote environments in ways that extend beyond our natural capabilities.

To allow users to "inhabit" remote environments, it is not sufficient to provide visual information. A separate project seeks to display virtual sounds in the user's environment that are indistinguishable from the user's real, actual surroundings. They use an eye-tracker, a chest strap sensor, a touch and a head tracker as well as a bone conduction headphone to display virtual sounds from a distance. Another framework, they developed is Quantizer a collaboration of ATLAS and the Media Lab. This framework supports diverse musical

[1] DoppelLab: http://doppellab.media.mit.edu/
[2] tidmarsh.media.mit.edu

compositions running on a real time ATLAS/LHC data. It composes music based on the detected particle collisions in the large hydron collider.

The ubiquitous deployment of sensors will not only allow us to modify our felt environments, it will also allow environments to modify themselves in response to our needs. In another project, wearable sensors were used in combination with sensors in the building to adjust the room temperature in a way that saved heating energy as well as optimize user comfort. Similarly , ambient lighting conditions were controlled using synchronized cameras within the infrastructure as well as a Google glass that adjusted reflected light to be optimal at the location that intersected with the user's line-of-sight. Also, the light conditions were regulated with a smartphone app to correspond with the user's moods (e.g., casual, focused). All of these serve a basis for create workspaces that are notified of their occupants' requirements such as to create a conducive ambience, for example mediated workspaces to relax employees (cf. Mindful Photons [3]).

4.2 Multimodal Notifications for Ambient Environments

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Stephen Brewster presented a substantial body of research that explored how multi-modal notifications could be effectively combined to create interfaces that display information, particularly in a way that exploit available sensors.

One key example that was provided, which would benefit from this endeavor, was home support for aging. Here, the goal is to support an elderly person with reminders about medication, appointments, and food intake. In this case, it is important to be able to provide discreet and private notifications that are considerate of the context and do not embarrass the user. A key factor for design is the fact that users tend to desire a feeling of being in control. Therefore, notifications has to be delivered to the user with the right notification modality and at the right moment, e.g, during performing everyday activities or potentially concentrating on a current task or interacting with others.

Vision continues to be the most dominant channel for delivering notifications. This is because it affords a large design space (e.g., shape and color). Another form of a notification is the earcon – non-speech audio such as music, structured sound and other sound effects. However, auditory notifications suffer from the disadvantage that they are not typically private. In this regard, tactile notifications represent a more private channel but one that requires near proximity in order to be detected.

More exotic channels of delivery have been explored. For example, olfactory notifications, such as the smell of dark chocolate. Temperature can also communicate strong and intuitive notifications where by values of cold, warm, or hot are arguably related to strong emotional responses (e.g., warm for loving, cold for distant). Typically, the palm is the most receptive body part, but acceptable sensing can be achieved with the wrist and arm. Temperature

[3] Mindful Photons: https://www.media.mit.edu/projects/mindful-photons-context-aware-lighting/overview/

notifications can be embedded in our environment, whereby a door handle can be either cold, warm, or hot. User studies have shown that this is consistently interpreted as the occupant being, respectively: away, present, or busy.

Several studies showed that combining traditional notification modalities, e.g. tactile and sound, results that notifications were perceived as more urgent and critical. In addition, the use of physical objects within the environment of the user as a notification channel is a completely new approach to display notifications, which should be investigated in future work. Another research questions is how traditional and new notification modalities can be combined to display notifications.

To conclude, Stephen Brewster issued a list of challenges and key questions that beset the design of future notification systems:

1. How can we assure that people who sent the message and those who receive perceive the importance and urgency levels to be equivalent?
2. How can we ensure that notifications are discreet and private?
3. How do we give people a sense of control over their notifications?
4. What do notifications suggest about a person's character (e.g., discipline, attention, control) ?
5. Is this generally true that notifications affect performance (in a memory game), choice of modality did not affect performance.
6. Why is the urgency increasing with increasing redundacy across modalities.
7. Can we physically change an object to create notifications (eg., more easily seen or felt)?
8. How to combine modalities successfully?
9. Are more notification channels always better?
10. What new possibilities are there for other notification strategies?
11. When should we use which channel or strategy for which users?

Altogether, multi-modal design spaces are more varied than would be conventionally imagined. This is especially when dimensions beyond our natural senses are considered (e.g., temperature). A key challenge lies in understanding how they can be effectively combined to communicate notifications in a way that is intuitive to our instinctive interpretations and in a way that can be pragmatically embedded in our environments.

4.3 Augmenting Social Interactions

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In this talk, Elisabeth André expounded on the state-of-the-art capability of computing systems to sense and interpret social cues, for the purpose of generating appropriate responses to their users. She presented use cases that relied heavily on augmented reality and social signal processing, the latter for which her research has developed numerous algorithms that can be readily implemented with off-the-shelf sensor devices.

With regards to social signal processing, her work targets the decoding of emotions, facial expressions, gestures, speech, physiological measurements, interest, engagement, trust, personality, rapport, group cohesion as well as functional roles. As mentioned above, her extensive research has resulted in the development of a social signal interpretation framework [4] that seeks to be readily deployed across research labs and different environments. This framework allows for the synchronization of a large variety of sensory data recordings as well as the interpretation of emotional and social behaviors of observed users.

In one use example, Elisabeth André reported how this allows social interaction to be supported in order to motivate targeted users to behave in a context-appropriate fashion. For example, she noted how the inappropriate behavior of candidates at interviews could have untoward consequences. Therefore, continuous feedback could provided, based on exhibited behavior to shape the behavior of the person that SSI observes. Project TARDIS is a milestone in this endeavor to inculcate desirable interview behavior [5]. Here, students are trained within a game that provides closed-loop feedback, to generate appropriate gestures and verbal speech that are typical to a successful job interview.

In another example, OpenSSI can be deployed to pick up and aggregate social signals from a target live audience. This can be used to provide real-time feedback to speakers, allowing them to modify their talks in response. In one study, participants gave short presentations with or without the support of such a system. The main findings were that the inappropriate behavior of the participants decreased when speakers were provided with real-time notifications, based on the social signals sensed and aggregated from the environment. In a separate qualitative study, more naturalistic discussions were set up to investigate if real-time feedback, which were based on sensed social behavior, would improve or disrupt social interactions. Participants were divided into groups that discussed a topic for 10 minutes. Different participants within each group provided notifications via a variety of channels (e.g., visual head-mounted-display, tactile and audio output). The study's results demonstrated that real-time notifications based on social sensing resulted in discussions that were more balanced. Furthermore, the notification system were not considered to be particularly disruptive. Participants reported that they appreciated feedback and modified their behavior accordingly: "It was a good feeling to see the icons in green. It lasts longer than a nod [and easier to detect]." Tactile notifications were rated to be the most disturbing and audio as the least.

An interesting outlook of this work would be to investigate whether participants might pay attention under conditions that provide subliminal feedback. Currently, behavior only appears to be responsive to supraliminal notifications. Nonetheless, this could be a matter of its implementation. The rapid advances noted in wearable devices (e.g., Google Glasses) could provide the means whereby notifications could be delivered that are at the same time accessible to their users' consciousness without being obtrusive.

4.4 Debates

During the seminar, three debates were organized on topics that participants voted on. The first debate was on whether user control is an illusion regarding notification systems and their applications. The second debate dealt with the question of whether artificial intelligence will be able to solve all problems regarding notifications in the future. The last debate addressed whether adding a cost for messages is a good idea for restricting the deluge of unnecessary and undesired notifications.

[4] OpenSSI: https://hcm-lab.de/projects/ssi/
[5] TARDIS: hcm-lab.de/logue

Figure 3 Seminar participants debating controversial topics.

Every debate featured an advocating as well as an opposing team, with four speakers per team. Each speaker spoke for 3 minutes. The summaries are structured to capture the turn-by-turn dialogue between the advocates and their opponents.

4.4.1 Debate 1: User control is an illusion

Advocates:

Control is something that directs behavior or the turn of events. In contrast, illusion is a deceptive idea or belief. The user is under a false impression. In addition, users might not be allowed to make changes for certain applications. If I want the app, I have to give up control (i.e., terms and conditions) Also, developers want to have the control rather than to allow it to users. Users may believe that they are in control but they are not.

Opposition:

The control freaks also looked at some definitions Users can always switch their phones off. That is an ultimate point of control. Humans are able to focus and cut out unwanted information. New methods to present information.

Advocates:

We are not hermits. We are surrounded by devices that we cannot turn off. We have attention that is less than a goldfish. We cannot understand the rules behind these systems so how can we control them? We cannot turn things off because notifications are sent by our loved ones and we do not wish to turn things off and hurt people's feelings. Because of our risk-averse nature, we fear turning off notifications in case something bad happens. We cannot control our participation.

Opposition:

Personal notifications need not be in everybody's face (e.g., vibrotactile cues). Systems can learn from what you do. You are in control of the information that you supply to notification systems. Adjustable parameters allow for control.

Advocates:

The reality is that we are bombarded by notifications. Attention is an ability that we have evolved to control. This ability evolved from many centuries of physical manipulations. It is not developed to deal with modern technology. You cannot switch off your brain.

Opposition:

We are responsible for information overload. Nature holds more information than systems can send us. Stimuli are changing (becoming more salient) than the natural environment. Any notification can be dealt with in different ways. We have a wonderful capacity for ignorance, and we can learn to ignore new stimuli

Advocates:

Providers have a lot of influence their applications. We cannot switch our technology off for the whole week. Opting-out is not an option because it takes too much effort.

Opposition:

These applications are something that we created ourselves. Humans grow up in new systems and are able to adapt to these new systems. Never before have users had more control than now, over things that they have never imagined was possible.

4.4.2 Debate 2: Artificial Intelligence will solve all of our notification problems

Advocates:

What are the problems in the moment? Incoming notifications grab our attention, therefore the task completion rates are getting lower. Also, the receiving notifications is poorly timed. Thou, users receive notifications in inappropriate situations. In contrast, artificial intelligence (AI) is designed for scheduling. Humans are bad in dealing with notifications and set up their notification systems. However, in the future notifications will adapt to autonomous systems (not humans). In addition, the most irritant notifications come from things that people don't care about which will be acted on by autonomous agents.

Opposition:

AI has consistently been over-rated and failed in its promises. Precision: we want 100% precision this requires sensitivity to context and content. Even if we have the perfect algorithms, the sensing capability will not be there. Also, people want the illusion of control. They will always prefer even their own bad decisions. We will not be able to build these systems and even if we can build them, they will not be accepted.

Advocates:

Today, AI is playing better games than humans (e.g., chess, go,). Why is AI better than the human? Google is working on things to help predict (better than humans) when we need notifications. AI will filter information automatically and help the users dealing with information overload.

Opposition:

If machines are communicating to one another without considering the human, would that not create a new species? We do not govern our life and universe on the basis of mathematics, which is what governs AI.

Advocates:

We do not need a general AI, we need only an AI that deals with notifications. This is a rather small area and such problems are dissolved by AI. Today, the user has to read all notifications and the user had to read emails in the beginning. Today, the spam problem of emails is solved by AI. AI will be fundamental in dealing with filtering notifications according to user's wishes.

Opposition:

We are talking about general area AI because notifications pervade our every day activities. There are no sensors to correctly interpret things like being in love. Allowing AI to make decisions, such as who to marry will create problems since they cannot sense and infer correctly.

Advocates:

The opposition argues that AI will take over our lives. In contrast, the technological gap will narrow. AI will allow us to enjoy our lives by pushing things that we do not care about into the background.

Opposition:

Economics not technology will solve the problems that we face. AI will ask many people about information sensing from the real world. Notifications are the essential thing from our lives in the future.

4.4.3 Debate 3: There should be a cost to send messages

Advocates:

Systems are not designed to take our attention as a valuable resource. Today, we have costs for sending messages as time, social capital. Also, there is a social opportunity cost when one has to deal with notifications. Not just on the sender but also on the recipient.

Opposition:

Adding cost to messages is a threat to basic human rights. It is discriminating and will divide the world population. Imagine a world where poor people are not able to communicate with others anymore. In addition, some institutions will be disconnected. In total, the world will be more disconnected and people will feel lonely.

Advocates:

There are already existing costs, for example in the way of advertisements. There are negative costs of not sending messages. We have limited resources such as time and attention that we invest when we send messages.

Opposition:

There are issues of practicability and implications of introducing such costs. We currently have systems that allow for free messages. If a cost is introduced, there will be higher risks of being locked into systems. The only way to do so would be to have a government regulating communications. This poses a risk to net neutrality. In the end, this will reduce connectedness. Introducing costs will address the symptom but not the problem.

Advocates:

We are already paying for communications anyway. Costs be handled in a different way. You are considering the sender and the receiver even though there are many agents in-between. The net is NOT neutral today. You made a confusion about infrastructure and common pool resources (e.g., attention). We suffer from problems of congestants. How do we deal with common pool resources? The best strategy from an economic point of view is to introduce a cost to reduce throughflow.

Opposition:

The government has a too narrow viewpoint. It is not a capitalist industrialized world. The Arab revolution would not have happened if costs were involved. Therefore, costs for messages will kill democracy. Micropayments in developing country are based entirely on free SMSs. In an age of democratic change, we need to look at remote schooling, which depends on no cost messaging. Another important factor is the crisis management. There is a need to inform people in certain situations.

Advocates:

We have no metric or model for the inherent costs of messaging and notifications. Trump was using notifications. Perhaps a cost to him that was imposed based on the number of recipients could have avoided populism.

Opposition:

You just want to receive fewer messages. Adding a cost is a selfish decision. Humans want to communicate with one another. No one has the right to prevent people from speaking to each other. We want everybody to be able to communicate. People will use services that are available and free. Costs will NOT stop people from communicating to one another, just restrict communication.

4.5 Speed Dating Session

Speed dating sessions were conducted throughout the seminar to motivate spontaneous discussions between the participants on “burning questions”. In this activity, participants comprised two rows that faced one other. Every 3 minutes, one row would move to the left while the other remained static. The following are examples of questions that were posed:

- Is the scalability issue of notifications (50 per second in 2030) real or not?
- What are your strategies for dealing with notifications?
- Think of positive/negative examples of notifications!

Each question was discussed twice with different partners. This meant that participants were offered a new topic to discuss with new partners.

Figure 4 Short but intense discussions during the speed-dating session.

4.6 Open Maker Session

The Open Maker Session started with a short introduction into Arduino development and the ESP8266 chip. A small ultra-low power microcontroller which supports to connect to a Wi-Fi network and make simple TCP/IP connections, read sensor data, control connected device or receive notifications. Afterward, the participants brainstormed in small groups and started prototyping for two hours. Many groups continued developing after the dinner to finalize their prototype.

During the morning session of the final day, participants presented their new concepts for handling the vast amount of notifications we receive daily. The proposed solutions covered a broad range of different approaches. Creative groups worked on a project to investigate how colorful their lives are. Therefore, they used a color sensor to detect colors in their environment and displaying the detected color with an RGB LED. Others build a tangible notification lighthouse which informs the user about urgent or important notifications by different illumination. In figure 6 (center) a destructive notification system is displayed. It notifies the user (e.g. to drink more) by knocking over a drinking glass. Concluding, participants were able to rapid prototype functional notification mechanisms and explored new concepts on how a notification environment could be established in the future.

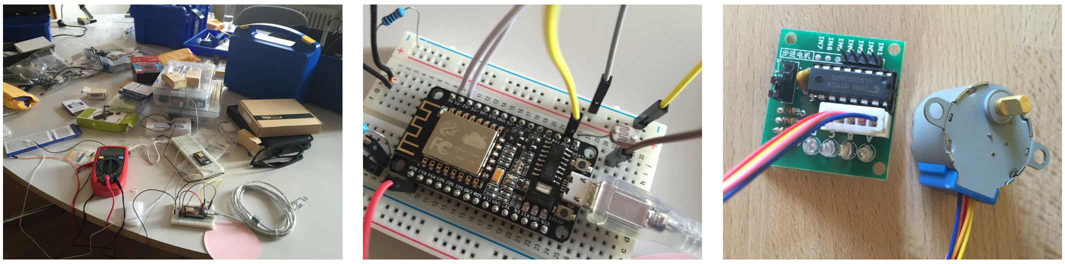

Figure 5 Plenty of hardware was provided to support creative prototype development.

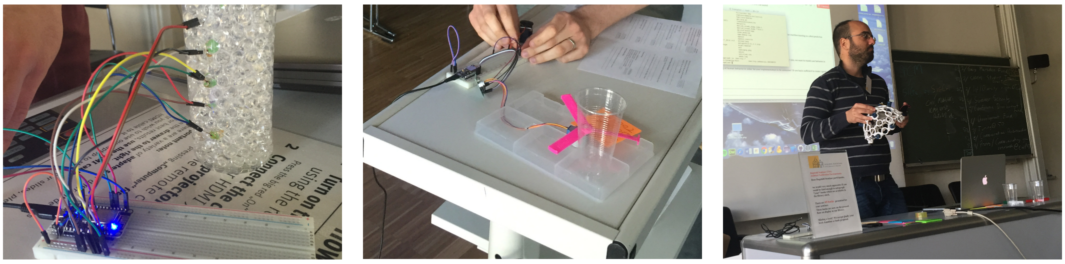

Figure 6 The prototypes developed during the open maker session were presented at the last day of the seminar.

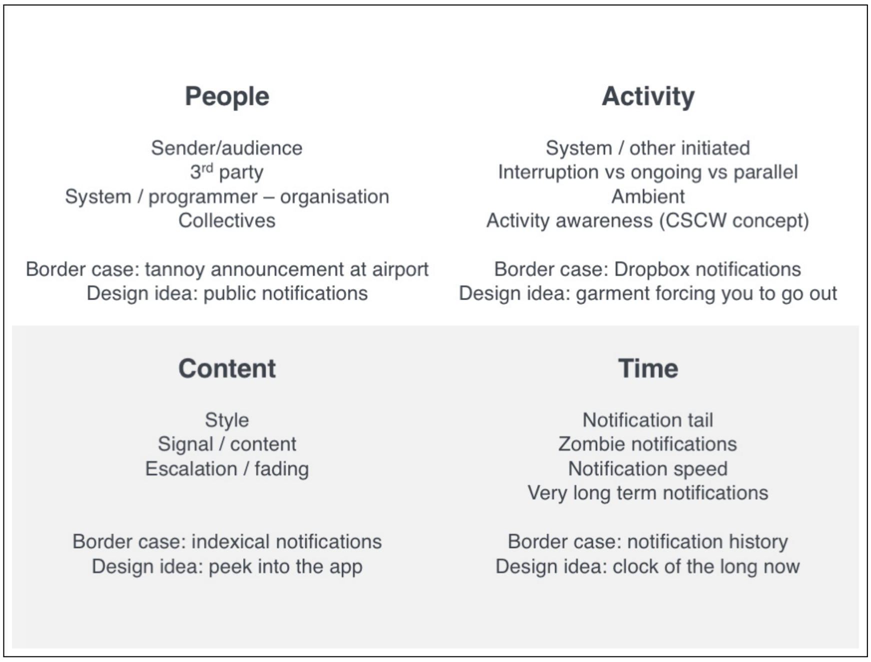

Figure 7 Taxonomy of notifications

4.7 Conceptional Maker Session

The taxonomy for a notification system that handles notifications has to consider the person who sent the message, the current receiver's activity as well the content of the notification itself as well the time when the notification is received (cf. Figure 7).

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