Designing for Awareness in Interactions with Shared Systems: The DASS Framework

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Most systems that we use in everyday life are shared—because multiple people can interact or because an interaction by one person can affect other people. However, everyday Internet of Things systems are often designed for individual use. Prior research on collaboration technologies (Computer Supported Collaborative Work) has shown that to coordinate system sharing people require awareness of the social context, which interfaces can support by making salient information visible. Although literature exists on how to design for awareness, this can be fragmented and difficult to relate to other application domains. To introduce a broader audience of interaction designers to awareness, we aim to make the available design knowledge more generalizable and operational. With this aim, we construct the Designing for Awareness in Shared Systems framework that gives a structured and comprehensive overview of design considerations for awareness. The framework can stimulate reflection and inform decision-making when designing interactions with shared systems.

CCS Concepts: • **Human-centered computing → Interaction design theory, concepts and paradigms**; *HCI theory, concepts and models*; User interface design;

Additional Key Words and Phrases: Design for awareness, shared use, social translucence, multi-user interaction, interaction design

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1 INTRODUCTION

Most objects and systems that we use in everyday life are shared. In most daily environments—a family living room, a student kitchen, an open-plan office, and virtually every (semi-) public space—all furniture, entertainment systems, equipment and appliances can be used by multiple people. This is especially the case when we consider not only the input, but also the output of interactive systems. For example, if one co-worker changes the light using a personal application

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on his/her mobile phone, everybody in that room is affected by this change. Or if the host changes the music playlist at get-together of friends, this affects the atmosphere and thus the other people.

Perhaps because of its ubiquity, system sharing is often overlooked [7, 51, 110]: "*Exclusive, private use of possessions appears in the literature as the normal, default mode of material relationships, such that 'sharing' appears to be relatively rare or innovative, or perhaps revolutionary. I say 'appears' because in reality [...] Sharing resources has always been the norm, and exclusive use of resources has always been relatively rare.*" [110:199]. There are, of course, many researchers that have looked at interaction design for shared systems but primarily when systems are shared as part of their functionality, such as in collaboration and communication systems (e.g., in the research area of Computer Supported Collaborative Work; CSCW). Outside of the domains where sharing is an inherent property of the system, most systems seem to be designed with the individual user in mind. Especially when looking at interactive Internet of Things (IoT) systems, "personalization" seems to be the standard, judging from the prevalence of personal applications, use of data from individual user accounts, and interactions through personal devices such as smart phones or smart watches. But when we extent the definition of shared use to include both input and output, system sharing becomes property of the context instead of a property of the system—meaning that most systems could be shared depending on whether multiple people are present. This indicates that interaction designers should consider whether their interfaces support shared use in the majority of systems they design for. To speak with the words of Brush and Inkpen: "*As we begin to think about the realities of using ubiquitous computing devices in a domestic environment, we are immediately confronted with questions about whether these devices should support sharing and personalization.*" [15:109–110].

Before we go into what "support of sharing" could be in interactions with IoT systems, let's explicate what we mean with IoT. There are different ways of characterizing IoT, and so far, not one term is agreed upon [4]. In line with Gubbi et al. [52] and inspired by Streitz's definition of smart environments [118], we see IoT systems as a network of interconnected objects that can process information to self-direct actions that change the system's output. For our focus on system sharing, a few elements of this definition are important to specify further. Firstly, the "Things" in IoT make that there is a connection to the physical environment through input devices (sensors, controls) or output devices (actuators that impact the physical environment). Secondly, the information that the system can take in to direct actions can come from different sources, including sensors, more direct controls, or external databases. Although IoT systems that completely take the human out of the loop exist (e.g., in process monitoring systems), we focus in this article on systems that use some form of explicit human interaction. Related to this interactivity, a third aspect of present-day IoT systems is the emergence of new interaction paradigms: next to the obvious Graphical User Interfaces (GUI's), more spatially distributed, tangible, auditory and gesture-based interaction styles become available, which increases the role of interaction design in developing IoT. Examples of IoT systems from the everyday context that fit this definition include home entertainment systems (e.g., Smart TV's, connected speakers, online streaming services), smart environment systems (e.g., connected thermostats, lights, or window blinds), or connected security systems (e.g., motion detectors, camera's, locks, and doorbells), among many others.

From research in the domain of CSCW it is known that in order to coordinate system sharing among each other, people need awareness of their social context: "*Whether it is wrapping up a talk when the audience starts fidgeting, or deciding to forego the grocery shopping because the parking lot is jammed, social information like this provides the basis for inferences, planning, and coordination of activity.*" [36:60]. Therefore, interfaces that present the user with the right information at the right moment can help people to coordinate activities among each other, and to do actions in the right order, at right time, and in the right way [36, 54]. Within the field of CSCW, designing for awareness has become a standard point of consideration for interaction designers. Also, outside of collaboration, awareness has been used in the design of systems for social connectedness [14, 64, 90, 126], coordination of home routines [18, 89], and collaborative and competitive games [40, 66]. However, all these examples still include systems that are shared as part of their functionality.

When designing interactions with everyday systems that are shared in use—i.e., systems that are integrated in the routines of people's everyday lives and environments—we feel that designing for awareness deserves even more attention and should become a standard consideration. We can illustrate this argument with our previous work, in which we investigated designing for awareness in interactive lighting systems [92, 93]. We designed three interfaces for an interactive office lighting system, which differed in the type of information they allowed people to share among each other through the interface. Evaluation of the interfaces demonstrated how the availability of information can help people to coordinate shared use among each other, by lowering the threshold for verbal communication, by making social norms more prevalent, and by increasing feelings of accountability [93]. Moreover, we found that when people have too little information about the subjective rules around system sharing, this leads to more conflict-avoiding behavior and fewer interactions with the system [92, 93].

Designing for awareness can be difficult, however, as we know from experience. There are many interrelations and tradeoffs between the different aspects on which design decisions have to be made, which "*breaks down intuitive decision-making*" [50]. Although excellent overview papers exists (e.g., [48, 108, 112]), they often primarily explain what awareness is and what research has been done; information that can be difficult to operationalize when designing. And many of the works that present design cases (e.g., [1, 6, 29, 35, 55]) are either based on a limited number of explorations, or do not make the implications explicit, which makes it difficult to generalize the knowledge. As a result, finding a good starting point in the literature can be challenging for the designer that is a novice in designing for awareness: "*Faced with a blank slate for each new application, designers must reinvent awareness from their own experience of what it is, how it works, and how it is used in the task at hand.*" [54:412].

Our aim is to introduce the concept of designing for awareness to a broader audience of interaction designers. In order to do so, we present the Designing for Awareness in Shared Systems (DASS) framework in this article. The DASS framework is the result of a thorough review of literature on awareness and presents two main contributions. Firstly, it structures design knowledge on awareness that has been build up by researchers in the field of CSCW into a comprehensive overview. Such an overview is beneficial both to novice designers that want to get a head-start when designing for awareness, and to the design-research community by capturing the state of knowledge to-date that can be build-up from and expanded in light of a broader range of systems—including everyday interactive IoT systems. The second contribution of the framework is that it presents the background knowledge in a format that can be easily integrated within a design process. The framework presents a list of design considerations—i.e., important questions about the implementation of awareness information—that can be used to stimulate reflection within the design process.

In the remainder of this article, we start with giving a brief background on designing for awareness in Section 2. We also explain the need for a new framework here. In Section 3, we describe how the DASS framework was constructed. In Section 4, we give an introduction of the framework. We present its structure, introduce the themes and considerations the framework consists of, and give directions on how to use the framework in a design process. Section 5 goes into much more detail. We explain the relevance of each of the themes in depth, and we give examples from literature for each of the considerations. We have written each of the discussions in Section 5 as self-contained essays, with plenty of examples and with cross-references to related themes where needed.

Because of this structure, Section 5 does not necessarily need to be read in order. Instead, we present it as a resource that can be referenced at the moment of need, providing considerations and background to anyone that aims to design interactions for shared system use. We conclude this article with a discussion of the strengths and limitations of the framework in the context of new system developments. We have shaped this discussion as a research agenda, to inspire further research on designing for awareness in interactions with everyday systems that can be shared in use.

2 BACKGROUND: DESIGNING FOR AWARENESS

In order to act in the world, people need an understanding of "*what's going on*" [33:36]. This understanding is also called *awareness*, which is people's knowledge of the state of an environment "*created through interaction between an agent and its environment*" [54:416]. Since the state of an environment can change, awareness needs to be maintained. This makes awareness both a *product* (a state of knowledge) and a *process* (of maintaining awareness through perception and action) [55]. It is only because of awareness of their environment that people are able to understand a situation, anticipate, form goals, act, and evaluate outcomes [87]. Consequently, having awareness of *other* people—of the social context—lays at the basis of any social behavior, including communication, cooperation, and collaboration [17, 54, 114] and thus forms a crucial element in interaction with systems that are shared in use.

In the field of CSCW aiding awareness has become a standard design strategy for any well-designed groupware system. Interfaces that present the user with socially salient information can help people to coordinate activities among each other, and to do actions in the right order, at right time, and in the right way [36, 54]. It supports seamless shifting between individual and shared activities [28, 43, 55] and it can help people to anticipate on next actions or arising conflicts [54, 55, 120]. Moreover, if awareness is mutual—if "*it is not just that I am aware of you and you of me, but we are mutually aware of each other's awareness*" [131:1:8]—people become accountable for their actions. This accountability, in turn, leads to the establishment of more formalized coordination mechanisms, such as norms and customs: "*It is through such individual feelings of accountability that norms, rules, and customs become effective mechanisms for social control.*" [36:62].

The need for contextual and social information to interact in shared contexts has been identified in other fields than CSCW as well, such as when designing interactions for the home environment (e.g., [8, 89, 90, 92, 95, 100, 104, 121]). As mentioned before, we think that designing for awareness deserves even more attention in domains beyond work- or education-related collaboration, than it has received to date. An area where awareness has received attention—worthy of mentioning—is in the design of ambient displays, including *social awareness systems* [76]. Social awareness systems aim at "*increasing people's sense of social connectedness by providing them with peripheral awareness of information about people from their social network (e.g. presence, availability, activities).*" [126:129]. In these systems, sharing of awareness information is their primary functionality. The designing for awareness that we aim at in this work is, instead, not part of the primary functionality but a *requirement* to help people in fulfilling a different primary task in compliance with the social context [54]. The system's functionality and can be virtually anything where other people are potentially impacted by an interaction (e.g., playing music, setting the light, driving a car, or watching TV). Since the perspective on awareness as a secondary goal resembles the perspective from the field of CSCW best, most of our reviewed work comes from this area. However, where suitable we will also review some examples of social awareness systems.

When designing interactions that aid awareness, one would like to build up on the extensive knowledge that has been acquired by the research communities that have focused on awareness. Several researchers have highlighted considerations, claims, or elements of awareness based on their own design experiences when designing, for example, widgets for distributed groupware

[55], an online collaborative drawing tool [6], visualizations of the whereabouts of geographically distributed colleagues [27, 29], or online chat systems [1, 35]. All these insights are invaluable to other designers, since the lessons learnt are directly related to interface features represented in design examples. However, these close ties to the designs that the implications derived from can at the same time make translation of these implications to other designs more difficult. To not rely on personal experience only, design-spaces have been presented that compare design examples to certain dimensions—for example, on availability-sharing systems [58], social awareness systems [75], or ambient information displays [102]. The combination of themes and corresponding design examples in such design-spaces form a valuable setup that presents overview yet maintains a strong relation with design examples. However, their focus on a single type of system can limit generalization.

There are also more descriptive frameworks available in which insights from different directions are combined (e.g., [9, 33, 36, 109, 131]). For example, the model of Situation Awareness in [33] describes how awareness informs dynamic decision-making during interaction. Yuill and Rogers' framework [131] lists three core mechanisms that underlie collaborative tasks on shared table top interfaces: *awareness, control of action*, and *availability of background information*. The Social Translucence framework [36] describes how *visibility* of information can lead to *awareness* and eventually *accountability*. All these frameworks are highly relevant to help designers with understanding *what* awareness is and *why* it is useful. However, they seem to be less support to for finding out *how* to design for awareness. Their descriptive nature can make it difficult to operationalize the knowledge and translate it to interface features.

To conclude, in order to interact with systems that are shared in use, people require an understanding of the (social) context to base their decisions upon. This awareness can be supported by rendering important information visible in the interface. Although many researchers have worked on designing for awareness, we found that it can be difficult to find a good starting point in this body of research for a non-expert in the field. Even though current design knowledge is extensive and valuable to build upon, it can be fragmented, difficult to operationalize in a design process, or difficult to generalize towards other application domains. In order to introduce designing for awareness and shared systems to a broader audience of new generations of interaction designers, we think that a new framework could be of use that combines previous research into a comprehensive overview of knowledge that can be operationalized within an interaction design process. Constructing such a framework is what we set out to do in this article.

3 CONSTRUCTING A FRAMEWORK

In order to construct a framework about design knowledge on designing for awareness, we performed an iterative literature review. In the search for relevant work to build upon when designing for shared use, we started with broad search queries on topics like "*multi-user interaction*" and "*shared use*," which gradually became more focused on "*awareness information*" and "*social translucence*." Through further snowballing on the relevant literature, we constructed a library of 123 papers that we summarized on a number of pre-defined topics (*keywords, main contribution, design knowledge, design examples, methodology*). While reading and summarizing, we highlighted the papers that surface intermediate design knowledge—that is, papers that go beyond individual design implementations, and that formalize insights into more transferrable guidelines, considerations, or recommendations for design. This resulted in a selection of 23 papers,[1] which formed the content for our first clustering analysis.

[1]Namely: [1, 8, 10, 19, 22, 27–29, 31, 34–36, 50, 54, 55, 59, 60, 74, 77, 79, 83, 111, 131].

In an open coding analysis, we first considered the findings, conclusions, and design recommendations of the 23 selected papers in light of their transferability to designing interactions with everyday interactive systems that are shared as a consequence of use. We searched for overlap between the recommendations by different researchers and identified common themes (e.g., *type of information, expression and representation, explicitness, prompting and timing, effort*, and *privacy*). Based on this first thematic clustering structure, we revisited our library of 123 summarized papers again. The majority of these papers described detailed design examples, in which we tried to identify evidence that the themes from our clustering were also implicitly considered in these designs. If so, they were coded with the themes of the clustering structure. We also conducted additional searches on the topics of the draft themes and we followed up on references in the reviewed papers. Based on the growing content of coded literature we refined the thematic structure again, which made the process highly iterative. We ended up with 11 themes: *type of information, detail & abstraction, inference & explicitness, privacy & control, representation & placement, effort & intentionality, initiative & presence, persistence, anticipation & revisability, interaction alternatives*, and *recoverability & intervention*.

Within each theme, we summarized the important findings in the corresponding literature and aligned the different definitions. To give an example, in the theme "type of information" (see Section 5.1.1) we clustered literature that mentioned some sort of taxonomy of types of awareness information that might be relevant to represent in an interface. To align these different taxonomies, we wrote out all the specific information types that were mentioned (e.g., *identity* of the person interacting, *state* of the system, *content* of a message), and identified a new overarching structure that combines all the information types mentioned in the literature within this theme. We captured such analyses in a detailed essay per theme,[2] in which the relevance of the theme for shared use of everyday systems is explained and the design recommendations mentioned in literature are illustrated with examples—from CSCW literature and translated to everyday IoT systems. To make this background information in the essays more operational when designing, we summarized the main message for designers in one or more *design considerations* per theme: questions to ask oneself when designing for awareness.

Since 11 themes are too many topics to easily memorize, we searched for a top-level structure that would be easier to comprehend. We found such a structure in the descriptive framework of workspace awareness by Gutwin and Greenberg [54]. Gutwin and Greenberg present three questions in their framework: (1) "*What information makes up workspace awareness?*" (2) "*How is workspace awareness information gathered?*" and (3) "*How is workspace awareness used in collaboration?*" They derive these three questions from the *perception-action cycle* of Neisser [86], which has received much follow-up in awareness literature (e.g., [2, 54, 112, 115]). The perception-action cycle describes how people's actions can be seen as an exploration of their environment to retrieve information. This information modifies people's knowledge of that environment (*awareness*), which directs further exploration again. The three questions of Gutwin and Greenberg follow the logic of this process of maintaining awareness: the first question refers to the type of information that makes up the "environment," the second question asks how this awareness is retrieved and used to modify awareness, and the third question relates to how the awareness can be used to direct further exploration and action. We decided to use the same questions as a top-level structure in our framework, to ensure alignment with the previous literature on design for awareness. We slightly rephrased the questions to make them more generalizable to a broader range of application domains and divided the themes over the questions as shown in Figure 1.

[2]This format of having detailed background essays is inspired upon the "*assertions of conflict*" framework by Easterbrook and colleagues [31], which we have found to be highly useful in our own design work.

1 What information is needed for awareness?		
	▪ Type of Information	▪ Inference & Explicitness
	▪ Detail & Abstraction	▪ Privacy & Control
2 How can the awareness information be embodied?		
	▪ Representation & Placement	▪ Initiative & Presence
	▪ Effort & Intentionality	▪ Persistence
3 How can the awareness be used effectively in interaction?		
	▪ Anticipation & Revisability	▪ Recoverability & Intervention
	▪ Interaction Alternatives	

Fig. 1. The themes resulting from the thematic analysis, divided over three overarching questions that were inspired upon the framework by Gutwin and Greenberg [54].

The described process of searching, clustering, summarizing, and analyzing literature evolved over the course of two years. In parallel, we worked on multiple design implementations of awareness information in the field of interaction with connected lighting systems. These interaction designs were both from our own hand and were designed together with students (see [91, 93, 129] for some of the outcomes). In these design projects, we have used the design considerations of the framework in various stages of completion. The practical insights and our understanding of the literature developed alongside each other. Moreover, by observing students when designing for awareness, we noticed which themes were easier and more difficult to implement, which lead to numerous moments of rephrasing and refining of the considerations.

After a number of such informal evaluations, we evaluated the use of the DASS framework more structurally by observing how an experienced interaction designer that is new to designing for awareness would integrate the framework in a design process. With this reason, we presented the third author of this publication with the draft manuscript of the DASS framework—complete with all essays and design considerations. She is an industrial designer with over eight years of design and research experience in different interaction design areas but was not familiar with the literature on design for awareness and did not have a background in CSCW. She was also not familiar with the framework nor was she introduced to it apart from through the draft manuscript. The designer applied the framework while contributing to the design of a smart IoT room that changes the lighting and indoor climate based on environmental conditions as lighting intensity, CO_2 levels and temperature, people's presence and activities, as well as on their physical parameters such as heart rate and facial expression. Awareness did not receive attention in this design before introducing the DASS framework. The designer used the framework in three ways. On first usage, she aimed to understand what kind of awareness information people would need about each other and of the meeting room (thus placing emphasis on part one and three of the framework*: what information is needed,* and *how can this information be used?*). On second usage, the framework was used as a way to generate ideas for interfaces that show the identified awareness information to the users of the room (emphasizing part two, about *the embodiment of information* in the interface). The third time the framework was adopted, the designer selected a single use case for the room and tried to understand the requirements and tradeoffs for awareness for that specific scenario, thus leading to a more integrated use.

After each of these three phases, the other authors sat down with the designer to discuss and reflect upon the experiences. These experiences—in particular the misunderstandings and integration into the design process—led to further refining of the framework. In particular, we realized that more direction was needed on how to use the framework. Therefore, together with the interaction designer, we reflected on how the framework can bring value in different phases of a design process. This led to the identification of four design phases in which the framework can be of use: when *analyzing* the context, *exploring* the design space, *refining* interface concepts, and during concept *evaluation*. For each of these steps we added pointers on how the framework can be of used in Section 4.2 to help other designers with integrating the framework in their own design practice. Moreover, the wording of the considerations in Sections 5.1 and 5.2 was refined to clarify the considerations to novices in awareness.

4 THE DASS FRAMEWORK

In this section, we present the DASS framework. The framework comprises two parts: an overview table with themes and considerations and 11 thematic essays. The overview table is presented in Figure 2 and presents 11 themes clustered over three overarching questions that require in-depth consideration when designing for awareness. Every theme contains multiple design considerations that can support reflection on awareness information in interactions and that can be used to make implicit design decisions more explicit when designing for awareness. The essays are presented in Section 5. The essays describe the relevance of the considerations, give pointers to further reading, present examples from CSCW literature, and relate the considerations to everyday IoT systems (e.g., smart TV's, connected thermostats, or home assistants).

Please note that this article is not meant to be read in one go. Instead, we advise to read just Section 4 now, to get introduced to the overview table of the framework (Figure 2) and to get an understanding of how to operationalize the framework in a design process (Section 4.2). This should provide all the information needed to get started with the DASS framework. If during use doubt arises on how to implement or interpret a certain consideration, or reflection on explorations in a design process is required, the corresponding essay in Section 5 can be referenced.

4.1 Introducing the Themes

The DASS framework clusters the important considerations when designing for awareness within three main questions that build upon each other. The question of *what information is needed for awareness* can help to specify what people need awareness about, and what information might be useful to build up this awareness. The second question—*how can the awareness information be embodied?*—focuses on how the required information is presented to the users. The third question—*how can the awareness be used effectively in interaction?*—considers ways in which people can act upon their awareness and consider other people, change their planned interaction, or hold others accountable. Naturally, these three questions are highly related to each other. A decision on the considerations within question one will impact those in question two and vice versa. For example, it is impossible to separate the type of information (Section 5.1.1) or level of detail (Section 5.1.2), from the representation of the information (Section 5.2.1) or from the chosen method of capturing the information (Section 5.2.2). Therefore, the three overarching questions should be seen as a structuring of the themes, opening opportunities for iterations, not as an ordered sequence. Below, we introduce the themes in each of the questions.

4.1.1 What Information is Needed for Awareness? Awareness is both the knowledge that people have about the state of the environment, and the process of maintaining this awareness by retrieving information to update awareness [54, 87]. So in the core, designing for awareness is an information sharing problem [1], which makes the question of *what information is needed for awareness* a starting point when designing.

Section	***Theme***	***Considerations***
5.1 What information is needed for awareness?		
5.1.1	Type of Information	▪ *What information about the actors, interaction, or situation do people need in order to gain awareness?*
5.1.2	Detail & Abstraction	▪ *What is the highest level of abstraction that still results in meaningful information?* ▪ *Do people have access to more detailed information or direct communication channels if required?*
5.1.3	Inference & Explicitness	▪ *Is there a risk of misinterpretation of the information?* ▪ *Can the information lead to socially awkward situations?* ▪ *Does the information allow for deception?*
5.1.4	Privacy & Control	▪ *Is all the information that is shared sufficiently useful to justify the inference on privacy?* ▪ *Do people have control over what information is shared? Is the information sharing symmetrical?* ▪ *Do people know what information is shared of them at what moment?*
5.2 How can the awareness information be embodied?		
5.2.1	Representation & Placement	▪ *Can information be highlighted in the environment or does the information need to be presented through the interface?* ▪ *Can the information be presented situated or is separation from the source of information necessary?* ▪ *Are interface elements expressive enough to feedthrough information?*
5.2.2	Effort & Intentionality when providing information	▪ *Should providing information require effort or initiative from people or can information be retrieved as a consequence?* ▪ *Is the information up-to-date and is accuracy ensured?*
5.2.3	Initiative & Presence when retrieving information	▪ *Is information that has an alerting function present at the right moment, without requiring extra initiative from people?* ▪ *Is the information sufficiently present, yet not obtrusive?*
5.2.4	Persistence	▪ *How long does the information remain relevant?* ▪ *Can the persistence of historic information lead to meaningful structures or patterns?* ▪ *Should individual instances be presented, or can information be accumulated?*
5.3 How can the awareness be used effectively in interaction?		
5.3.1	Anticipation & Revisability	▪ *Are people supported in estimating what the effect of an interaction will be on other people?* ▪ *Can people explore functionalities without affecting others?*
5.3.2	Interaction Alternatives	▪ *Are there sufficient alternatives to change the planned interaction based on awareness?*
5.3.3	Recoverability & Intervention	▪ *Is it possible to intervene in an interaction by other people?* ▪ *Can people recover from errors, also when made by others?*

Fig. 2. The Designing for Awareness in Shared Systems (DASS) framework.

In the clustering process, we identified four themes that are related to the selection of information for awareness: the *type of information*, the level of *detail & abstraction*, *inference & explicitness* of information, and *privacy & control*. While it can be tempting to design as much information as possible in an interface, more information is not necessarily better: it can lead to clutter and can make people miss important information. Hence, the *type of information* (Section 5.1.1) and the level of *detail* or *abstraction* (Section 5.1.2) of the information need to be carefully considered. Also, information does not equal awareness: the information requires inference and interpretation [87], which—whether done by the system or by the user—can be wrong or socially awkward. Therefore, the *inference* of information and its *explicitness* require attention when designing (Section 5.1.3). Lastly, and arguably most importantly, there is an unavoidable tradeoff between awareness and *privacy*. Therefore, when deciding on what information to share, the usefulness of the information needs to be very carefully weighted with the invasion of privacy that is caused by presenting that information to other people. And in any case, people need to be given feedback and *control* over the sharing of their information (Section 5.1.4).

4.1.2 How Can the Awareness Information be Embodied? The information that is required for awareness must be presented to the user in a simple and straightforward way to help in the maintenance of awareness [54]. Several mechanisms are known on how people gather information from their environment—"*basically, how people find the answers to the who, what, where, when, and how*" [54:422]—which can be helpful in considering *how to gather the required information* for awareness and *how to present* it again to the user at the right moment. Yet, this required information might be constrained by characteristics of the design and environment, such as the applicable technology and the physical placement of input and output devices. Therefore, this second question is closely related to the first question in the DASS framework: what information to represent is highly dependent on the retrieval mechanisms and embodiment to process, store, and represent the information. Therefore, this second part relates more to the design effort: it considers the "*how*" rather than the "*what*."

We identified four themes that have to do with the way that the information is embodied and presented to people: *representation & placement* of the information, the *effort & intention* requested from people in providing information to the system, the requested *initiative & presence* of the information to the person retrieving the information, and the *persistence* of the information. In the presentation of awareness information, the *representation and placement* of the information needs to be chosen—information can be situated at the same place where it was produced, or separated from that location and represented in a different way. Not all information always needs to be designed explicitly in the interface—especially in collocated interactions the environment and other people might already show information that sometimes just requires highlighting (Section 5.2.1). If the required information has to come from people that are using the system, it is important not to ask too much *effort* from people—otherwise there is a risk that people do not provide the information regularly enough or even do not provide the information at all. Therefore, crucial information can best be collected at the lowest threshold possible: as a direct consequence of people's interaction. If information is not strictly required, more *intentional* communication can be used (Section 5.2.2). Since awareness information can have an alerting function, the information should be noticeable without requiring *initiative* from people. However, there is a fine line between sufficient *presence* of information and obtrusiveness (Section 5.2.3). Lastly, the time during which the information stays relevant requires consideration. *Persistent* information that remains available for a longer time can have a number of benefits, such as allowing asynchronous communication, making higher level inferences possible, and create patterns of related information. But it can also require a considerable design effort and can form a risk for privacy, which are advantages of more transient information (Section 5.2.4).

4.1.3 How Can the Awareness be Used Effectively in Interaction? Building up of awareness is never a primary goal; it is a way to help people to interact with the system in a way that matches the social context [54]. The benefits of increased awareness have been researched thoroughly in situations of collaboration. Based on increased awareness, people can communicate more easily, coordinate interactions, anticipate on actions of others, and assist where needed; all in a much less effortful and error-prone way (e.g., [48, 54, 60]). And because of mutual or reciprocal awareness, people can hold each other accountable for undesired adjustments or bad behavior in the interactions and establish agreement on the social protocols surrounding system use [36]. However, just increasing awareness does not mean that people are also able to *use the awareness effectively* in the interaction. Therefore, in this third question we investigate what interaction characteristics make it possible for people to use the awareness to mediate conflicts, take other people into account, anticipate, or recover from errors, for example.

The three themes on how the awareness can be used effectively in interaction have been least explicitly addressed in other literature. Where the themes in Sections 5.1 and 5.2 primarily result from literature, these themes in Section 5.3 form a direct result of our own research (especially [91, 93]). The themes included are *anticipation & revisability, interaction alternatives*, and *recoverability & intervention. Anticipating* on the needs and wishes of other people requires awareness as well as experience to predict what the impact of an interaction will be. But in IoT systems, where different input or output devices can be connected and disconnected, this experience can be limited. It is important to support people in making accurate predictions of the effect of their interaction on other people, before their interaction takes place. Feedforward and revisability of actions could be strategies to do so (Section 5.3.1). Second, increased awareness of potential conflicts can make it possible to resolve these conflicts before they manifest themselves. But to make conflict resolution possible, the system should present a sufficient granularity of control to ensure that people can choose between different *interaction alternatives* (Section 5.3.2). Lastly, there is always a possibility for error when designing for awareness, since the person interacting can miss or misinterpret important information. Therefore, people that are not directly interacting with the system but that are influenced by interactions of others need to be given a way to *intervene* and to *recover* from errors (Section 5.3.3).

4.2 Operationalizing the Framework when Designing

The DASS framework is meant to help designers in designing for awareness by presenting them with relevant questions to answer when designing new interfaces (see Figure 2). Although one might argue that questions still do not help designers in getting grip on "how to design for awareness," we deliberately choose to present design *considerations* instead of design guidelines—*questions* instead of *answers*. This is firstly because most of the themes are connected and a design decision on one of the considerations can affect other aspects. Often, the considerations even form *tradeoffs*. For example, presenting more detailed information might result in more detailed awareness of other people in the system but can negatively influence privacy (see Sections 5.1.2 and 5.1.4). And although *feedthrough* can be an effective and lightweight strategy to present information (Section 5.2.1) it can limit visibility and presence of that information (Section 5.2.3). Because of such interrelations, it is important to make decisions consciously when designing. A second reason why questions are more useful than answers is that designing for awareness is highly context dependent. Although some of the considerations express general recommendations—e.g., the consideration "*What level of abstraction is possible to still have meaningful information?*" recommends abstracting information where possible—exceptions to those recommendations can easily be imagined. Especially because the majority of the literature that we build up upon in the framework is the result of research on collaboration systems and groupware, which might not hold up in other contexts like the home. It is therefore up to the designer to find the optimal answer to the questions in the framework in light of the specific context and application domain s/he is designing for.

When designing, the DASS framework can serve as a tool for reflection: it helps to make implicit design decisions more explicit, and to recognize the consequences of design decisions on the availability of awareness information during interaction. Although the ordering of the considerations might make it come across as a fill-out template, it is important to emphasize that we do not aim to prescribe use of the framework. Instead, the considerations should become a part of the designer's own process. That having said, we can provide examples of how the framework can bring value to a design process, based on our observations of how the framework was used by a designer novice to awareness (as described in Section 3). In this section, we describe four steps of an interaction design process in which the framework can bring value: when *analyzing* the context, *exploring* the design space, *refining* interface concepts, and during concept *evaluation*. By providing a detailed examples for each of these steps, we aim to provide evidence for the value that the framework can bring and inspire a broad range of implementations.

Analyzing the context of use is an important early step in most user-centered design processes. The resulting understanding of people's habits, activities, aims, needs, and wishes can be used to sharpen the design challenge and to formulate design requirements. When doing so, we expect that the DASS framework could be of help to formulate requirements from the perspective of awareness. For example, imagine designing a self-driving car. In order to get an understanding of the awareness needs that people might have in this situation, one could use the considerations in the DASS framework to get a better understanding of the awareness information that is available to the different actors in a traffic situation in a more traditional situation with human drivers. Looking from the point of a pedestrian, for example, an important awareness need might be estimate whether the car will stop or not, in order to estimate whether it is safe to cross the road. In order get such awareness, important types of information (Section 5.1.1) include whether the pedestrian has been noticed, the mood or hurry the driver is in, or the aggressiveness of the driver's driving style. Looking at the second part of the framework (Section 5.2), this information is currently primarily expressed by the driver, namely, through facial expressions and eye contact. Therefore, when designing a self-driving car, an important design requirement might be to find an alternative way to communicate the intentions and attention of the car to pedestrians and other road users.[3]

Exploring the design space is another common step in any design space. By this we mean a stage of divergence, in which ideas are generated and an overview of possibilities is laid out and compared to other work. When doing so, the themes in the DASS framework can be used to specify the dimensions on which ideas can be compared. When using these dimensions as a starting point, they can form challenges for idea generation. For example, when designing a new smart thermostat, one might have specified that it is important for other people in the room to be aware of who made the adjustments to the normal temperature—i.e., to communicate *authorship* as type of information (Section 5.1.1). An aim for a brainstorm could then be to come up with as many different ways as imaginable to embody this authorship information in the thermostat interface. Examples could include taking a picture of the person that is interacting and showing that in the interface, letting people log-in with a personal RFID token, locating the thermostat on a central stage so that everyone could see someone interacting, or allowing people to pick up the interface and keep it with them so that the previous author could be identified by his/her possession of the interface. When using the framework to explore possibilities, the essays in Section 5 can also be of use. They can serve as a way to find inspiring connections to related designs in less related application areas, such as CSCW. For example, collaborative editing tool Google Docs [45] would

[3]This example is inspired upon the work by Dey and Terken [21].

not typically be the first source of inspiration when designing a smart thermostat. Yet the use of profile icons and the visibility of the cursor in Docs do show inspiring examples of communicating authorship information.

Using the framework to refine a chosen interface concept is probably the most direct use of the framework. The themes can provoke discussion and help designers to consider design decisions that might otherwise be overlooked or taken implicitly. Also, the considerations can be used to ensure that the consequences on the availability of awareness information are considered for design decisions that are more functional. Moreover, the cross-relations between the themes as described in the essays in Section 5 can help to recognize tradeoffs. For example, when designing a music streaming service, one might have made the decision to offer pre-made playlists that are categorized based on the mood of the music (e.g., people can choose for a happy, sad, heart-broken, or cozy playlist). While this selection based on mood gives much information about the intention with which a playlist was chosen to the other people in the room and could therefore be a good choice of information representation, it might negatively impact the number of interaction alternatives that people have (Section 5.3.2), which could be problematic in case of conflict. Based on this realization, the designer might decide to manually allow people to remove or add songs to the automatically generated playlist or to give additional manual control over the parameters that are used to create the playlists, such as the beats per minute or the harmony in the songs.

Finally, we expect that the framework could be of help when preparing concept evaluations. The themes in the framework could be used as vocabulary when defining criteria for the evaluation of an interface. For example, in our own evaluation of lighting interfaces for a connected office lighting system [93], we compared three types of information (preference, intention, and authorship) to see which would be most useful. Also, we assumed during the design process that the level of detail (Section 5.1.2) of authorship information was less important than privacy protection (Section 5.1.4): if people could identify which controller was used to make a light setting, that would be enough detail to ask the people around that controller for permission to change the light. However, during evaluation we found out that people rather wanted to see the real identity of the person that had made the adjustment. This example demonstrates how the assumptions that are used to answer considerations during the design process could be used as hypotheses that can be challenged in evaluation.

5 CONSIDERATIONS WHEN DESINGING FOR AWARENESS

In Section 4, we have introduced the themes and considerations of the DASS framework, we have explained how it came into existence, and we have illustrated how the framework can be of use in a design process. Next, we will go into more detail on the literature behind each of the themes in the framework. For each theme, we discuss why the corresponding considerations are important, by reviewing related work that highlights its relevance and possible consequences. We also give examples of design implementations from the field of CSCW, and we speculate on how these examples might relate to interactions with IoT systems—including, e.g., connected lighting systems, music streaming services, and home security systems. The examples of IoT systems that we refer to are all part of normal everyday routines (as opposed to specialist professional systems) to make them easy to explain and easy to relate to. Since the field of IoT is quickly developing, the commercial products, services, and apps that are available today might not be accessible anymore tomorrow. When we use commercial examples, we therefore mostly refer to generic product types instead of to specific brands or products.

As mentioned in Section 4, these detailed essays are meant as a reference guide: a resource of reviewed and categorized background material that can be consulted at the moment of need. Instead of reading this section in order, we therefore advice designers to first use the overview of themes and considerations in Figure 2. Where needed, this section can be consulted to find explanations, recommendations, background literature, and design examples to fuel reflection and inform design decisions.

5.1 What Information Is Needed for Awareness?

Awareness is the knowledge that people have about the state of the environment, but this can entail a host of different types of knowledge. Probably not all knowledge about the environment is equally useful for the interaction with a certain system. "*The first question to be addressed thus is, of what are actors supposedly aware when we in CSCW use the term 'awareness*': awareness of what?" [113:288]. This requires consideration of the *information type* (Section 5.1.1), the level of *detail* (Section 5.1.2), and the *explicitness* of that information (Section 5.1.3). Furthermore, since sharing information about people always has a cost on *privacy*, people should be given *control* over what information is shared at what moment (Section 5.1.4).

5.1.1 Type of Information.

- What information about the actors, interaction, or situation do people need in order to gain awareness?

A first step for designers is to identify the type(s) of information that are required to build up awareness. The answer to this question—and other questions in the framework—is highly dependent on the context of use. In literature, a variety of taxonomies of awareness information have been presented. For example, in a domain analysis for collaboration systems, McDonald and colleagues [79] categorize information types based on the representation of an individual action or *instance*. In their clustering, instances can be *systemic* (presenting information about the status within the system; e.g., a person being online) about the *interaction* (such as the act of sending a chat message), about the added *content* (the actual message text), or about a *relationship* (e.g., tagging or friending). Gutwin and Greenberg [54] categorize information types for groupware systems based on the *who, what, where, when*, and *how* questions: "*when we work with others in a physical shared space, we know who we are working with, what they are doing, where they are working, when various events happen, and how those events occur.*" [54:420]. Dourish and Bellotti [28] describe two main types of information: *content* and *character*. Content represents the object of collaboration and individual contributions. Character is information about how an object is produced, including its significance with respect to the whole group and its goals. Based on such taxonomies—especially [8, 20, 25, 28, 54, 55, 79]—we identify three overarching information types: information that can be about the *actor*, about the *interaction*, and about a situation.

Information about the actors:

- Identity: the identity of the people that are interacting with a system
- Capabilities: roles, abilities, skills, and influence of people in the system
- Intention: the intentions, plans or motivations of those people
- Status: including presence or availability, activity level, and attention

Information about the interaction:

- Action: the change to the system state that is being made
- Goal: the larger activity or goal that an action contributes to
- Subject: the artifact or object that is being altered in the interaction
- Content: the actual content (e.g., the message or parameters)
- Authorship: who performed the action

Information about the situation:

- State of the System: the current system setup and the state of the interface
- Governing rules: the abilities of the system and roles that people can have

To give some examples from CSCW literature, *Babble* [38]—an information visualization for a chat-based collaboration platform—mainly shows information about the actors (*identity* and *status*): who they are, whether they are online, and how active they have been in the last 20 minutes. Through this information, people who log in can get an idea of the coherence of the group and the state of the discussion but not of the topic or intention of the participants [38]. Collaborative drawing tool *GroupDesign* [6] gives information about the *interaction*: functionalities *Echo* and the *Age* show the type of interaction (through icons representing the operation that is happening), subject of change (in the location of the icon), authorship (through the color of the icon), and change itself (objects turn from blue to red if they have been changed recently). In this way, people are aware of changes and conflicting actions are prevented because people can see that an object is being edited. An example of a system that gives awareness of the *situation* (*system state*) is the Dangling String by Jeremijenko [127]. The string starts to spin if a shared network gets busy, making it possible for people to estimate the appropriateness of their own downloading actions or to discuss with others about network use. Where these previous examples represent only one of the information types, information types are often combined. For example, in the main screen of the shared browser-based text editor Google docs [45], information of all three types are shown: the identity of users and their status (*presence* and *availability*) are shown through profile picture icons that become partly hidden when people become inactive; the cursor that moves along when people type also shows *status* (activity level and attention), as well as *action, subject of change*, and *authorship* at the moment of interaction; and the top-bar presents the *state* of the system: whether it is in viewing-, editing-, or suggestion-mode. In IoT systems, which are typified by their ability to integrate different information streams, such combinations are also likely to be made. For example, a smart thermostat might indicate *status* of people (whether they are present and taken into account in the current temperature settings), the *actions* and *content* of interactions (e.g., the setpoint has been manually adjusted to increase the temperature with 1 degree in the last 10 minutes), and *governing roles* (e.g., set to energy-saving mode).

While it might be tempting to just provide users with all information available in the hope that they filter out the useful cues to build up awareness themselves, this is probably not the best way to go: the solution approach "*to just 'throw everything you have' at the problem [...] is expensive and time-consuming, is difficult to justify when it is not clear that the information will even be of value, and may still omit critical information.*" [46:285]. Yet the decision on what information to represent has a great effect on what people have awareness on; and thus how they coordinate behavior, how they decide on social norms and constraints around use of the system, and what actions they feel accountable for. For example, in the experiments presented by Jessup et al. [63], different group decision support systems were compared: one in which information about the *identity* of a contributor was attached to a comment, and one where contributions were anonymous. They found that anonymity leads to a "*reduction of normal inner restraints*" [63:343]; a result that can be positive (participants mentioned that the detachment of their identity from the comments lead to more focus on content) or negative (leading to less accountability of what is being said)—depending on the situation, intended behavior, and the functionality of the system. Similarly, one could imagine that if a living-room television would publicly show the viewing hours per channel per family member, this would lead to other viewing behavior then if this information is invisible. And if the previously mentioned smart thermostat communicates impact on energy use for every manual adjustment for every user, this probably results in more heated conversations between family members.

In summary, a starting point when designing for awareness is to consider the type of information people need of other people and of the social setting. More information is not necessarily better: with more information people's understanding of the social context can become more complete but it can also lead to clutter and, more importantly, privacy invasion (see Section 5.1.4). The decision on what information to represent should be based on understanding what people need awareness of in order to coordinate behavior. This is again directly related to the envisioned use of the system and surrounding social setting, the degree of interaction between participants, the dynamic of the information, and the anticipated conflicts and foreseen faults—all of which are highly system and context dependent.

5.1.2 Detail & Abstraction.

— What is the highest level of abstraction that still results in meaningful information?
— Do people have access to more detailed information or direct communication channels if required?

Each of the types of information identified in Section 5.1.1 can be presented in different levels of detail. In the early-day systems, the level of detail in information was often restricted by the technical limitations. For example, *Polyscope* [13] and *Portholes* [29]—both among the first digital collaboration systems that presented explicitly designed awareness information—each show highly detailed photographs of a remote workspace to indicate *presence* and *activity* in those non-visible sights. Their struggle with the limited bandwidth motivated research on more abstract information visualizations of presence [99], which lead to the realization that "*effective communication matters more than communication bandwidth*" [31:36]. Therefore, even though modern-day networking technologies no longer restrict information sharing, designers still need to carefully consider the optimal level of detail in the information.

In research, a number of benefits of using abstracted information have been identified. First of all, there is usually a tradeoff between the level of detail of the information and overview over that information—especially because of limited space in the interface. To investigate this tradeoff, Gutwin and colleagues [55] evaluated a number of information widgets for a digital collaboration space that each present a different balance between scale and detail. They found that people liked the more abstracted views because, although less detailed, they gave an overview of *all* interactions that happened which gave people the idea of "working over a big table." Providing overview rather than detail is also recommended by Erickson [35], stating that the information can be distorted depending on the scale of the interaction, because the role of awareness—in Erickson's words—is not to present all information in detail but rather to provide "*grist for inferences.*" "*It is OK to distort activity, to magnify small amounts of activity, and to dampen large amounts of activity; for example, it is much more important for users to be able to tell whether there are 3 or 7 people present, than whether there are 103 and or 107 present.*" [35:847]. Following the same line of reasoning, when a person wants to take over control over a connected speaker system, it is more important to know if song that is playing is an individually selected song or part of a longer playlist, then to know exactly how many hours of songs are waiting in line. A creative example of how the balance between scale and detail can be adjusted dynamically can be seen in the media player by Greenberg et al. [47], where people's proximity to the screen alters the level of detail in the information presented on that screen.

A second benefit of using abstraction is that the information can become more calm and peripheral [99, 127] by removing detail (also see Section 5.2.3 on *presence of information*). Pedersen and Sokoler [99], for example, describe abstraction (or *feature degradation* [75]) techniques for rich media (including *pixelating, thresholding, feature extraction,* and *silhouetting*). An implementation of such techniques can be seen in the work of Hudson and Smith [62], who design a shared audio channel where a speech audio signals are transformed into a soundscape. By removing the intelligible words, muffling the sounds, filling in gaps and silences, they create a background sound that is much less disruptive than the full audio feed, yet still gives awareness about the presence and activity of co-workers. A third and last benefit of abstractions is that it can help to deal with *privacy concerns* [62, 99]; see Section 5.1.4).

Despite the benefits, Kahn et al. [65] showed in their evaluation of a social awareness system communicating a child's whereabouts at school that their abstractions to protect the privacy of the child made the system less meaningful for parents. Likewise, in our evaluation of lighting interfaces [93] people could communicate their *intention* with the chosen light setting by selecting an abstracted activity icons (showing, e.g., a coffee cup, a laptop, or two speech bubbles). It turned out that these icons were too abstracted to infer the relevant details behind intention of the previous actor: the speech bubbles could indicate an informal conversation or a formal presentation, for example. These findings show that precision in selecting the right level of abstraction is required [75].

Even if the right level of abstraction is carefully determined for *most* situations, specific situations can occur in which more detail is required. Dabbish and colleagues [19] studied the use of cues in GitHub—a collaborative online coding platform [44]. They found that where the social proxies of activity information provided too little information for the purpose at hand, more direct communication was setup through code comments, mailing lists, and other web-based communication tools. They advise that collaboration systems require a channel for two-way communication to resolve situations where the passive indicators do not suffice. Of course, in IoT interactions that are situated in a shared living room or open plan office this more direct communication can often take place face-to-face. In Section 5.2.3, we will further discuss the balance between abstraction and detail in relation to the *initiative* required from people to retrieve that information.

In short, although "*conflict can be reduced by better communication,*" better communication does not necessarily means *more detailed* communication [31:14]. Too little information results in less meaningful awareness and overly abstracted information might result in misunderstandings, but abstractions can be highly useful in providing overview, clarity of information, and calmness. So it is important to find the optimal point where the information provides as much overview as possible, yet is still meaningful. It is important to have more direct communication channels available when more detail is required, but this can be initiated on people's own initiative.

5.1.3 *Inference & Explicitness.*

- —Is there a risk of misinterpretation of the information?
- —Can the information lead to socially awkward situations?
- —Does the information allow for deception?

The information types reviewed in Section 5.1.1 all present factual information—what action was taken, when, and by whom—whereas awareness results from processing and interpretation of this information [87]. It is known that people use one type of information to infer other knowledge, especially if the information forms patterns of actions over time (see Section 5.2.1). For example, Dabbish and colleagues [19] found in their interview study on the use of activity awareness information in GitHub that people generate social inferences of the information that is beyond the factual information: activity level and number of contributions resulted in inferences about commitment and interest; and projects and people that received much attention by other users were followed to find expert users. People also started to actively steer the information based on this inference, as the following participant quote from their study shows: "*I'm kind of giving them some token of my attention. I'm saying, I like what you're doing (P23)*" [19:1285].

With AI developments and with the potential of widespread sensor networks of IoT systems, it is likely that systems will take a more active role in interpreting the information. For example, the smart meeting room described in Section 4.2 could either represent participant heart-rate data (factual information) or participant stress levels (interpreted data). And a home security system could communicate that presence is detected (factual) or it could indicate danger (interpreted information).

Showing interpretations presents opportunities for attention management (see Section 5.2.3) and could help to limit privacy risks [75]. However, in awareness research, system-made interpretations have been a topic of debate. Many researchers argue that systems should refrain from making interpretations and should only portray actions (e.g., [35, 50, 54]). The arguments against system-made interpretations are twofold. First of all, context is much more complex than an accumulation of sensor data [34] and it can be debated how correct the interpretations can be, especially in complex environments such as the home. Moreover, people often use systems or features in unanticipated ways [35, 50], especially because in multi-user situations foreseeing all possible use cases is impossible for designers [50]. This probably holds especially true for connected IoT systems, with their dynamic functionalities, depending on which objects and which third-party applications are part of the network at a given moment. For example, a connected home security device that is used for security purposes should make very different inferences than when the same device is used to monitor pets. On the other hand, technology and research in context-aware computing and data interpretations have developed since the late nineties. And it is also not a given that the interpretations that people make are necessarily the correct ones, as the evaluation of digital communication system *MyVine* [39] shows. MyVine presents office workers with availability information: it shows for each contact whether that person is *present* at work and his/her self-reported *availability* for communication. In evaluation of MyVine, however, it was found that people often mixed-up these terms and interpreted presence as availability, which lead to many undesired interruptions during evaluation. So even if there is no system interpretation, the risk of misinterpretation of similar information streams needs to be considered.

Next to the risk of misinterpretation, explicating inferences instead of more neutral factual information could also be risky in a social setting [50]—as the heart rate and stress level example in the meeting room above also intuitively shows. In daily life, the social inferences that we base our decision-making on is rarely made explicit and it would often be highly untactful to explicate every piece of sensed information about others, even if that information might be relevant in the interaction (also see Section 5.1.4 about the *awareness-privacy tradeoff*). For example, Grudin [50] mentioned a priority-based meeting scheduler that required people to publicly acknowledge that a certain meeting is of low importance, something people were highly reluctant to do. Likewise, while appropriate in an anonymous online platform, it might be awkward to vote for added songs in a shared playlist at a party. Or to publicly rate the lighting preset created by your boss in an open-plan office. On the other hand, presenting inferences instead of factual information might give present people with more opportunities to deceive. The ability to deceive is essential to safeguard privacy [103] and an important social skill in face-to-face interactions: "*In the course of our face to face interactions, it is often the case that we go to considerable effort to project impressions that don't represent our underlying feelings. We may feign interest, nod understandingly when we are baffled, and act pleased to meet people we loathe. These are vital social skills, and the last thing a social visualization should do is undermine them.*" [35:847]. Presenting deceivable system interpretation might makes it easier for people to hold up appearances by facilitating so-called *plausible* *deniability* [46]. For example, in social proxy *Babble* [38], people can feign interest in a certain conversation by clicking in the chat window (which moves their attention indicator that other people can see to the center) or they can pretend not to have read a certain message yet by deliberately not clicking in that window [35]. If the system would show factual information about whether something was actually read, this would be more difficult. In a similar way, if a streaming service presents interpreted recommendations for shows to watch, it could be easier for people to pretend to others that a system is mistaken, than if it shows actual previously watched shows, for example.

To conclude, people are highly skilled in making inferences on literal information, which can make the presentation of more literal and factual information the better strategy. Yet their factualness can also limit opportunity for deception. System-made interpretations are perhaps more likely to be mistaken, especially when dealing with complex context, but offer opportunities for attention management and abstraction. In any case, when explicating social information—whether factual or interpreted—the awkwardness of the possible inferences need to be carefully considered.

5.1.4 *Privacy & Control.*

- Is all the information sufficiently useful to justify the inference on privacy?
- Do people have control over what information is shared? Is the information sharing symmetrical?
- Do people know what information is shared of them at what moment?

Issues of privacy are inseparable from sharing information: "*Simply stated, the more information about oneself that leaves your work area, the more potential for awareness of you exists for your colleagues. Unfortunately, this also represents the greatest potential for intrusion on your privacy.*" [62:248]. The tradeoff between awareness and privacy has discussed by many (e.g., [13, 36, 42, 62, 98, 99]) and forms an important—arguably even the most important—topic of consideration when designing for awareness.

Because awareness and privacy form a tradeoff, the usefulness of information and its possible inference on privacy need to be carefully balanced. A possible surplus of information due to the selected retrieval method or sensor (see Section 5.2.2) or due to an unnecessary level of detail (as discussed in Section 5.1.2) should be obscured. For example, in Hudson and Smith's [62] remote collaboration system, video feeds of co-workers can be accessed to get information about their presence and activity. However, this information does not require a full life-stream feed. Therefore, they transform video feeds into so-called *shadow-views*—still images of a room with an overlay of darker blocks where movement is detected, thus showing a ghost image of a person's movement in space—to remove privacy violating details. In general, all inference of privacy that comes from information that is presented needs to be justifiable by the usefulness of that information in the interaction. This could mean that information should not be available at any moment (also see Section 5.2.3). In an intercom system in an apartment building, for example, video footage can normally only be accessed at the moment someone rings the doorbell. Most "smart" video doorbell systems, however, give access to the camera at any moment, which could have serious consequences for the privacy of neighbors.

Since the optimal balance between information requirements and privacy differs per person—depending on, among others, cultural differences [72]—an often-named strategy to safeguard privacy is to give people *control* over what information is shared [13, 42, 75]. Markopoulos [75] describes four levels of such control, which at the lowest level can be turning all information on or off, and at the highest level allow for full control of all information flows. Interesting examples of how people can be given control over information sharing in physical environments are given by Streitz et al. [118]. Their Personal Aura, for example, is a personal artifact that gives people direct and dynamic control over whether and what information they want to communicate to a smart environment, by sliding different "role" cards in to a personal keyholder. And View.Port allows people to "drag and drop" information streams from a private to a public display and back, to directly update their information sharing preferences at any moment.

Allowing for control over what information is shared can also be tricky, as it is a form of customization of awareness information—a notion that has been critiqued as it goes against the function of awareness as a social mediator: "*If I see something, I know that you see it as well and that you know that I know. It is this mutuality that supports people being held accountable for their actions, and that leads to useful social phenomena such as feelings of obligation and peer pressure*" [35:846]. Hence, researchers largely agree that control over information should be combined with *symmetry* or *reciprocity* of awareness [13, 35, 131]. Symmetry refers to the rule that in order to access a particular type of information by others, a person needs to share that same type of information to those other people. In simpler words: "*if you can see full live video of me, I should be able to see full live video of you*" [13:14]. The concept of symmetry has been critiqued for being too disruptive (e.g., [42]) but it is important not to implement it too rigidly: "*This principle doesn't mean that I must see you if you can see me, only that I have that option if I should choose to exercise it.*" [13:14]. Examples of control over information sharing in combination with symmetry of that information are widespread. Think, for example, of the blue checkmarks—indicating that a message has been read by the sender—in the instant messaging application WhatsApp [130]: this information can be turned off by the receiver if s/he does not want that the reading information is shared, but is—when turned off—also not available for his/her own sent messages.

Next to control and symmetry, people should be given feedback on what information is being shared of them. The more intrusive the representation (think, for example, of live video or audio), the bigger the need for real-time (or even anticipated) feedback about what is being accessed by whom. For example, in the *RAVE* system [42], people can access video streams of co-workers. Whenever someone opens a connection, the person of whom the video is accessed is notified through audio. Different sounds indicate different intentions behind the connections—for example, a sound of an opening door and a closing door indicate the start and end of a so-called *glance connection*: a quick peek into the office. Feedback is also given when presenting the information from a third person point of view [35], so that people can see the information that is shared about them in the exact same way others can see that information. This third person perspective has an additional advantage of encouraging reflection upon one's own actions and thus increasing the understanding of the visualization [35]. For example, our social collocated photo-sharing application Shoto [91] allows people to privately browse their personal photo collection on their mobile phones and share selected photos on a shared screen to others. The shared screen shows everyone's browsing behavior in the same, abstracted way, which allows people to infer who is planning to share photos and how many, thus adjust their own input accordingly, to hold others accountable for being too dominant, or to encourage others to share more. More examples of information that is presented from a third person point of view can be found in *feedthrough* of information (see Section 5.2.1).

In this section, we have only discussed privacy considerations surrounding the sharing of awareness information among the direct users of a shared system—so where information sharing is limited to, for example, people present in a single living room or to the colleagues sharing an office. Because of the connectedness of IoT systems through the Internet, the sharing of information could reach much further and could include, for example, other users of similar systems (e.g., through recommendation services), third party stakeholders (including advertisement companies or governmental agencies), or the service provider. While outside the scope of this article, it is important to realize that privacy considerations in those connected systems entail much more than just awareness information (also see Section 6.3, and for an overview of privacy challenges in IoT systems, see [4, 70, 100]).

To sum up, designing for awareness always results in a tradeoff between awareness and privacy. Designers have the responsibility to ensure that the shared information is sufficiently useful to make up for a possible privacy invasion. Individual differences in where the sweet-spot of the tradeoff lies can be overcome by providing feedback on what information is accessed (for example, by showing people their information as others would see it) and by giving people the option to control what information is shared.

5.2 How Can the Awareness Information be Embodied?

In Section 5.1, we reviewed the question of *what* information is needed to support awareness. Now, that the information is identified, this information needs to be presented to the user in the right way and at the right time so that it can lead to increased awareness. We review considerations on how to *represent* the information, and where to *place* the information in relation its source (Section 5.2.1). We look at the effort and intentionality that is required from people when providing the information to the system (Section 5.2.2) and—on the other side of the system—the *initiative* required to retrieve the information again (Section 5.2.3). Furthermore, we look at the timing and need for *persistence* of information (Section 5.2.4).

5.2.1 Representation & Placement.

- Can information be highlighted in the environment or given by other people, or does the information need to be represented in the interface?
- Can the information be presented situated or is separation from the source necessary?
- Are interface elements expressive enough to feedthrough information?

To answer the question of where to represent the information, we should start by looking at how people normally obtain information from their environment. Gutwin and colleagues [55]—by basing themselves on prior research on workspace awareness by Dix et al. [25] and Norman [94]—describe five different mechanisms that people use to obtain the awareness information: *direct communication, indirect productions, consequential communication, feedthrough*, and *environmental feedback*. In these five mechanisms, we can identify three ways of representing awareness information. The information can be embodied as follows:

- Other *people*: through direct communication (e.g., speech, gestures), expressive actions, or indirect observations.
- The environment: through observation of surrounding information (e.g., time of day, ambience, use of space) and the effect of an interaction on the environment (e.g., seeing the light turn off).
- The *interface*: through status change of interface objects (e.g., sliders changing position) or in designed awareness elements (e.g., social proxies).

Since in distributed shared use—which most of the examples from CSCW represent—the environment and other people in that environment are not shared, all the necessary awareness information has to be represented in the interface. Collocated interactions can instead also exploit the presence other people and the environment. This means that not all information that is required for awareness has to be designed in the interface; sometimes, accentuating or guiding attention towards the information in the context can be sufficient. This is still a design effort: common design decisions—on the interface modality or distribution of an interface—largely influence what information in the environment can be perceived [93]. For example, a television remote control gives more awareness of the identity of the person interacting than a smart phone application that is used to change the content on a shared screen, because the TV remote—in contract to the smart phone—is a dedicated device that requires visible gesturing when interacting [91]. Multi-purpose devices such as smart phones or tablets do not always have to obscure the identity of the person interacting: increasing the visibility just requires a bit more of an interaction design challenge. A nice example of how the visibility of interactions on multi-purpose devices can be increased can be seen in the "Smarter objects" tablet application by Heun et al. [56]. In this application, digital controls of interactive objects are placed on top of the camera's image of that object. So for example, pointing the camera at a lamp will make the controls of that lamp appear on screen. As a result of this chosen interaction style, the camera of the tablet has to be pointed at the object, resulting in a gestural interaction that is much more visible to other people in a shared space. Other examples of consequential information during interaction are seen in voice-controlled home assistants, where the command given during interaction is audible to all in the room. And in the visibility of the in-air gestural controls by Sørensen et al. [116]. For a systematic overview of performative gestures, we refer to Van den Hoven and Mazelek [61].

Information representations can be situated or separated. Situated information is retrieved in the same place as that information is generated, while separated information is translated and represented in a different way [54]. Information that is embodied in other people and in the environments is situated by nature, but when presenting the information in the interface, it can be both situated and separated. Separated information is, for example, seen in social proxies: visualizations of social information that form a separate element in the interface [37, 79]. Think, for example, of the avatar in the corner of your connected TV, showing who's channel-viewing preferences are currently active. Situated placement of information in interface elements is often based on the concept of feedthrough—information that is retrieved by observing the effect of a manipulation on an object [25]. Think of how the position of a wall light switch gives information about its current state: up is on, down is off. Making use of situated feedthrough information can have a number of advantages [54]. First, since feedthrough is represented in the same way as it was produced, it usually forms literal information without system interpretation (see Section 5.1.3) that is easy to understand. Second, feedthrough matches how information is generally retrieved from other people and the environment and "*allows people to use their existing skills with the mechanisms of feedthrough, consequential communication, and gestural communication.*" [54:433]. Third, feedthrough is consequential information that requires no extra effort to produce (see Section 5.2.2). And fourth, feedthrough information is passively available in the environment and can thus be accessed by people at the moment of need [29, 54] (see Section 5.2.3). The amount of feedthrough that an interaction element provides is commonly referred to as its expressiveness [54].

Tangible interfaces are known for their expressiveness [54, 59, 124]: "*they form spatial relationships to other objects, they contain visual symbols like words, pictures, and numbers, and their states are often shown in their physical representation. Artifacts also contribute to the acoustic environment, making characteristic sounds when they are created, destroyed, moved, stacked, divided, or manipulated in other ways.*" [54:423]. Furthermore, tangibles allow for performative actions and expressive gestures [59, 61, 85], thus combining information from the interface with information from the people using it. Yet, as we indicated before with the example of the Smarter Objects [56], performative actions can also be achieved in digital interactions (for more information, see the study on visibility and identifiability of digital interactions by Reetz and Gutwin [105]). Lastly, tangible interactions with physical objects provide natural constraints [59, 131]—e.g., when I am manipulating something, you cannot manipulate it at the same time (think, for example, of the television remote control vs. a smartphone interface again). These benefits of tangible interaction are well exemplified by Eden and colleagues [32], who present a co-located multi-user tool for urban planning, consisting of a digital map and physical tokens that can be placed on the map. When using this tool collaboratively, the physical tokens can placed with emphasized gestures to attract attention from others, the tokens can be held back to prevent other people from manipulating the objects, and their number on the board show in one glance how far the task has advanced; all information that would be much harder to communicate with digital icons. Interesting IoT-related examples of expressive tangible interfaces are given by *sLight* and *Swivel* [5]. Both of these tangible lighting interfaces express in their physical setting information about the current state of the lighting, whether the setting deviates from the automated preset, and the amount of effort that was put into creating the current setting.

In summary, awareness information can be presented through other people, from the environment, or from the interface, and can be presented situated or represented separated from the location where it was retrieved. Situated information is generally easier to understand. Collocated interactions—as often the case in IoT interactions—offer a number of advantages when deciding on where to represent the information. Since other people are generally visible and the environment is shared, not all information needs to be represented in the interface. Second, interaction with spatially distributed objects (that can take a location in space) and tangible interaction styles that allow for feedthrough of information are easier to achieve than in distributed scenarios.

5.2.2 *Effort & Intentionality When Providing Information.*

- Should providing information require effort or initiative from people or can the information be retrieved as a consequence?
- Is the information up-to-date and is accuracy ensured?

In order to represent information in the interface, this information needs to be obtained first, e.g., through sensors or by explicitly asking people to input information. When asking people to provide the required information to the system, it is important to consider how much effort people would be willing to spend to provide this information. If the providing of information requires effort without resulting in direct benefits for people providing that information—if people have low *collaboration readiness* [96]—it is likely that people will refrain from providing the information. Next to effort, one should consider whether the initiative to provide information should be placed with people, or with the system. If people should take initiative to provide information or to keep information up-to-date, there is a risk that people forget to provide the required information, as the evaluation of *AvBox* showed [78]. AvBox is an availability system for office environment, where people can manually input their current *availability, concentration, time-pressure*, and *disturbance* level on a 7-point scale. The information is communicated to co-workers on public screens in the hallway. The evaluation showed that even though people were highly motivated to indicate their availability, they still frequently forgot to update their status [78]. We found the same in our evaluation of lighting interface Canvas: although people appreciated the option to indicate their preferences to other people, in practice, updating this information required too much effort and initiative to keep the information up to date [93]. So in short, if certain types of information are required to increase awareness and have to be accurate and up-to-date at all times, the capturing of information should not ask too much effort or initiative from a user.

So how can information be retrieved effortlessly and with low initiative? In the five mechanisms that people use to obtain awareness information [54]—*direct communication, indirect productions, consequential communication, feedthrough*, and *environmental feedback* (see Section 5.2.1)—there is a difference in whether the communication is *intentional* or *consequential*—a distinction that is also made described in Rittenbruch's Atmosphere framework [106]. Intentional information—also called *manual* or *explicit* information [75]—is provided through an action that is aimed at giving information. Examples of intentional information include adding a status description in chat applications, annotating interactions with the objective or other details, or manually inputting reviews of other people's actions. Consequential information—also called *passive information* [29] or *implicit information* [75]—is in contrast provided as a side effect of another action and therefore requires, per definition, no initiative or extra effort from the user. Examples of consequential information can be the communication "*produced by arms and bodies as people carry out actions*" [85:192], e.g., walking up to an interface or pointing a remote towards the television (also see the expressive actions in Section 5.2.1). Consequential information can also be digitally gathered by the system: it can be sensed (e.g., in the status information in the Nest thermostat [88], that is gathered by a motion sensor), or *feedthrough* in digital interaction elements (such as in the position of the Nest temperature scroll wheel that shows deviation from automated settings; also see Section 5.2.1).

There are different advantages and disadvantages to using intentional and consequential information. For example, an advantage of intentionally provided information is that it gives control to people (see Section 5.1.4) and allows people to express more detailed or more meaningful information: "*If users are enabled to provide additional contextual information, they can add meaning to seemingly disjoint activities. For instance, people generally know why they are editing documents, in which work context particular changes are made, whether the edits are rushed or thorough and so on.*" [107:368]. For example, in the *Information Lens* emailing system [73], people can share information about their motive and the action that they require from others in the header of an email message, which is information that would be very difficult to extract automatically. And since adding the information is not required to send the email, *not* specifying a motivation becomes an additional type of information (indicating to the receiver that no direct action is required or that deciding on an appropriate response is up to the receiver). The same principle was implemented in previously mentioned lighting interface Canvas [128]: people could draw a boundary around a physical token to indicate their preference. Because people have the ability to add this information, not adding a boundary could be seen as an explicit action to not add a boundary. Although intentional information generally requires more effort from people, the action required can be designed to be simple as the AnyBif system demonstrates [107]. However, completely effortless intentional information is impossible [106, 107] and there is always some level of initiative required. Therefore, if accuracy of the information is important and if there is low collaboration readiness, it might be better to use consequential information. For example, when designing a security system that shows presence of people in the building in case of an emergency, accuracy of information is crucial and consequential information gathering (using, e.g., motion sensors) would be the better choice. However, consequential information can come with tradeoffs on other considerations. If information is retrieved as a consequence of another action there is a chance that people do not notice that the information is being retrieved, which presents a higher risk on privacy invasion. This makes it more important to design adequate feedback about what information is being stored or presented to other people (see Section 5.1.4). Also, *deceiving* others (see Section 5.1.3) could be more difficult in consequential information. So, in cases where the information is additional, does not require frequent updates, or is potentially sensitive, *intentional* ways of providing information are preferred.

In brief, it is important to make the input of information as low-threshold as possible and to carefully consider the effort and initiative that is requested from the user in order to gather information in the system. If the information should be accurate and up-to-date at all times, then providing that information should not require initiative or effort and it is best to gather this information as a *consequence* of people's interactions. If information is not strictly needed, if it represents potentially sensitive values or opinions, or if people should be made aware that the information is retrieved, *intentional* information could be the better option.

5.2.3 Initiative & Presence when Retrieving Information.

— Is information that has an alerting function present at the right moment, without requiring extra initiative from people?
— Is the information sufficiently present, yet not obtrusive?

Needless to say, in order to increase awareness, the information needs to be perceived by whoever requires this awareness in their interactions. Therefore, designers need to consider at what moment and on whose initiative the information becomes available, as well as how much attention that information should attract.

An important role of awareness information its *alerting* function [1]—"*its primary role is to provide grist for inferences*" [35:847]. In order for information to fulfill that role, the information should be available without the need for the user to actively search for this information [1], which means that it cannot be hidden in personally manipulable views [117] or behind extensive menu-structures [55]. Note that this does not mean that all information is necessarily in sight at all times. It only needs to be available at the moment where alerting is needed. For example, in availability system *InterruptMe* [58], information about the availability status of colleagues and their preferred medium of contact is *only* projected on the wall at the moment people pick up the phone to make a call. Not *all* the awareness information that can be of help during an interaction necessarily has an alerting function. As we also mentioned in Section 5.1.2, more detailed information could become available only on user request. For example, in home IoT devices, deviations from the normal settings should perhaps be alerting—e.g., the switch to manual mode instead of automated mode on a connected camera; use of a higher washing temperature because of detected dirt in a smart washing machine; or the calling mode of a voice-controlled home assistant. Details on *why* it is in that manual setting or *who* turned it to that setting can become available on request only. A nice example from CSCW of this combination of alerting and additional information can be seen in the *WikiDashboard* [119]—a social proxy for Wikipedia that gives awareness of the editing history of a page. The WikiDashboard is always available at top of a Wikipedia page, and shows a graph of the number of edits over time. By clicking on the timeline, a more detailed graph unfolds that shows the number of edits per person. The main graph, although limited in detail, alerts the reader about suspicious processes: if editing is still in full progress or if the text has not been updated for years, and if the page was written in one go instead of incrementally changed; this might say something about the quality of the Wikipedia page. More detailed information to further investigate the suspicion—on, for example, who made the main contributions and on how collaborative editing was—can be found on the user's initiative.

Since there is a possibility that people do not notice important information, the *presence*[4] of the information requires consideration, especially in combination with decisions made on the *placement* (situated information is generally less visible; see Section 5.2.1) or *persistence* of information (information that is only available in the moment is easily missed, see Section 5.2.4). For example, in Google Docs [45], seeing the cursor of another remote user in can be highly effective to signal what pieces of text other people are working on to prevent interference or conflicting actions. However, since the information is non-persistent (the cursor only shows real-time, current edits) and situated (at the location of the adjustment), the information is not available if people are

[4]Note that in literature this is generally referred to as *visibility*. Since we do not want to favor visual information representation over other modalities like sound and touch, we use *presence*.

working on different pages of the document or if someone joins the session later on. To tackle this common problem, Gutwin and colleagues [55] present *radar views*: smaller and abstracted images that give awareness about the activities of other collaborators. Researchers have also argued that tangible interaction styles can help to increase the presence of information [131]. Tangible interfaces have presence in the space because of their physicality, and often—although this is depending on the size of the interface—a noticeable location. This spatiality of the information makes it easier to glance up and perceive the information (also see Section 5.2.1 on feedthrough, and Section 5.3.3 on intervention). An example of the power of such a spatial layout of information is given by An et al. [3], in their evaluation of a network of connected tangible interfaces for classroom teachers. Tangible interactions also allow for more expression [59]: "*freedom of input enables gesturing, speaking, and touching. These can all be seen, heard, and experienced by others whereas mouse clicking and key pressing are individual, private acts.*" [131:1:3]. This is interesting for the interaction with IoT-like systems, which currently offer smart phone applications as a main interaction style, even though smart phones result in especially private and invisible interactions [128]. For even more explicit signaling of information, stimuli with higher salience [67] can be used, by using movement (as, for example, described in Norman's [94] *obvious actions* for aircraft cockpits) or auditory feedback (as, for example, used in the RAVE system [42] described in Section 5.1.4). For an overview of notification levels with different levels of salience, we refer to the taxonomy of ambient information displays by Pousman and Stasko [102].

Note that higher presence of information is not always better. There is a fine line between presence and *obtrusiveness* [54, 58, 99], because of the "*trade-off between being well informed about other's activities but being distracted by that information from the task at hand.*" [53:11]. For example, in the virtual collaboration environment *ActivityExplorer* [84], all users in a particular group were notified when someone accessed a shared object. The alerts were designed with relatively small groups in mind but in practice, large threads with many members were often created that could lead to obtrusive streams of alert messages. The power of awareness information is that it stays in the periphery of attention, providing people a grist of what is going on without requesting specific attention: "*awareness information does not need to be sought out.*" [27:2]. Therefore, although presence is important to consider when designing to aid awareness, sometimes it is better to accept the risk that some information might be missed.

To conclude, an important function of awareness information is to *alert* people of, e.g., the acceptability of their own changes or the indented changes by others. Information that has this alerting function should have been available at the right moment without requiring initiative from people, while or less important background information or more detail can be available upon request. To make sure that the information is perceived at the right moment, presence of that information needs to be considered and sometimes enhanced. However, the fine line between presence and obtrusiveness needs to be carefully considered.

5.2.4 Persistence.

- How long does the information remain relevant?
- Can the persistence of historic information lead to meaningful structures or patterns?
- Should individual instances be presented or can information be accumulated?

The discussion up-to-now has mainly been about information that is attached to a single action happening in present time. However, it might be that the information stays relevant for a longer period of time. McDonald and colleagues [79] present three layers of information in their domain analysis on social translucence. The lowest layer consists of the single bits of information called *instances* (which is what we have reviewed in Section 5.1.1)—think of logging in to an application (*status*), or a changed parameter in a single interaction (*content*). The second level consists of instances that are coupled together to form a *series*—one complete interaction, e.g., the combination of logging into a shared movie streaming application with a personal account, selecting a movie to watch, forwarding through the movie, watching a 10-minute piece, and turning it off again. The highest level describes *structures*: combinations of series and instances that over time can form recognizable patterns, such as "*expectations, normative behaviors, patterns of social interaction, and social roles*" [79:640]. For people to recognize patterns, however, the information needs to persist for a longer period of time.

The potential benefits of persistent information has been underwritten by many [19, 28, 35, 79, 131]. First of all, if information is persistent it remains available even after an interaction is completed. This is especially of importance if shared use is not continuous or synchronous [27, 28], which is the case in many of the IoT systems that we address in this work. In shared use of home automation or entertainment systems, for example, one person might turn on the light or start music playlist and another person then adjusts the setting after a while. Since people find it important to take the previous actor into consideration when making changes to a setting [16, 82, 93], some information about the previous interaction should persist in the interface. A second benefit of persistence is that it allows people to see the changes in a certain information stream over time, which allows people to make inferences beyond what is shown [19, 35]. For example, in the evaluation of Timeline proxy of Babble—a display modeled after an audio signal, showing availability and engagement in the conversation over time—people could infer sleeping hours (indicating location and time zone) as well as holidays of other participants [37]. Similarly, one could imagine that—in the previously named shared movie streaming application—seeing a list of previously watched movies can give information about a room-mates preferences for a certain genre, week schedule and time of being at home, hobbies, and sleeping routines (see Section 5.1.3 for more examples of such inferences). As a third benefit, seeing accumulated information or information structures is a unique quality of designed awareness information. In face-to-face interaction, much of the information is transient, making the accumulation "*subject to the vagaries of each person's unreliable or biased memory.*" [131:1:7]. Presenting persistent information more objectively for everyone to see can be beneficial. For example, social proxies for meetings that show the accumulated speaking time per participant (e.g., [11, 23, 122]) show benefit for leveling meeting participation. Even though all the *instances* of information—*action*: speaking; *authorship*: who is speaking; and *content*: what is being said—are already available to the meeting attendees in the verbal communication, it is the persistency of this information over the duration of the meeting that triggers reflection upon the balance in contributions (at *structure* level).

Since awareness information is contextual information, most of this remains relevant for a limited amount of time. Therefore, designers should consider the duration for which the information should persist. Information can be available:

- Only during the interaction: Voice-controlled interactions are an example of such transient interactions: although highly present during interaction, the moment a person stops speaking information about the interaction is lost.
- For a *given amount of time:* Designers might make information digitally available for an extended moment. For example, 3D editing software *NetSketch* [68] quickly moved objects leave a ghost images behind to extend the time in which other people can notice that a certain change has been made and possibly undo that change. After a few seconds, the ghost image disappears.

—Until the *next interaction:* All feedthrough information (see Section 5.2.1) is available until the interaction element is changed again in the next interaction. For example, in the tangible interface for search engines by Blackwell et al. [12], the physical tags representing a search query stay around until the next search so other people can understand and discuss about the currently displayed results in relation to the search terms.

—*Until it is removed:* Removing information can be turned into an explicit action, which indicates to others that the information is no longer relevant. For example, *review comments* in Microsoft Word [80] remain present until it is explicitly removed by a user, indicating that the comment has been resolved or is no longer relevant. And in lighting interface Canvas [128], boundaries stay visible until removed by another person.

—Until an event *ended:* Information that should form structures might stay relevant for a longer period than one interaction lasts, but not indefinitely. For example, the bidding information in the *Auction proxy* [37] is only relevant for the bidders while the auction lasts. It is removed ones the auction has ended.

—*Indefinitely:* Some information might require indefinite accumulation. The *Editing and Reading Wear* of Hill and colleagues [57], for example, accumulate information about the edits in a document indefinitely. In this way, always shows the full history of the document.

Design choices on persistence of information influence many of the other considerations. If information persists for a longer amount of time, the possibility that the information is misinterpreted without its context increases (see Section 5.1.3), as well as the risk on privacy invasion [98] (see Section 5.1.4). Also, depending on other considerations, it can become difficult to keep the information persistent. In digital visualizations of available information, persistence is relatively easy to achieve but when communicating *consequential* information (see Section 5.2.2) or when using information that is available in the environment (see Section 5.2.1), it can be more difficult to make the information last: voice-based commands and expressive gestures are only available in the moment and *feedthrough* information cannot show the structures in the history. The *History Tablecloth* [41] presents a clever way of making feedthrough information more persistent: the table top starts glowing around objects that are placed on the table. The longer the object remains, the brighter the halo becomes. Also note that we only discussed the relevance of persistent information to the direct users of one system. The information can remain relevant indefinitely when looking at it from a system AI or for third party stakeholder perspective, but then the consequences for privacy increase even more (see Section 6.3).

To summarize, information that persists in the interface have a number of benefits, depending on the duration in which the information persists and on whether individual instances of information remain visible or are accumulated. Information can be made available for just a *brief amount of time* or *until it is removed* make sure that important information is not missed, *until the next interaction* to inform people that want to make adjustments to a current state or setting and thus support a-synchronized use, *until a certain event has ended* to maintain awareness about the process or character of that event, or *indefinitely* to allow people to recognize patterns or see structures in the information. However, the tradeoffs with other considerations—especially the one on privacy (Section 5.1.4)—need to be taken into account.

5.3 How Can the Awareness be Used Effectively in Interaction?

In the previous two sections, we reviewed how to design to aid awareness. Section 5.1 reviewed *what* information should be presented, including its detail, explicitness, and the risk of invading privacy. In Section 5.2, we looked at *how* the information should be presented and in what way the information is gathered. In this section, we assume that all actors in the system "*know what is going on*"—that people are aware of all the information required to communicate more easily, coordinate interactions, anticipate on actions of others, to assist where needed, and to hold each other accountable. However, awareness is never a primary goal; it is a way to help people to interact with the system in a way that matches the social context [54] and the mechanisms in which awareness is used—communication, anticipation, assistance, and accountability, for example—might require *more* than awareness only. So in this section, we review other interface characteristics that allow people use their increased awareness effectively in the interaction with a shared system. In Section 5.3.1, we look at *anticipation*, which requires awareness as well as *experience* with the system. Section 5.3.2 discusses how people can be assisted to resolve conflicts if they are given sufficient *interaction alternatives* to choose from. And we consider accountability and defense mechanisms for other people that are influenced by an interaction, through *recoverability* and *intervention* (Section 5.3.3).

5.3.1 Anticipation & Revisability.

- Are people supported in estimating what the effect of an interaction will be on other people?
- Can people explore functionalities without affecting others directly?

Endsley's [33] definition of awareness consists of three levels. Level one is the perception of relevant elements in the current situation. Level two is the comprehension of the situation based on those elements and the integration with prior knowledge. And level three is the prediction of the future state of those elements, based on which people can "*decide on the most favorable course of action to meet one's objectives*" [33:37]. This third level—or the ability to anticipate on the effect of an interaction, actions of others, and the interplay between these two—is generally seen as main result of awareness: "*People anticipate others in several ways. They can prepare for their next action in a concerted activity, they can avoid conflicts, or they can provide materials, resources, or tools before they are needed.*" [54:430]. The ability to anticipate builds upon awareness and *experience*: people make a prediction of what the effect of an interaction is based on their knowledge of the current situation (awareness) in comparison to expectations build up from prior interactions (experience, or *schema* in Neisser's [87] words).

In ecologies of connected IoT objects, chances are that this prior experience is less developed and slower to build up, since the setup of the ecology can be altered, since interaction and control over such objects can be new and unfamiliar to people, and since there is a larger number of possible system states due to fine-grained interaction possibilities. This makes anticipation on the effect of an interaction more difficult: even if people are aware of other people and want to take them into consideration, they might not know the system's possibilities well enough to adjust an interaction based on the awareness. For awareness to be used effectively, it is important that people understand the effect of an interaction on the system state *before* that interaction takes place. This makes well-designed *feedforward* [8, 26, 125] a crucial element in interfaces for shared use, since feedforward "*tells users what the result of their action will be*" [125:1931]. Examples of feedforward are numerous and include simple yet powerful examples as labels on buttons, or previews of presets. However, there are many cases in which feedforward fails to tell people what the effect of their interaction is going to be, especially when it comes to the effect of the interaction on other people. For example, in the file sharing system Dropbox, shared folders have a different label than personal folders. Yet that label does not show what happens if a file is deleted from the shared folder [30]: will the person deleting the file just lose access or is the document deleted for all users? Or when using the "follow-me" function on a connected home audio system, does this mean that the music will also continue to play in the room you have just left and where someone else is still present? Or will it turn off the music in that room when transferring music to another room?

Another use of feedforward could be to give people a way to experience the effect of their interaction privately, before applying the setting and impacting other people [129]. In this way, the interface could present a safe environment for exploration. In communication, this strategy is called *revisability* [17]. In email and instant messaging applications, for example, typing and sending are two separate actions, which allow people to privately revise an utterance before making it public. In this way, the repair cost of faults is much smaller than in, for example, non-revisable telephone conversations [17]. Revisability can also be seen in the software used by Disc Jockeys, for example. Using their headphones, DJ's can privately experience their planned next song and fine-tune their selection and the transition—all in the moment but before actually starting the song and affecting the audience. Another example is in the presenter view of PowerPoint presentations [81], where the presenter can preview the next slide privately on his/her own laptop to prepare the story for what is coming, or to select another slide if needed. While revisable interactions can be more effortful—the "apply" requires an extra step in the interaction—this effort could be well spent, especially if the effect of an interaction is difficult to predict or if the cost of recovering from errors is high (see Section 5.3.3).

In short, anticipation requires both *awareness* and *experience*, since people will need to know what the result of their interaction will be on the system's state before being able to predict the possible effect on other people. Therefore, it is important to make people aware of the effect of their interaction *before* the interaction takes place. This can be done through well-designed feedforward or by offering revisable interactions that allows for safe and private exploration.

5.3.2 Interaction Alternatives.

— Are there sufficient alternatives to change the planned interaction based on awareness?

Awareness allows people to coordinate activities among each other, in order to avoid potential conflicts and negative influence on others [29, 48, 54, 60]. Interactions can be seen as moments of decision making: people make a choice in what system state best matches their objectives with the interaction [33] by taking their preferences, values, activities, and contextual information into account [71]. In shared use, awareness of other people and their predicted preferences, values, and activities also influence the outcome of that decision. If people's own preferences, values, and activities and those of other people do match and thus can result in potentially interfering preferred system states, this is perceived as a potential conflict [31]. People can resolve conflicts through different strategies, of which collaborative or sharing strategies where an alternative outcome is searched that satisfies all are seen as most constructive [123]. This highlights an important system requirement: if people want to resolve conflicts by searching for a better suiting alternative, the system needs to present the user with sufficient interaction possibilities to have options to choose from [91].

In order to present people with interaction alternatives, there need to be a certain granularity in the control given to the user [24, 25], with control referring to "*the ways in which users can effect changes in actions within the system and hence decisions within the group.*" [131:1:5]. If people are only offered discrete control (e.g., on or off), there is no way to mediate in a conflicting situation, no matter how high their awareness of the conflict is. In a lighting system for example, if one person wants darkness to get a cinematic feeling while watching TV, while their partner wants to read, this could be seen as a situation of potential conflict. If the system only allows interaction with discrete presets (as for example in the Hue Tap controller [101]), this conflict can be difficult to resolve. To take each other into account and find a resolution that satisfies all, people need to be offered higher granularity of interaction, e.g., by providing dimming control or the possibility to fine tune individual lamps [92]. There is a second reason why sufficient alternatives need to be available in interaction with systems that are shared in use. While individual habits are relatively constant over time and thus predictable, group activity is much more difficult to characterize. Therefore, in shared use a higher flexibility of use is required and infrequently-used interactions should be allowed [50].

In summary, increased awareness of potential conflicts can make it possible to resolve these conflicts before they become manifested. To make it possible to take each other into account in the interaction, the system should present sufficient interaction alternatives to choose from.

5.3.3 *Recoverability & Intervention.*

— Is it possible to intervene in an interaction by other people?
— Can people recover from errors, also when made by others?

The issue of recoverability—"*the ability of the user to take corrective action once an error has been recognized*" [25:270]—is a standard consideration in any interaction design. In shared use, however, it requires even more attention, since recoverability should not only refer to the ability of restoring one's own mistakes but also of the potential mistakes made by other users. Whenever people make decisions on behalf of others, there is the possibility of missing important information (see Section 5.2.3), misinterpreting the information (see Section 5.1.3) or acting upon that interpretation in a conflicting way (see Section 5.3.1). It is therefore important to give the impacted people a way to express their dissatisfaction, ask the person interacting for an explanation, hold the person interacting accountable for undesired changes, or propose alternative solutions.

Hornecker et al. [60] found in their study on collaborative tasks on multi-touch tabletop interfaces that increasing awareness of each other's action leads to significantly more interference into action of other people. Because the increased awareness resulted in more fluid interactions and quicker resolving of interference, the participants took more risk in the interactions themselves. The researchers suggest, based on these findings, that it is more important to have resources available to negotiate interference than to restrict interference within the system. At the most basic level, this would mean that the people that are being affected by the interaction are given a way to respond [8]. This response requires two-way communication, which in collocation interaction can take place face-to-face but which needs to be mediated by the system in distributed interactions (also see Section 5.1.2). Second, people need to be able to retrieve a previous setting in order to recover from an undesired interaction. While allowing for people to undo unwanted changes is among the standard interaction design principles [25], this can be more challenging in shared use of IoT systems, since this often means revising of operations of other users that are potentially made through a different account or using a different input device [91]. For example, if one person decides to change the music to a different playlist but then wants to undo this action, the previous playlist that came from their partner's personal account is not accessible.

Even better than recovering from errors would be to prevent errors in the first place and to allow possible impacted people to intervene before the interaction even occurred. This would require that the intention to interact becomes visible to all actors in the system. Tangible interaction styles are especially promising for this because they have physical presence in the space (see Section 5.2.3) and because tangible interfaces are generally dedicated to a certain interaction or functionality, while screen based interfaces often take place on multi-purpose devices [128]. For example, a mobile phone can have a virtually endless number of applications and for an outsider it is not visible what application is being accessed at that moment, making it more difficult to intervene. In contrast, walking up to a tangible wall-mounted interface forms a visible cue to others in the room that are then given the opportunity to interfere in time [91, 93].

To conclude, there is always the possibility for error in awareness systems: the person interacting can miss or misinterpret important information, leading to an undesired effect on other people that are influenced by the system's state. Therefore, those people that are not directly interacting with the system need to be given a way to intervene or recover from errors. In order to allow for response, negotiation, and accountability, two-way communication is a basic requirement for systems that are shared in use. Other strategies to increase recoverability are to consider the possibility of retrieving a previous state, to allow for intervention even before an interaction occurred.

6 RESEARCH AGENDA FOR AWARENESS IN SHARED USE

In this work, we have presented the DASS framework. We expect that the framework can help interaction designers when designing for awareness, by providing a structured overview of design considerations, as well as rich background readings for each consideration. In the construction of the DASS framework, we have mainly based ourselves upon examples and findings from work on prior research from the field of CSCW. However, as introduced, we see awareness as a useful strategy for any type of system that is potentially shared in use, no matter its functionality. Although we have discussed the relevance of the considerations in IoT systems and have given examples of how the considerations relate to interaction with such systems, more direct advice on how to design with the considerations in mind for different contexts is speculative. Furthermore, IoT systems are constantly changing due to developments in, e.g., networking technology, data analysis, and Artificial Intelligence (AI). This means that the interaction paradigms and the recommendations for awareness in the interaction with these systems will have to be developed alongside. For these reasons, we do not see the DASS framework as an end state, but rather as a consolidation of the current state of knowledge that can form the foundation for further research. To focus this future research, we sketch out a research agenda in this section, consisting of three directions:

1. *Improving the design considerations* for different applications and different contexts.
2. *Identifying evaluation criteria* and awareness indicators for interaction with shared systems.
3. *Extending the framework* in light of technological developments, to include more stakeholders and system autonomy.

6.1 Improving the Design Considerations

The DASS framework forms a first translation of knowledge from CSCW to a broader area of interactive IoT systems that can be shared as a consequence of use. In the formulation of the considerations and in the review of recommendations for each consideration in Section 5, we primarily built upon the extensive research on groupware and (distributed) collaboration systems and give limited and mostly speculative examples for IoT systems. When broadening the scope from collaboration to include (contemporary) shared systems in general, it is likely that the recommendations, the relative importance of the considerations, and perhaps the considerations themselves, require further refining. To refine these aspects of the considerations for a new type of systems, many more interfaces need to be designed, that systematically vary in their implementation of specific considerations. Comparing such interfaces in real-life situations of shared use can give insights into how the considerations apply to shared use in that specific application domain and that specific context. Such insights can then be used to further specify, prioritize, and refine the considerations. We have recently started with such investigations ourselves [93] and would like to invite other researchers to join.

There are three topics that we feel are particularly under-exposed in the current CSCW literature and that therefore require further investigation. First, the far majority of the research that we reference investigates distributed interactions. However, many of the interactions with everyday interactive systems—such as climate control, entertainment, and transportation systems—take place in a *collocated* setting. This collocated setting brings new opportunities for communication of awareness information, including overhearing, a shared visual space, shared spatial memory of artifacts, and more tangible interaction styles (as highlighted by [19, 49, 60, 97]). We have reflected upon these opportunities in Section 5 but more examples are required. A second area that receives more attention includes different types of users, or actor *roles*. In groupware and collaboration systems, users often form—or are at least often described as—a rather homogenous group in terms of engagement, activeness, access, and benefits. However, as we have argued, in many cases people that have no direct access to the interaction or interface can still be influenced by an interaction of others. They should thus be perceived as actors in the system. This group of people brings additional challenges for the considerations in Section 5.2 (*how can the information be embodied*), since information placed in the interface is most likely not seen by these actors. We have tried to bring the perspective of the person being influenced by an interaction into the framework, but we think that there are many yet-to-be-explored opportunities to increase awareness for the people impacted by interactions of others. Thirdly, Section 5.3 (*how can the awareness be used effectively interaction*) deserves much more attention. To our knowledge, this received least attention in literature and most of the considerations were derived from our own previous work (in particular, [91, 93, 129]). Therefore, it is likely that there are many more features that are yet to be explored that can help people to use their gained awareness more effectively in interaction.

6.2 Identifying Evaluation Criteria

Increasing awareness is not a goal in itself but a support for people to act in accordance with their social context, which can result in a better user experience. While the considerations in the DASS framework can help designers to analyze and reflect upon whether their interfaces increase people's awareness, they do not support evaluation of the main goal: does the increased awareness help people to act in accordance to the social context? And does this together lead to a better use experience? Therefore, future research should aim at defining the behavioral mechanisms in which people use awareness and the corresponding positive and negative awareness indicators.

Even in collaboration systems, defining measurements for successfully achieving awareness can be difficult [54]—again because awareness is not a goal in itself. Also, awareness is not for the individual, which means that it cannot be measured by looking at a single user's interaction experience. Instead, the success of the implementation should be measured by, for example, looking at how effortful, error-prone, or effective communication and coordination between the different users is. In the descriptive framework of workspace awareness, Gutwin & Greenberg [54] describe five activities in which workspace awareness is used: management of coupling, simplification of verbal communication, coordination, anticipation, and assisting others. Based on observational studies of people collaborating, they give indicators of increased awareness for each of these mechanisms. Examples of these indicators include the time shifting between tasks takes, use of deictic references in conversation, and visual evidence of understanding [55]. Similar sets of positive and negative awareness indicators for collaboration have been proposed by Hornecker et al. [60] and by Leichtenstern and André [69]. In order to evaluate the success of awareness implementations in other types of systems, it is vital to identify such specific indicators for specific contexts of use. As an example, in order to evaluate lighting interfaces for a shared office environment, we need specific indicators that show what *simplified communication* means for interaction with a lighting system. Just as has been done in the CSCW field, ethnographically inspired studies of observations of shared use in different contexts and with different types of systems are required, to formulate the criteria for evaluation of design interventions and interaction paradigms.

6.3 Extending the Framework

Since the nature of interactive systems is evolving in terms of data use, system intelligence, and autonomy, it is vital to develop the interaction with such systems—and thus the design considerations for interaction with these systems—alongside. In light of current developments, there are two primary extensions to the DASS framework that we think require further investigation: (1) extending the number of *stakeholders* and (2) regarding the system as an *actor*.

In the current DASS framework, we present considerations on how to share information between different actors in the system that is shared in use. We have currently limited the actors to two types, namely the people interacting and the people who are affected by the outcome of an interaction by someone else. However, if systems become connected to each other and to the Internet, they could potentially share information among many more people. The detailed use data that awareness information consists of could be relevant to a large number of stakeholders. While sharing of this data opens up opportunities for more tailored services, any data sharing comes with a risk of privacy infliction that goes far beyond our current privacy discussion in Section 5.1.4. Note that this realization is not new: many IoT researchers have indicated the tension between data sharing and privacy. See, for example, the review of privacy issues in ubiquitous computing systems by Price and colleagues [103], or the discussion of Atzori et al. [4:2797] of challenges on *data integrity*, *privacy*, and *digital forgetting*. Nevertheless, because designing to aid awareness is inherently about data gathering and sharing, we think it is important to include such considerations directly in the framework and to extend the framework to include this broader range of stakeholders. Considering what information can be accessed and by whom is a responsibility of the designer, and we think that including such considerations in the framework can help designers to be aware of this responsibility.

Secondly, in the current setup of the framework the role of the system has not been specifically addressed: we mainly talk about sharing information between different actors *through* the system. But in light of developments, it is not unlikely to think that systems themselves might become an actor and should explain their behavior to the human actors through awareness information. This idea has been mentioned before. For example, Dourish [27] claimed that awareness information can be used in single-user systems as well as in shared systems to synchronize the mental models that users have of the system's behavior. Similarly, Bellotti and Edward's [8] key features for interaction with context-aware systems—*intelligibility* and *accountability*—have much overlap with constructs from awareness, such as Erickson and Kellogg's social translucence principles [36], and Clark and Brennan's [17] factors to avoid conflict. The DASS framework can in its current shape already form a starting point when designing communication between *system* and *user*. Nevertheless, it is unlikely that the exact same types of information are needed about different people, as about the system. And even if the information requirements are the same, there are consequences for how the information should be embodied, especially since all information from the system has to be represented in the interface if the space is large (see Section 5.2). Therefore, we see an interesting direction for further research in extending the framework to include more specific considerations for giving awareness about the system's reasoning and its actions.

7 CONCLUSIONS

Most everyday systems are shared in use, either because multiple people can interact with the system or because an interaction by one can affect others. However, not all interactions are currently designed to support sharing optimally. When interacting with shared systems, people need awareness of each other and of the social context. It is only because of this awareness that people can coordinate shared use among each other, can adjust their interactions to avoid or compromise in conflicts, and hold others accountable for unacceptable actions. In systems that are shared as part of their functionality, such as communication and collaboration systems, increasing awareness by making important information visible in the interface is a key strategy. However, in interaction design for IoT systems—that become shared as a consequence of a particular scenario of use—we see much less attention to designing for awareness.

To introduce a broader audience of interaction designers to designing for awareness, we have aimed to provide a starting point and overview of the current design knowledge on how to design for awareness. With this aim we constructed the DASS framework. The DASS framework builds on a thorough review of literature from CSCW and our own experience when designing for awareness. We have structured and translated the available design knowledge into considerations, to support interaction designers during their design process. The themes and considerations can fuel reflection upon how the interaction can be improved to support people during situations of shared use. Moreover, the in-depth reviews on each theme highlight tradeoffs, give advice, present inspiring design examples from CSCW, and speculate about implementations in IoT systems to help inform design decisions. In the current shape, the framework can be used regardless of the application domain and context that the designer is designing for. We invite interaction designers to use the DASS framework and to reflect on the relevance of particular considerations during their processes. The resulting body of design examples and reflections can be used to translate, specify, order, prioritize, and refine considerations for different types of systems and different contexts.

Designing interfaces for systems that are shared as a consequence of their context of use seems to be a rather new area in interaction design research. Furthermore, IoT systems are currently still in development. Therefore, the framework should not be seen as an end point but as a foundation to build upon. To stimulate and focus further research, we have concluded this article with a research agenda consisting of three topics: (1) improving the considerations and extending the examples in the framework, (2) specifying evaluation criteria and awareness indicators for evaluation of designs, and (3) extending the framework to include more stakeholders and more system autonomy. We are pursuing this research agenda ourselves and we hope to have inspired others to do so as well.

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