Ambient Connectedness: A Scoping Review on the Convergence of Ambient Interfaces and Connectedness among Distant Users

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Abstract. Ambient Interfaces present digital information in the physical environment of the user (e.g., as light or sound). Connectedness refers to a feeling of being connected or related to another person over distance. Since Connectedness is a low-fidelity and long-lasting interaction, Ambient Interfaces offer a high potential to support it effectively and efficiently. This scoping review examines Ambient Interfaces supporting Connectedness. The goal is to distil the characteristics of current Ambient Interfaces facilitating Connectedness. We found 671 publications and reduced it to a final corpus of 24 works, contributing 33 systems. Those systems showed interesting patterns of input and output modalities as well as direction and user attention.

Keywords: Ambient Interface, Ambient Display, Connectedness, Literature Review.

1 Introduction

Seamlessly integrating digital information into everyday settings has long been a topic of Human-Computer Interaction and Ubiquitous Computing (cf. [16, 47]). Several devices for presenting information to users peripherally have been researched and developed. Such devices take advantage of the physical environment and are known as Ambient Displays [50]. This concept is extended by Ambient Interfaces, which "use the whole environment of the user for the interaction between the user and the system" [18, p. 68]. Ambient Interfaces present digital information in the physical environment of the user, for instance as light or sound. They can either complement the computer or can be used without the computer. Very often, they leverage the user's peripheral perception. They present information in a subtle way, to inform the user without distracting them [17]. This peripheral nature makes them particularly suitable for long-lasting interactions that primarily take place in the background of the user's attention.

One such long-lasting interaction in Human-Computer Interaction and Computer-Mediated Communication is Connectedness, where geographically distributed users want to stay in touch with each other. Typically, this staying in touch is in the background, rather than an explicit high-fidelity interaction such as a phone call or video conference (cf. [43]). Connectedness can be defined as "the feeling of being in touch with [another person]" [20, p. 928]. It can be a strong and pleasant experience [20]. Connectedness may also reduce loneliness. Decreased social interaction and loneliness have been identified as severe problems during the COVID-19 pandemic [13]. However, data from 2000-2019 (before the COVID-19 pandemic) suggested that problematic "levels of loneliness are experienced by a substantial proportion of the population in many countries" [44, p. 1].

We use the term Ambient Connectedness to describe the intersection of Ambient Interfaces and Connectedness—particularly the use of the core capabilities of Ambient Interfaces for supporting Connectedness.

Despite the importance and the timeliness of this topic, systematic overviews of the current state of Ambient Connectedness are rare. This highlights the necessity of conducting such a review. Our scoping review sets out to answer the following research question: *What are the characteristics of the current Ambient Interfaces used for supporting Connectedness?*

In order to address this research question, we searched several databases, yielding 671 works. We identified 24 works contribution 33 systems facilitating Connectedness between humans separated by distance. We identified interesting characteristics of those systems, which led us to derive implications for design.

2 Related Work

Previous research over the last decades in Human-Computer Interaction and Computer-Supported Cooperative Work has many contributions on Ambient Interfaces for Connectedness, some literature reviews on Ambient Interfaces per se, and literature reviews on Connectedness per se.

2.1 Ambient Connectedness

Many works contribute Ambient Interfaces that facilitate Connectedness. Early concepts include Feather, Scent, and Shaker [43]. These objects integrate into the user's environment to subtly signal the presence of an intimate partner or friend. Another early example is the Bench object [12, 15]. Paired benches, equipped with heaters and sensors, communicate their occupancy through temperature. "When someone sits on one of two cold steel benches located in different cities, a corresponding position on the other bench warms up" [12, p. 64]. Other ground-breaking work was conducted by Wisneski *et al.* [50], who introduced several Ambient Interfaces and explained the importance of modalities in such systems. Recent work features wireless networking. One example is the Nimio system by Brewer *et al.* [7]. It consists of connected, interactive toys which trigger one another when moved or when a nearby sound is detected. Other recent examples include the There Chair, Fragrance Frame, and ReminiScents objects by Shakeri *et al.* [41]. These Ambient Interfaces integrate into the users' homes and facilitate Connectedness between family members separated by distance.

2.2 Literature Reviews on Ambient Interfaces

Three literature reviews provide an overview of works contributing Ambient Interfaces and Ambient Displays. Börner *et al.* [5], Börner *et al.* [6] conducted two literature reviews of works featuring Ambient Displays for learning. In the first review, 53 works were deemed eligible, while in the second review, 69 works were included. In both reviews, they searched the ACM Digital Library, the IEEE Computer Society Digital Library, and SpringerLink. The years searched ranged from 2000 to 2010, for both reviews. The authors employed different search strategies between the databases. They used the keyword "Ambient Display" for SpringerLink and IEEE Computer Society Digital Library. For ACM Digital Library, they used the author keywords "Ambient" and "Display." In a more recent review, Shelton and Nesbitt [42] provide an overview of 459 Ambient Displays from 410 works. They searched the ACM Digital Library, IEEE Xplore, Scopus, and Web of Science. The years searched ranged from 1996 to 2016. The keywords used were "Ambient Display," "Ambient Information System," and "Peripheral Display." The authors searched for works in English.

However, these reviews do not specifically address the intersection with Connectedness.

2.3 Literature Reviews on Connectedness

Some literature reviews provide an overview of works related to Connectedness. One recent example is a broad systematic review by Wenhart *et al.* [48], which investigates works contributing various systems facilitating Relatedness. Relatedness is closely linked to but distinct from Connectedness and defined as "the need to feel belongingness and connectedness with others" [39, p. 73, 48, p. 2]. In the 208 works in their final corpus, they identified 241 concepts or prototypes of systems facilitating Relatedness. They searched ACM Digital Library for works in English.

However, this review does not specifically focus on Ambient Interfaces and includes other types of devices as well.

2.4 Literature Reviews on Ambient Connectedness

To the best of our knowledge, a thorough review of works on the intersection of Ambient Interfaces and Connectedness has not been conducted. Therefore, there is a need to conduct such a literature review.

3 Method

Our approach is based on the PRISMA Extension for Scoping Reviews (PRISMA-ScR) [45]. Scoping reviews have for our purpose the great advantage over systematic reviews that they typically answer broader questions and that they do not require an assessment of risk of bias [45]. We also used the previous literature reviews on Ambient Displays [5, 6, 42] as well as the scoping review conducted by Ringfort-Felner *et al.* [37] to guide the design of our method. In this section, we describe our search strategy, screening process, final corpus, and analysis.

3.1 Search Strategy

We searched subject-specific databases, including the ACM Digital Library, EUSSET Digital Library, GI Digital Library, IEEE Computer Society Digital Library, IEEE Xplore, and SpringerLink. Our choice of databases was inspired by the previous literature reviews on Ambient Displays [5, 6, 42], and contained works from journals and conferences related to the subject matter. Some examples of journals and conferences included are CHI, DIS, TEI in the ACM Digital Library; JCSCW, ECSCW in the EUSSET Digital Library; i-com in the GI Digital Library); IEEE Pervasive Computing in the IEEE Computer Society Digital Library; IEEE PerCom in IEEE Xplore; and HCII, DAPI, etc. in SpringerLink. Additionally, we corroborated our results by searching Web of Science, which indexes works from various sources. We used JavaScript to extract the entries from the search results.

We searched for recent works from the last decade of 2016 until 2025. One reason was that we wanted to follow up on Shelton and Nesbitt [42] until the year 2016. We were looking for works in English (to ensure international accessibility), and published in scientific journals or conference proceedings (to ensure high-quality, academic results).

Table 1. Summary of the filters used in our search.

Filter	Value
Years	2016–2025
Language	English
Types	Journal articles, conference proceedings

We first conducted an initial search on 5 August 2025. Our search query consisted of keywords based on the previous literature reviews on Ambient Displays [5, 6, 42] as well as keywords commonly associated with Connectedness. The initial search query was as follows:

("Ambient Display" OR "Ambient Information System" OR "Ambient Interface" OR "Peripheral Display") AND ("Awareness" OR "Connectedness" OR "Distance" OR "Proximity" OR "Togetherness")

We searched within all available fields. This initial search yielded 573 results. To assess the comprehensiveness of these results, we cross-checked them with known related work. Thereby, we identified keywords not included in our initial search query. We conducted an extended search on 14 August 2025, which included all initial keywords as well as the new keywords we identified. The extended search query was as follows:

("Ambient Device" OR "Ambient Display" OR "Ambient Information System" OR "Ambient Interface" OR "Ambient Technology" OR "Peripheral Display") AND

("Awareness" OR "Connectedness" OR "Distance" OR "LDR" OR "Proximity" OR "Togetherness")

The extended search yielded 671 final results, which included all results of the initial search as well as new results.

3.2 Screening

Two reviewers independently decided on the inclusion or exclusion of a work by screening the title and abstract of the 671 results. Our inclusion and exclusion criteria were inspired by Ringfort-Felner *et al.* [37] (cf. Table 2). Included works had to contribute at least one original concept or prototype of an Ambient Interface facilitating Connectedness between humans separated by distance (i.e. Ambient Connectedness) (IC1) as well as being academic (IC2). Both IC1 and IC2 had to be met for a work to be included.

As noted in the previous literature by Shelton and Nesbitt [42], Ambient Displays are difficult to define. To minimise ambiguity, the reviewers agreed upon the following definitions:

Ambient: Refers to Ambient Interfaces which "use the whole environment of the user for the interaction between the user and the system" [18, p. 68].

Connectedness: Describes "the feeling of being in touch with [another person]" [20, p. 928].

Ambient Connectedness: Connectedness facilitated by Ambient Interfaces between humans separated by distance.

Works that did not contribute at least one original concept or prototype of an Ambient Interface facilitating Connectedness between humans separated by distance (i.e. Ambient Connectedness) were excluded (EC1). Additionally, we excluded works that were not in English (EC2), works that were not primary research (literature reviews, meta-analysis, or similar) (EC3), works that were a book, studio or workshop proposal, demo, poster, video showcase, forum, anthology, or similar (EC4), as well as works that were duplicates of other entries (EC5). If any of these exclusion criteria were met, the work was excluded.

Table 2. Inclusion and exclusion criteria, inspired by Ringfort-Felner *et al.* [37].

Code	Inclusion criteria
IC1	The work contributes at least one original concept or prototype of an Ambient Interface facilitating Connectedness between humans separated by distance (i.e. Ambient Connectedness).
IC2	The work is academic.
Code	Exclusion criteria
EC1	The work does not contribute at least one original concept or prototype of an Ambient Interface facilitating Connectedness between humans separated by distance (i.e. Ambient Connectedness).
EC2	The work is not in English.
EC3	The work is not primary research (literature review, meta-analysis, or similar).

EC4	The work is a book, studio or workshop proposal, demo, poster, video showcase, forum, anthology, or similar.
EC5	The work is a duplicate of another entry.

We calculated inter-rater reliability with Cohen's Kappa. Cohen's Kappa is a common statistical measure, "appropriate for use when there are two coders coding the same dataset" [34, p. 7]. We reached a moderate [27] level of agreement (Cohen's Kappa = 0.578). The reviewers then discussed the results and reached a 100% consensus. We outlined our selection and screening process in a PRISMA flow diagram (cf. Figure 1).

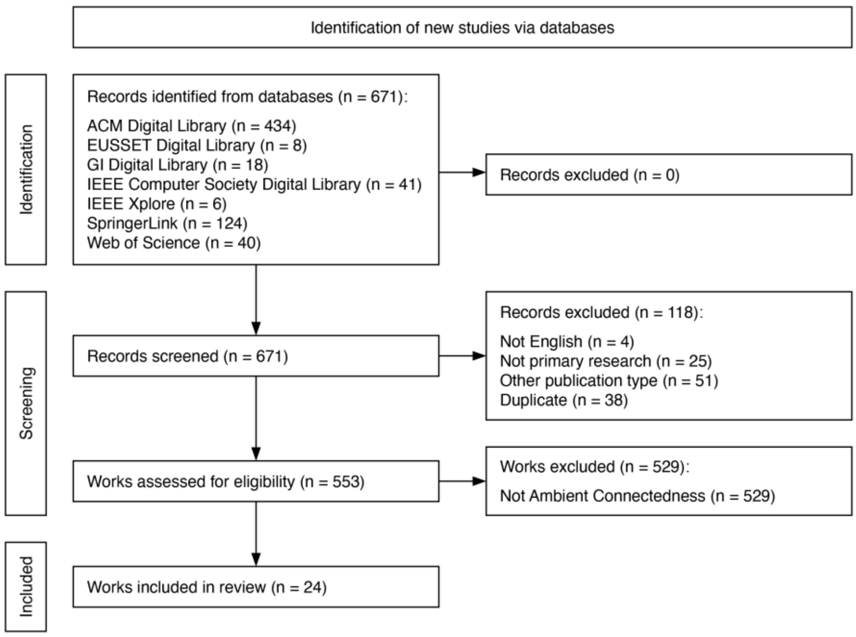

Figure 1. PRISMA flow diagram of our review.

3.3 Final Corpus

Our final corpus consisted of 24 works. If a work contributed multiple systems, all systems were considered individually, as was done in previous literature reviews (cf. [42]). To determine the number of systems, the two reviewers first counted them independently, and subsequently together. The works in our final corpus contributed 33 prototypes or concepts of systems with Ambient Interfaces facilitating Connectedness.

3.4 Analysis

To provide an overview of the characteristics of the current Ambient Interfaces facilitating Connectedness, we categorised the systems in the final corpus. The two reviewers first completed the categorisation independently. Subsequently, the results of these independent categorisations were compared, and a 100% consensus was reached. Since the primary purpose of Ambient Interfaces is on output—that is, the subtle presentation of information (cf. [43])—we started with the output before the input, for both the analysis and the findings. For output as well as input, we categorised which modalities the systems used, whether they were multimodal, whether an implicit or explicit action was required from the user to interact with the system, and whether peripheral or focal attention was required. We additionally categorised whether the systems used bidirectional or unidirectional communication.

Output Modalities. First, we categorised the output modalities (visual, auditory, tactile, olfactory, gustatory, other) of the systems (cf. [33]), because in "the presentation of ambient media, one of the key elements is the modality chosen to present a source of information" [50, p. 8]. To minimise ambiguity, the reviewers agreed upon the following definitions:

Visual: "Vision, or sight, is the human ability to receive information from the environment in the form of visible light" [33, p. 30].

Auditory: "Hearing, or audition, is the detection of sound by humans. Sound is transmitted in the environment as sound waves – cyclic fluctuations of pressure in a medium, such as air" [33, p. 34].

Tactile: "Tactile feedback, in HCI, refers to information provided through the somatosensory system from a body part, such as a finger, when it is in contact with (touching) a physical object" [33, p. 36]. Note that the somatosensory system provides other information as well, however, in this context we are specifically interested in touch.

Olfactory: "Smell, or olfaction, is the ability to perceive odours. For humans, this occurs through sensory cells in the nasal cavity" [33, p. 36].

Gustatory: "Taste, or gustation, is a direct chemical reception of sweet, salty, bitter, and sour sensations through taste buds in the tongue and oral cavity" [33, p. 36].

Other: Miscellaneous modalities not included in the modalities above, or unspecified modalities.

Input Modalities. Because of the importance of modalities in Ambient Interfaces, we also categorised the input modalities of the systems. Devices can be equipped with "perceptional capabilities" [40, p. 195]. For consistency, we used the same modalities for input as we did for output (visual, auditory, tactile, olfactory, gustatory, other). These modalities were defined as the equivalent perceptional capabilities of the system to the human senses. For instance, a system that could "see" using a camera was deemed to have visual input, and a system that could register touch through a pressure sensor was deemed to have tactile input.

Multimodality. The systems may use one or more modalities for output and input. To discover which category is more prevalent in the current systems, we categorised whether the output and input were multimodal, which was defined as having one or more modalities.

Interaction. Ambient Interfaces for Connectedness can be specifically designed to support "implicit, personal, and expressive communication, as opposed to [...] explicit, goal-oriented, and informative communication" [43, p. 29]. Because Ambient Interfaces integrate into the user's environment [18, 50], they are particularly suitable for presenting implicit output rather than explicit output. Likewise, systems may capture implicit or explicit actions for input [40]. To discover which category is more common, we categorised whether the systems presented implicit or explicit output, and whether they captured implicit or explicit input from the user or the environment. The reviewers agreed upon the following definitions:

Implicit Output: Refers to "implicit, personal, and expressive communication" [43, p. 29].

Explicit Output: Refers to "explicit, goal-oriented, and informative communication" [43, p. 29].

Implicit Input: An "action performed by the user that is not primarily aimed to interact with a computerised system but which such a system understands as input" [40, p. 198]. Note that Ambient Interfaces can capture information from the environment [17]. Therefore, the environment may substitute the user in this context.

Explicit Input: "The user tells the computer in a certain level of abstraction (e.g. by command-line, direct manipulation using a GUI, gesture, or speech input)" [40] what to do.

Attention. Ambient Interfaces are particularly "useful for situations, in which users want and need permanent background information without being disrupted in their foreground tasks" [18, p. 68]. To discover whether the current systems are primarily interacted with peripherally or focally, we analysed the attention required from the user to perceive the output and provide input. The reviewers agreed upon the following definitions:

Peripheral: Refers to peripheral awareness, which "concerns activities that are not foreground tasks" [15, p. 476].

Focal: Refers to focalisation, which "implies withdrawal from some things in order to deal effectively with others" [21, p. 404, 22, p. 40].

Direction. Some early concepts for Ambient Connectedness consisted of unidirectional systems (cf. [43]). Here, the Ambient Interface acts as an Ambient Display that does not capture information from the environment [17], and may instead receive information from another device. In contrast, bidirectional systems, such as the Bench object by Dunne and Raby [12], can capture information and send as well as receive information. Typically, such systems consist of two or more paired Ambient Interfaces of a similar type. To discover which category is more prevalent, we categorised whether the systems in our final corpus used bidirectional or unidirectional communication. The reviewers agreed upon the following definitions:

Bidirectional: The Ambient Interface can "present as well as capture information" [17, p. 61] and typically can send information to and receive information from a similar Ambient Interface.

Unidirectional: The Ambient Interface is "for presentation purposes only" [17, p. 61] and typically can only receive information from another device.

Pairing of Output and Input Modalities. After the analysis of the individual data, we analysed which output and input modalities coincided, to discover how systems used for Ambient Connectedness are typically interacted with by the users.
Connectedness. Additionally, we made some general observations to discover how the systems facilitate Connectedness. This was open-ended in nature and not part of the categorisation. We observed and identified the scenarios in which Connectedness was facilitated as well as the relationships involved, and whether the systems presented information slowly and continuously in the background or attempted real-time information transfer for short-term interactions in the foreground.

4 Findings

In this section, we present our findings in the final corpus, including the output and input modalities of the systems and whether they were multimodal, the interaction required (implicit vs. explicit), the attention required (peripheral vs. focal), the direction of the communication of systems (bidirectional vs. unidirectional), and parings of the output and input modalities. We also present the results of our observations on how the systems facilitate Connectedness.

4.1 Modalities

We categorised the output and input modalities of the 33 systems into the five modalities (visual, auditory, tactile, olfactory, gustatory) [33] as well as the category "other," for modalities not included, or unspecified modalities (cf. Table 3). The categories were non-exclusive.

The most common output modality was visual: 31 systems (93.94%) included some type of visual output component. Eight systems (24.24%) included some type of auditory output component. Four systems (12.12%) included some type of tactile output component. Three systems (9.09%) included some type of olfactory output component. No systems used gustatory output (0%). Two systems (6.06%) included output modalities categorised as "other".

The most common input modality was tactile: 23 systems (69.70%) included some type of tactile input component. Six systems included some type of auditory input component (18.18%). Three systems included some type of visual input component (9.09%). No systems used olfactory or gustatory input (0%). Twelve systems (36.36%) included input modalities categorised as "other".

Additionally, we analysed whether the systems used two or more output modalities as well as two or more input modalities. Eleven systems (33.33%) had multimodal output, and eleven systems (33.33%) had multimodal input.

4.2 Interaction

We analysed the action required from the user or the environment, and whether the systems presented explicit or implicit output and captured explicit or implicit input. 22

systems (66.67%) presented implicit output, and eleven systems (33.33%) presented explicit output. Twelve systems (36.36%) captured implicit input, and 21 systems (63.64%) captured explicit input.

4.3 Attention

For both output and input, we analysed whether the systems required peripheral or focal attention from the user. For output, 22 systems (66.67%) required peripheral attention, and eleven systems (33.33%) required focal attention. For input, eleven systems (33.33%) required peripheral attention, and 22 systems (66.67%) required focal attention.

4.4 Direction

Lastly, we analysed whether the systems were bidirectional or unidirectional. Most systems, 25 systems (75.76%), were bidirectional, and 8 systems (24.24%) were unidirectional.

Table 3. Classification of our results.

Variables		Values	Devices	Reference
Output	Modality	Visual	31	[1, 3, 8-11, 14, 19, 24-26, 28-32, 35, 36, 38, 41, 46, 51-53]
		Auditory	8	[1, 8, 25, 30, 31, 41, 53]
		Tactile	4	[28, 35, 52, 53]
		Olfactory	3	[32, 41]
		Gustatory	0	-
		Other	2	[41]
	Multimodal	Yes	11	[1, 8, 25, 28, 30-32, 35, 41, 53]
		No	22	[3, 9-11, 14, 24, 26, 28-30, 35, 36, 38, 41, 46, 51, 52]
	Interaction	Implicit	22	[3, 9-11, 14, 19, 26, 28-30, 36, 38, 41, 46, 51, 53]
		Explicit	11	[1, 2, 8, 24, 25, 30-32, 52]
	Attention	Peripheral	22	[3, 9-11, 14, 19, 26, 28-30, 36, 38, 41, 46, 51, 53]
		Focal	11	[1, 2, 8, 24, 25, 30-32, 52]
Input	Modality	Visual	3	[26, 30, 52]
		Auditory	6	[1, 25, 30, 31, 36]
		Tactile	23	[1, 3, 8, 24-26, 28-32, 35, 38, 41, 46, 51, 53]
		Olfactory	0	-
		Gustatory	0	-
		Other	12	[1, 8-11, 14, 19, 24, 30, 36, 41]

	Multimodal	Yes	11	[1, 8, 9, 24-26, 30, 31, 36]
		No	22	[3, 10, 11, 14, 19, 25, 28, 29, 31, 32, 35, 38, 41, 46, 51-53]
	Interaction	Implicit	12	[9-11, 14, 19, 24, 36, 41, 52]
		Explicit	21	[1, 3, 8, 25, 26, 28-32, 35, 38, 46, 51, 53]
	Attention	Peripheral	11	[9-11, 19, 24, 36, 41, 52]
		Focal	22	[1, 3, 8, 14, 25, 26, 28-32, 35, 38, 46, 51, 53]
Direction		Bidirectional	25	[1-3, 8, 9, 11, 19, 26, 28-32, 36, 38, 41, 46, 51]
		Unidirec-tional	8	[10, 14, 24, 25, 30, 52, 53]

4.5 Pairing of Output and Input Modalities

We analysed which output and input modalities coincided (cf. Table 4). The most common modality pairs were visual-tactile: 23 systems (69.70%) had a visual output component as well as a tactile input component. This was followed by visual-other. Ten systems (30.30%) had a visual output component as well as an input component categorised as “other”, such as motion or distance. Less common modality pairs were auditory-tactile with seven systems (21.21%), visual-auditory with six systems (18.18%), auditory-auditory with five systems (15.15%), visual-visual with three systems (9.09%), auditory-other with three systems (9.09%), tactile-tactile with three systems (9.09%), olfactory-other with two systems (6.06%), other-tactile with two systems (6.06%), tactile-visual with one system (3.03%), and olfactory-tactile with one system (3.03%). No systems had other coinciding modalities.

Table 4. Contingency table of coinciding output and input modalities of the systems in our final corpus.

Input / Output	Visual	Auditory	Tactile	Olfactory	Gustatory	Other

Visual	3	6	23	0	0	10
Auditory	0	5	7	0	0	3
Tactile	1	0	3	0	0	0
Olfactory	0	0	1	0	0	2
Gustatory	0	0	0	0	0	0
Other	0	0	2	0	0	0

4.6 Connectedness

In addition to the categorisation of the systems, we observed how Connectedness is facilitated. We identified the scenarios in which the systems were used and the types of relationships involved.

The first scenario concerned the users' personal environments, such as keeping in touch with a partner, family member, or friend while separated by distance ([1, 14, 19, 24-26, 28, 29, 31, 36, 41, 46, 52, 53]). The relationships involved in this scenario were intimate relationships as well as long-distance relationships, families, parent-child relationships, and other types of social relationships, such as friends.

The second scenario was related to work, such as remote or hybrid word ([30, 35, 51]). In this scenario, the relationships were of a professional nature.

The third scenario was intergenerational, or a scenario involving the care of older individuals, ([3, 9-11, 38]). The relationships involved were between caregivers and care recipients, or peer relationships between older individuals.

The fourth scenario involved education, in which Connectedness was facilitated in a teacher-student relationship ([32]).

The fifth and last scenario involved promoting healthy habits through Connectedness in intimate relationships ([8]).

We observed that most systems did not attempt real-time information transfer and primarily acted as background medium. This is evident by the fact 22 systems (66.67%) only required implicit action and peripheral attention for output.

5 Discussion of the Findings

In this section, we elaborate on the typical characteristics of current Ambient Interfaces for Connectedness, derive implications for design, and discuss limitations of our review.

5.1 Characteristics of Ambient Interfaces for Connectedness

Here we discuss the main findings of our categorisation, including common and rare modalities, multimodality, action and attention, and communication.

Common Modalities. Ambient Interfaces facilitating Connectedness can potentially use various output and input modalities. For instance, early concepts such as the Scent object by Strong and Gaver [43] or the Bench object by Dunne and Raby [12] used olfactory and thermal output, respectively.

Indeed, some systems in our final corpus experimented with less common modalities. For example, the Fragrance Frame, which "is a paired picture frame that detects when a remote family member is passing by their frame, and emits a scent reminiscent of togetherness" [41, p. 3389].

However, most of the systems we analysed included a visual output component well as a tactile input component. Traditional systems, such as those consisting of a keyboard, monitor, and mouse, which do not take advantage of the environment [50], also involve these modalities.

Tactile and visual, along with auditory, comprise the modality dimension of the current iteration of the four-dimensional multiple resource model [49]. The model posits that when two concurrently performed tasks occupy the same "category along each of the four dimensions of the model [...], then there will be greater dual task interference, than when the two tasks share separate levels" [49, p. 713]. Because tactile and visual use different sensory channels (cf. [33]), concurrent visual output and tactile input may interfere less than when the modalities compete. For instance, a device that uses the same modality for output and input at the same time might be difficult to use. Likewise, choosing the same modalities as other common devices can result in the Ambient Interface competing for the user's attention:

"The choice of modality for the background media should be considered with the person's foreground task in mind. For example, if a person is in their office performing a visually intensive foreground task [...] a visually based ambient display on the wall behind the person might not be as effective as an auditory display" [50].

Rare Modalities. Some modalities were largely unexplored. No systems used gustatory output or input. Notably, the Co-Drink system [8] indirectly involved taste, as it consisted of "a pair of smart water bottles with ambient light" [8, p. 92], intended to facilitate healthy fluid intake in intimate relationships. However, the primary means by which the system received input were through a pressure sensor (tactile modality), and a water level sensor (other modality).

Although olfactory output was explored in early work on Ambient Connectedness (cf. [43]), few systems in our final corpus used olfactory output, and no systems used olfactory input. The three devices that did use olfactory output were Atmospheror [32], Fragrance Frame [41], and ReminiScents [41].

Olfactory output does not compete for the user's attention with typical devices (cf. [50]) and can be less distracting than auditory or visual output [4]. However, the fact that many users are unfamiliar with the use of this modality in such systems may explain why olfactory output is less commonly used. Olfactory notifications have been found to "negatively impact primary task performance" [4, p. 189], possibly for this reason.

Multimodality. Across the systems, we could see many different forms of either users giving explicit input to the system or sensors capturing information. Some multimodal systems required both user input as well as information from the environment, such as

Shared Wind [53], a system for couples in a long-distance relationship. It allowed the sender to signal to their receiving partner that wind was blowing by their window, by simulating wind at the reviver's window with a fan and "was designed for situations when there was a natural wind blowing [the] sender's curtain and if the sender chose to send out the signal" [53, p. 335].

Interaction and Attention. Most Ambient Interfaces can be described as delivering lightweight information, often serving as a background medium. One example is Bedtime Window [26], which links remote couples through a slow photo stream, rather than using full-fledged channels such as video conferencing.

Usually, for input as well as output, implicit action coincided with peripheral attention, and explicit action coincided with focal attention. EmoTree [14] was one exception to this rule. Users had to focally communicate on social media for input. However, as the action performed was "not primarily aimed to interact with" [40, p. 198] the EmoTree, the input was deemed implicit.

Across the systems, we could see many different forms of either users giving explicit input, such as TangiPen [35], to the mechanisms or sensors capturing information from the environment, such as Light Bridge [19].

Direction. Lastly, one notable finding in our review was that 75.76% of the systems we analysed were bidirectional, with the Ambient Interface typically communicating with another Ambient Interface of that type. This indicates a preference for such systems in current research and is in contrast to some early concepts (cf. [43]). Additionally, many of the systems made use of wireless networking.

5.2 Common Patterns and Implications for Design

Some common patterns emerged in the systems we analysed. Firstly, most systems did not aim to transfer information in real time. Real-time communication is very important in Computer-Supported Cooperative Work (cf. [23]). In addition to slowly transferring information, most systems were continuously running in the background rather than supporting only short interactions between the users. In scenarios of Connectedness, less seems to be more with respect to timing.

Secondly, the use cases, scenarios, and relationship types were diverse. The scenarios ranged from couples in long-distance relationships staying connected while spatially apart, such as Shared Wind [53], over professional, intergenerational, and educational scenarios, to promoting healthy habits through Connectedness, such as Co-Drink [8]. This indicates that Ambient Interfaces can facilitate Connectedness in a wide range of scenarios and solve different use cases for different users.

Thirdly, while some modalities were more common than others, the mechanisms for output and input were also diverse. Although visual output and tactile input was common, Connectedness can be achieved through various modalities, involving user input or information captured from the environment.

Based on our findings, the choice of modality should depend on how the Ambient Interfaces are intended to facilitate Connectedness. For instance, devices aiming to subtly signal the presence of another person can benefit from—and may even be made more noticeable by—using modalities that do not compete with other devices and do not compete for the user's attention. One example from the systems we analysed is There Chair [41], which—in addition to other output mechanisms—included heating pads to simulate the "body heat and passive awareness" [41, p. 3396] of a spatially separated family member.

In contrast, if the intention is to facilitate Connectedness through explicit action and to require focal attention, such as through the exchange of verbal or nonverbal messages, common modalities are needed. This can be seen in some systems we analysed, such LUNOST [31]. This system consisted of a pair of Ambient Interfaces that allowed for "emoji exchange, voice messaging and weather sharing between teenagers and parents over a distance" [31, p. 127]. It used a tactile input mechanism and included an OLED screen for output. Another example is CoCreate [35], an Ambient Interface intended to "enhance interpersonal connectedness in remote group brainstorming sessions" [35, p. 10], which used two tactile input mechanisms, and used an RGB LED matrix as its primary output mechanism.

5.3 Limitations

Our scoping review is not without limitations. Firstly, while we used the same search query for all databases, searches may be processed differently between databases. Notably, Web of Science, which indexes works from various sources, did not have the option to perform full text searches. However, Web of Science was only used to corroborate our results and did not yield any entries not found by searching the other databases. Secondly, the two reviewers reached a moderate [27] level of agreement, which may be due to Ambient Displays being difficult to define (cf. [42]). However, care was taken to define the inclusion and exclusion criteria, and all disagreements could be resolved during the discussion phase, in which a 100% consensus was reached. Lastly, our review was narrow and focused specifically the intersection of Ambient Interfaces and Connectedness. We did not explore related concepts, which may have limited our results.

Despite these limitations, we discovered that most systems in our review used traditional output and input modalities. The olfactory output modality was used in some devices, but olfaction and gustation were largely unexplored. An important finding and implication for the design of such systems was that the choice of modalities depends on how Connectedness is facilitated. Ambient Interfaces that signal the presence of another person can benefit from using non-competing modalities, while Ambient Interfaces intended to exchange more explicit messages can require the use of modalities that compete with other devices. Lastly, we found that most systems consisted of bidirectional Ambient Interfaces that typically communicated with another device of that type.

6 Conclusions

In our scoping review, we identified 33 systems from 24 works facilitating Ambient Connectedness. Our research indicates that bidirectional and wirelessly networked Ambient Interfaces are commonly used to facilitate Connectedness. The design of these systems depends on how Connectedness is facilitated and can be typically categorised into devices that require implicit action and focal attention and explicit action and peripheral attention. While earlier prototypes sometimes used experimental modalities, most of the Ambient Interfaces we analysed used modalities familiar to most users. These areas are often unexplored in modern systems for Ambient Connectedness. Future work could focus on a broad literature review, with a larger corpus. Additionally, future research into Ambient Connectedness may apply our findings practically in prototypes and design concepts.

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Works in our final corpus: [1, 3, 8-11, 14, 19, 24-26, 28-32, 35, 36, 38, 41, 46, 51-53].