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Explicating "Implicit Interaction": An Examination of the Concept and Challenges for Research

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ABSTRACT

The term implicit interaction is often used to denote interactions that differ from traditional purposeful and attention demanding ways of interacting with computers. However, there is a lack of agreement about the term's precise meaning. This paper develops implicit interaction further as an analytic concept and identifies the methodological challenges related to HCI's particular design orientation. We first review meanings of implicit as unintentional, attentional background, unawareness, unconsciousness and implicature, and compare them in regards to the entity they qualify, the design motivation they emphasize and their constructive validity for what makes good interaction. We then demonstrate how the methodological challenges can be addressed with greater precision by using an updated, intentionality-based definition that specifies an *input–effect relationship* as the entity of implicit. We conclude by identifying a number of new considerations for design and evaluation, and by reflecting on the concepts of user and system agency in HCI.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; *User models.*

KEYWORDS

Implicit interaction; explicit interaction; framework; intentionality

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1 INTRODUCTION

The last two decades witnessed an increasing interest in supporting interactions that differ from traditional purposeful and attention demanding ways of engaging with computers. A term that is often used to denote these new types of user engagements is "implicit interaction". Implicit interactions are now being pursued in domains as diverse as ubiquitous interaction [83], information seeking [18, 54, 99], attentive interfaces [95, 106] and physiological computing [28]. A public display that shows content when it senses human presence or a recommendation engine that utilizes user actions for social recommendations are typical examples. As computers are getting increasingly capable of sensing the environment and making inferences about the situation, we can expect similar interactions to proliferate and partly replace what is called "explicit interactions".

At the same time, there is a lack of consensus regarding the precise meaning of the explicit–implicit distinction. Over time, the distinction has come to serve as a placeholder for different meanings such as intentionality, attentional focus and awareness. The terms are generally used as a quality of interaction (itself a concept with diverse interpretations [44]), but it is common to apply them to other entities such as the interface, the input or the sensing capability of the system. When the terms do qualify interaction, they are often described through built-in properties of the interface rather than the interaction as it unfolds. Adding to the confusion are other distinctions such as foreground–background [15], overt–covert, command–non-command [64] and active–passive [25] that have overlapping meanings and at times used interchangeably with explicit–implicit. The broad use of the terms led to the introduction of other, more strictly formulated distinctions such as intentional–incidental [21] and reactive–proactive [51].

The ambiguity is problematic, firstly because the term implicit interaction has become part of the HCI lexicon. Even though an ambiguous understanding of the term can function as a convenient shorthand, its effective use requires researchers to clarify what they mean by implicit interaction, validate whether an interface actually facilitates implicit interactions, and demonstrate that implicitness informs design or evaluation in a way other concepts do not. Otherwise, the term risks either being redundant or obscuring more than it explains. Perhaps more consequentially, however, we find the ambiguity exposed by the various uses of the term representative of broader methodological challenges concerning a very central phenomenon in HCI, namely the relationship between a user's mental attitude and what is considered appropriate system behavior.

Thus, we see value in developing "implicit interaction" further as an analytic concept. In the following sections, we first review and compare different meanings that the term implicit stands for in HCI, psychology and pragmatics, and identify the methodological challenges concerning HCI's particular design orientation. We then revisit these methodological challenges with an updated, intentionality-based definition of implicit interaction as *user's attitude towards an input–effect relationship* in which *the appropriateness of a system response to the user input (i.e., an effect) does not rely on the user having conducted the input to intentionally achieve it*, and show how this updated definition can be deployed to address various methodological challenges. We conclude by identifying a number of new considerations for the design and evaluation of interfaces that aim to facilitate implicit interactions, and by reflecting on the concepts of user and system agency in HCI.

2 THE MANY MEANINGS OF IMPLICIT

The HCI use of the term implicit can be traced back to as early as 1983, when Revesman and Greenstein noted that *"if the computer were able to predict accurately the actions of the human, information would be communicated with no overt communication on the part of the human; an implicit line of communication would exist"* [78, p. 107]. The term has since appeared in different domains of HCI such as mobile computing [37, 43] search interfaces [18] and ubiquitous computing [63, 84]. Various formulations of implicit interaction soon followed. Schmidt defines implicit interaction as *"an action performed by the user that is not aimed to interact with a computerised system but which such a system understands as input"* [83]. This is somehow echoed in Ju and Leifer's definition of implicit interaction as *"those that occur without the explicit behest or awareness of the user"* [52]. While these formulations provide good departure points, they also lead to many further questions. Does implicit stands for purposefulness, awareness or any other meaning? Is it a quality of "an action performed by the user" or something that occurs as a result of an action? A meta-analysis that compares different meanings and implications of "implicit" has so far been missing.

Equally problematic is the term "interaction". Perspectives on interaction, such as Norman's dialogue model [65], control theory [100] and activity theory [10], take user goals as a departure point for their analyses, which poses a challenge for the notion of interaction as something unintentional [21, 44]. Similarly, when defined through a complete lack of attentional focus or awareness, implicit interaction has been called *"not proper interaction in the sense that it engages us in addition... to what we otherwise are doing"* [49, p. 122] and *"hardly... an interaction at all, since there is no activity or awareness on our part"* [52, p. 77]. The problem partly arises from the diverse meanings of implicit but also from the ambiguity of the word interaction. In HCI, interaction has been conceptualized in terms of mechanical consequence by antecedent, but also as user experience, tool-use or control [44], all of which make user attention or intention a prerequisite for interaction. Additionally, HCI uses are not limited to interaction and one can encounter other phrases such as "implicit sensing" [38, 81], "implicit input" [53, 75, 93], "implicit interface" [87, 93] or a specific outcome of user input, as in "implicit authentication" [13]. The diversity of uses raises the question of whether (or what entity within) interaction provides a useful unit of analysis.

This section discusses various meanings and entities that the term implicit interaction can stand for. There are two reasons for our focus on the word implicit instead of a predefined meaning. First, we examine how the use of implicit as a placeholder for multiple meanings might not be accidental but grounded in the context of particular cases in which they overlap. Secondly, by comparing and contrasting various meanings, we sharpen our own definition of the term. Overall, our examination is oriented towards identifying the consequences of different meanings for research rather than determining their prevalence in the literature. We do not claim comprehensiveness of all use instances, but refer to HCI examples for illustration.

We started the examination by identifying a number of often cited, key publications that discuss the term implicit interaction in depth [21, 42, 51, 52, 83]. Even though not cited by key HCI publications, explicit–implicit distinction also features in other fields, notably psychology and pragmatics, and work in HCI occasionally reflect similar meanings. Thus, we found the reviews in these fields [16, 20, 29, 85] useful for comparison. As we have proceeded, we also expanded the scope of analysis to other terms that have overlapping meanings and are used interchangeably with explicit–implicit. For example, Buxton's [15] distinction of "foreground" *"which are in the fore of human consciousness – intentional"* and

Table 1: An overview of different meanings, their description, the entity they qualify and potential motivations for design.

Implicit as	Description	Implicit qualifies	Example motivation for design
Unintentional	The degree a particular effect is intended by the user	Input–effect relationship	Providing appropriate responses that go beyond what the user has intended
Attentional background	Attention reserved during the execution of an input or evaluation of a system response	Input or output	Freeing up attentional resources through external backgrounding
Unawareness	The degree of awareness of a particular effect caused by the user's input	Input–effect relationship	Providing appropriate responses that go beyond what the user is aware of
Unconscious	User's awareness of own mental process	Mental process	Reduced need for mental processing
Implicature	The degree an action represents an agent's intention	Intention–action relationship	Accomplishing an intended effect with less effort

"background" activities *"that takes place in the periphery"* is conceptually similar and has been used together with explicit–implicit distinction in later work [e.g., 42, 51]. "Incidental" interactions, similarly, describe instances when a system utilizes user actions that have been *"performed for some other purpose"* than the one executed by the system [21]. These formulations emphasize the purposefulness of user actions in achieving a specific outcome, a meaning that we will henceforth refer to as *intentionality*. However, various definitions point to other qualities, namely *attentional focus*, *awareness*, *consciousness* (psychology) and *implicature* (pragmatics).

Implicit as Unintentional

The formulations of explicit–implicit [51, 83] as well as foreground–background [15, 41] define them in terms of user's intentionality. Editing a document by typing on a keyboard is an explicit interaction insofar as the outcome, and the purpose, of the action is editing the document. In contrast, a smart room that activates the lights when a person walks in facilitates implicit interaction (unless the person walked into the room specifically to turn on the lights).

A defining feature of implicit interactions is their occurrence as a result of the user input. Perhaps due to this feature, implicit has occasionally been defined as a quality of user's "action" (as in Schmidt's definition [83]) or "input" [e.g., 1, 53, 75, 93]. Yet we argue that the suitable entity for intentionality is a specific outcome that results from user's input, namely an *input–effect relationship*. This is first of all due to our focus on human–computer interaction where intentionality is categorically about future states in the environment. Of course, the user input itself can be considered unintentional in certain cases (as in involuntary muscle movements), but this qualifies a mind–behavior relationship instead of a user–environment relationship. Apart from categorical precision, defining implicitness as an input–effect relationship allows for including situations in which the system executes both intended and unintended effects as a result of the user input. For example, a search system can harness a user's browsing or bookmarking actions that are intended for examining web pages as implicit relevance feedbacks to infer user interests and improve future search results [2, 76, 99].

Most accounts of HCI view user intentions central to what makes a good interaction, in other words, postulating the norm that an interaction is judged by [44]. Thus, the definition of implicit interactions as unintentional has been scrutinized. From a control theory perspective, Williamson defines background interactions as ideally dependent on *"known intentions and the inferred intentions which they act as proxy for"* [100, p. 23]. We argue that the objection is due to the multiple meanings of interaction, which can refer to a granular input–effect relationship but also to an activity conducted through an interactive system. In many examples described above, even if a specific effect of the user input is unintentional, implicit interaction can be motivated by a purposeful activity that encompasses the specific input–effect relationship. For example, implicit feedback in search systems can be motivated through a user's goal of seeking particular information. In contrast, when there are no commitments to inferred intentions, the interaction can be motivated by the assumed benefit to the user [21]. In other words, beneficial or any other quality can replace intentional as the norm of interaction.

We so far treated intentionality as self-evident. Yet it is worth noting that the HCI understandings of the concept range from a general "directedness of meaning" [24] to "the decision to act so as to achieve the goal" as in Norman's framework [65]. The difference in HCI understandings can be traced back to the philosophical conceptions of intentionality in mentalistic (as in Husserl and Searle) and non-mentalistic (as in Heidegger and Merleau-Ponty) terms (see Dreyfus

[26, 27] for a treatment of the subject). As a mentalistic concept, intentions correspond to well-formulated goals that are *held* by a knowing subject. In its non-mentalistic conception, intentions are instead *embodied* in our everyday habitual performance toward practical ends and characterize things that we do without self-reflection. This partly amounts to the expansion of intentionality from the mind and deliberate reasoning to the body, habits and *unconsciousness*—another meaning that we will unpack later in this section. However, unconsciousness tells only part of the story. An insight from phenomenology as well as from the situated action perspective [90] is that successful accomplishment of activities relies on background assumptions, namely external dependencies that are taken for granted until a breakdown. Implicit interactions in HCI approximate to such external dependencies when they assume embodied knowledge on users' side about what to take for granted.

Implicit as Attentional Background

Implicit [49, 51] or background [15, 41] interactions have also been defined in terms of attentional focus during interaction. HCI research is often informed by the limitations to the human processing capacity [e.g., 6, 46, 69], which, as a consequence, requires selectivity regarding what is being attended to. Researchers directed their design efforts to make interactive systems less attention demanding, for instance, by devising ambient, peripheral and low-bandwidth output [48, 74]. The same design strategy can be extended to the design of input techniques that require minimal user attention. Manual selection of small targets on a screen is explicit, while automatic activation of lights upon entering a room is implicit. Mobile interfaces can switch between landscape and portrait modes by sensing the device orientation instead of through attention-demanding GUI control [42, 84]. Systems can be designed to be operated without fine motor control to accommodate "casual" user inputs [73].

Buxton defined background interactions as both unintentional and in the attentional background [15], but the two qualities do not necessarily overlap. Ju et al. build their implicit interaction framework on Buxton's foreground–background distinction but supplement it with an additional reactive–proactive distinction to separate intentionality from attentional focus [51]. An interaction can be both intentional and in the attentional background when the system automates various sub-tasks triggered by a user input without providing attention-demanding feedback. Conversely, an interaction can be at the attentional foreground but executed without the user's initiative, such as when the system provides attention-demanding feedback for an unintended effect.

When defined through attentional focus, implicit interactions are motivated by freeing up users' cognitive resources for other activities. Level of attention also allows explicit–implicit or foreground–background distinctions to be defined across a continuum [15, 41] in which attention serves as a quantitative measure that can be operationalized through information throughput [15, 73].

Implicit as Unawareness

We use the term awareness to denote users' knowledge about how their input is utilized by the system. Traditional interface design has put heavy emphasis on the predictability of action outcomes through affordances and feedback/feedforward mechanisms that communicate system responses back to users [65]. In contrast, interfaces that target implicit interaction might avoid such features. Implicitness has occasionally been defined in terms of awareness [52, 56, 71]. Typing into a computer is explicit as long as users are aware of the action outcomes, while the utilization of users' gaze [71] or physiological signals [56] without their awareness is implicit. As with attention, awareness can be defined as a continuum. Users can be unaware that they are providing input to a system, they can have ambiguous awareness about how their input is utilized by the system or they can be fully informed [97]. For more granular analysis, users can be considered to have varying degrees of awareness of different effects that result from the same input.

Purposefulness of interaction requires a certain degree of awareness of action outcomes, making awareness a precondition for intentionality. Thus, the motivations that are described under unintentional also apply to unawareness. On the other hand, awareness does not always entail intentionality. Dix distinguishes between awareness and intentionality through the concept of "expected" interactions in which the user is aware of the effect of his or her action but has not performed the action with the intention to cause the particular effect [21]. Paraphrasing Dix's example, a person can expect the lights to switch on when entering a room, even though this is not the intention for entering. Dix's other category "incidental" refers to interactions where the outcome is neither intentional nor expected.

Implicit as Unconscious

Implicit–explicit distinction can also be defined through consciousness. This meaning is prevalent in psychology and related fields.[1] Implicit learning is a process by which knowledge is acquired "independently of conscious attempts to do so" [77, p. 219]. Implicit memory is the facilitation of

[1]The precise definition of implicit and how it relates to other concepts such as voluntariness, verbalization or intentionality has been extensively discussed in different domains of psychology [20, 29, 85]. Here, instead of an in-depth discussion of different psychological concepts, we will limit our scope to what we perceive to be a salient concept, consciousness, and outline how it differs from the HCI meanings discussed earlier.

performance "without conscious recollection" [82, p. 501]. The meaning of the term is similar in social psychology [29, 33, 102] where implicit social cognition is "unconscious" in the sense that it is "unavailable to self-report or introspection" [33, p. 5]. Researchers employed experimental techniques such as Implicit Association Test (IAT) [34] to measure "implicit attitudes" towards age, gender and other socially relevant attributes [67, 79]. The definition of the term consciousness is contested, but generally corresponds to "online phenomenological awareness" (i.e., awareness of one's own mental processes) [85, p. 138]. Unconscious processes are described as faster, more efficient but also harder to modify and verbalize than conscious processes [85].

Some work in HCI employs this meaning of the term but without targeting implicit interactions as a design goal. Poeller et al. study "implicit motives" ([61]) to predict video gamers' behavior and play experience [72]. Denning et al. utilize the "implicit memory" of users to aid password recovery [19]. Additionally, we observe that motivations for facilitating implicit interactions occasionally evoke the unconscious meaning of the term. Consider Schmidt's reference to nonverbal cues during face-to-face communication: *"In many cases the robustness of human-to-human communication is based on the implicitly introduced contextual information, such as gestures, body language, and voice"* [83, p. 91]. It can be argued that gestures are part of a person's purposeful social act, but their realization is more or less automatic or unreflective; they are intentional but not deliberate. The term "internally backgrounded" (as opposed to both "foregrounded" and "externally backgrounded" [62]) denotes a similar distinction. Execution of tasks without conscious processing has been related to skilled, well-practiced behavior [55, 62, 66].

Implicit as unconscious qualifies the mental process that leads to an action rather than the relationship between the user action and its effect. To illustrate the point, whether the user action was unconscious (e.g., walking into a room without thinking about it) or its outcome was unintended (e.g., turning on the lights when walking into the room) point to different aspects of an action. Implicit as such also hints at an internal division ("internally backgrounded" [62]) rather than to the division of labor between the user and the system ("externally backgrounded" [62]). For this reason, Ju et al. argued for its exclusion from the scope of implicit interaction by advocating a distinction between *"situations where users don't have to think and plan because the users have developed tacit knowledge of how to operate a task, and situations where the users don't have to think and plan because the system is acting proactively on their behalf."* [51, p. 20].

Implicit as Implicature

Finally, implicit can be understood as akin to "implicatures" [36] (or analogous "indirect speech acts" [86]) in pragmatics, the field that studies the contextual aspects of human communication. Definitions of implicit in pragmatics [e.g., 16, 57, 101] often trace back to Grice and his concepts of speaker's meaning and "conversational implicature" [35, 36] where the analytic focus lies on the relationship between what is said (i.e., the explicit meaning of an utterance) and what is meant (implied) by a speaker. Consider approaching to a group of friends before a trip and saying "I am ready". In addition to its explicit meaning of stating one's readiness, the utterance can be an implicit invitation for departure, which is a meaning that is intended (implied) by the speaker. While understood through speaker's intention, this use of implicit better corresponds to how *literal*, as opposed to how intentional, an utterance is. In fact, what underpins conversational implicatures is a clear demonstration by the speaker that his or her utterance is directed at the listener. This allows the listener to infer the speaker's intention by assuming the relevance of the utterance for the given context [101]. Implicit as such differs from the HCI meaning of implicit as unintentional and not directed at a computer [e.g., 15, 51, 83].

Some work in HCI conveys the implicature meaning of the term. Sun et al. distinguish between implicit and explicit behavior strategies a robot assistant can employ when interacting with a user [91]. The robot assistant can direct a user's attention to itself by asking "Hey, listen to me, it's important!" (explicit) or by implying that it has something to communicate by saying "No problem, I will wait for you". In this example, implicitness qualifies the relationship between the system goal (of capturing the user's attention) and the system output. Yet implicatures can also qualify the relationship between users' intentions and their actions. For example, to save from effort, a user can intentionally make an ambiguous query with the expectation that the search interface will successfully retrieve the intended search result.

Within pragmatics, speakers' motivations for employing implicatures have been formulated through various "conversational maxims" [36] or achieving a greater effect on the hearer with less effort [101]. Similar motivations can explain HCI equivalents of implicatures. For example, the user and the system can have a shared understanding that the user would aim to minimize her effort when communicating her intentions to the system. This in turn can allow the system to compensate for seemingly erroneous or ambiguous user inputs while at the same time affording the user to be less precise *on purpose*.

Note that, Gricean view of implicatures conceptualizes communication as a process of intention recognition. As we discussed earlier, the mentalism that accompanies this conception is not without controversy and has been scrutinized from the viewpoint of interactional pragmatics [5, 12, 39, 40]. Interactional pragmatics emphasizes that speakers' prior intentions are inherently vague and negotiable, and can be practically observed only through their uptake by the hearer. A conceptual consequence of this is the reframing of intentions as retrospective accounts that are *attributed* to the speaker rather than prior mental states that predetermine the communication [39]. A methodological consequence is the shift of the analytical focus from the relationship between speakers' utterances and their mental states to the sequential relationship between speakers' utterances (as in most conversation analysis). Parallel discussions played their part in HCI. Work informed by linguistic pragmatics identified intent recognition and categorization as primary goals for system design [4, 103]. Situated action perspective, on the other hand, emphasized the inherent vagueness of intentions for prescribing action [90].

Summary

Early in the section, we noted that intentionality is central to many definitions of implicit, but not always overlapping with other meanings (Table 1). To summarize, intentional actions can be conducted with different levels of attention, lack of awareness rules out intentionality, but awareness does not necessarily entail intentionality. In contrast, implicatures presume intentionality. Consciousness refers to internal self-awareness of mental processes, which differs from the awareness or intentionality of external action outcomes. Note that, all of the meanings deviate from classical explicit interactions that assume a straightforward coupling between users' mental states, their observable behavior and what is appropriate. However, they illustrate different ways in which this can be achieved. They thus relate differently to the ordinary language use of implicit as *"being understood from something else though unexpressed"*[2]. As implicature, implicitness qualifies how literally the observable behavior represents the intention of its agent. As intentionality, implicitness describes whether the appropriateness of an effect is grounded on user intentions (explicit) or additional assumptions (implicit). This reference to expected appropriateness is, in our view, what justifies the term "implicit" instead of describing the interaction simply as "unintentional", or any other word.

Having reviewed different meanings of implicit, we can also more clearly identify the roots of the confusion with implicit "interaction". Simply put, interaction lacks a unified meaning in the context of implicit; researchers can refer to different entities by "interaction" depending on the particular meaning of implicit they employ (Table 1). Consider intentionality; implicit interaction as unintentional can be problematic when interaction stands for a temporal window of user engagement (since users are assumed to be intentional at the activity level) but not when it stands for a granular input–effect relationship. For attentional focus, implicit can qualify both how users attend to their own input and to a particular system output. Consciousness qualifies the mental process that leads to an action rather than the relationship between the action and its outcome. Thus, it is not truly a quality of interaction. For implicatures, the main entity is the relationship between an action and its intended effect. A commonality between different meanings is their reference to the *user's mental attitude (or lack of it) toward a particular entity*. Thus, when dealing with implicitness we are dealing with phenomena that is not directly observable; claims about implicitness relies on inferences from other units of observation.

The lack of direct observation is a general challenge for research and the previous section already gave a glimpse of the methodological differences between psychology and different traditions in pragmatics regarding their approaches toward mentalism. Work in psychology aims to find empirical measures of mental processes for implicitness, which has led to various experimental techniques such as Implicit Association Test [34]. In linguistic pragmatics, implicitness is determined by comparing what is meant by the speaker against the verbal content of an utterance in a given context. Unlike psychology, this often relies on the formal reasoning by the analyst instead of *"getting down to the messy business of experimentation"* [101, p. 280]. Psychology and linguistic pragmatics both aim to reconstruct a first-person account of mental phenomena from outside. Conversation analytic and situated action perspectives, on the other hand, emphasize the inherent vagueness of intentions, leading to their methodological preference for the procedural analysis of action over mental modeling. In doing so, they embrace a third-person perspective of intentionality and study intentions to the extent social agents publicly attribute them to each other.

Various traditions in HCI inherited these different approaches toward mentalism. In contrast to psychology and pragmatics, however, HCI deals with interactions where one of the partners in interaction, the system, is the outcome of design. Although a user's mental state is not directly observable, the system behavior can be specified, enabling HCI to make claims about implicitness through design. Consequently, HCI research on implicit interaction emerged with a strong constructive orientation toward building interfaces that facilitate implicit interaction [51, 83]. This constructive orientation is an additional source of methodological

[2] https://www.merriam-webster.com/dictionary/implicit

challenges such as potential mismatches between the system design and user experience perspectives. The following section will examine these challenges in more detail.

3 METHODOLOGICAL CHALLENGES

This section elaborates on the consequences of different meanings for what we identify as the particular methodological challenges of HCI's constructive orientation, namely 1) determining implicitness by design, 2) establishing design and evaluation criteria and 3) scoping design problems.

Determining Implicitness by Design

A methodological challenge concerning design is understanding the extent users' mental attitudes can be determined through interface properties. Implicitness is occasionally treated as a quality that is predetermined by design, independent from the uncertainties of the actual user interaction. This is most obvious in the phrase "implicit interface", but also apparent in other terms such as "proactiveness" [51], "attentional demand" [51] or "predictability" [49] that respectively define user intentionality, attentional focus and awareness in terms of system properties. As such, implicitness of the actual use experience is treated as unproblematic, but the claim is ideally informed through a number of design decisions that favor unawareness or unintentionality. For example, it can be hard for a user to comprehend causal relationships between inputs and system effects, as in the case of complex personalization algorithms or when there is no salient feedback [56, 89]. Or, the input collected by the system might not have any immediate consequences for a user, such as when it is used for ranking search results [2] or monitoring the audience engagement [38].

At the same time, it might not be possible to know users' intentions or awareness in advance for a given situation, nor there is any guarantee that they will remain static over time. The uncertainties posed by situational factors pose a limitation to determining implicitness through design. Among different accounts of implicit interaction, Dix has acknowledged the "fluidity" between user attitudes for the same method and introduced vocabulary to express their transitions [21]. Interactions can transition from incidental to expected when users *comprehend* the causal relationships between their inputs and the system effects, and from expected to intended when users *co-opt* to intentionally trigger an effect, as in walking inside a motion-sensitive room to intentionally turn on the lights. One can call all of these interactions implicit but only in the loose sense of the word (alternatively meaning unaware, unintentional and implicature).

Dix uses constructed examples to describe incidental, expected and intended interactions, but implicit as a contingent quality suggests making the validation of implicitness part of the evaluation. For example, Kuikkaniemi et al. start with an a-priori distinction between implicit and explicit feedback mechanisms in a first-person shooter game, but interviews during the study show that some participants became aware of the effect [56]. Fisk et al. report the evaluation of an "implicit-only" interface, where two remote users could control a shared workspace only indirectly, by talking to each other [31], but observe that the proposed interaction method resulted in participants modifying the flow of their conversation to control the shared workspace. Verbal accounts and qualitative differences can be harder to observe for low-level interactions, meaning that researchers can expand their methodological toolbox into experimental techniques. For instance, Coyle et al. borrow the experimental procedure of "intentional binding" from cognitive neuroscience to assess the personal sense of agency based on participants' perceived time between input and effect for pointing tasks [17].

Establishing Design and Evaluation Criteria

The constructive orientation of HCI also means that implicit interactions are deliberately targeted by designers. Yet various meanings emphasize different motivations for design, such as providing appropriate responses that go beyond what the user has intended, freeing up attentional resources, decreased need for cognitive processing (consciousness) or accomplishing an intended effect with less effort (implicature). Different motivations are not necessarily mutually exclusive. Unintentional effects can also be at the attentional background. Yet some are obviously so. Implicatures presume intentionality and rule out any unintended benefits. With the exception of implicature, a common theme across different meanings is *their relaxed assumptions of mental representation as a condition for good interaction.* This position diverges from the traditional HCI focus on predictability, direct control and attentional bottlenecks.

Motivations emphasized by different meanings also differ regarding their value as evaluation criteria. For example, freeing up users' attention for other tasks can be a design goal in its own right, but this is less obvious when implicit stands for unintentional or unaware; an interaction is not better simply because an outcome is unintended or unexpected (users' ability to model the system behavior can even benefit the task performance [70]). In this case, implicitness seems more like a by-product rather than a design goal. This relates to previous calls to formulate implicit interactions *"less as a hammer, and more as a lens"* [52, p. 82], that is instead of striving for making interactions implicit, designers should consider their designs as facilitating implicit interactions.

A contentious issue across different meanings is the normative relevance of users' prior intentions (i.e., users' activity-level end goals) for evaluation. One possible position is to evaluate implicit interactions based on how effectively they realize users' inferred intentions [e.g., 30, 100]: Users' prior intentions remain the ultimate metric that the interactive process is evaluated against, but unlike explicit interactions, their successful accomplishment does not presuppose mental representation and intentional execution. One limitation we have noted with this position is that prior intentions can be vague and negotiable, thus, not necessarily good criteria for evaluation. A related methodological challenge is their elicitation as independent ground truths.

An alternative position that we find more widely applicable is to consider interface design as oriented towards providing system responses that are expected to be appropriate *in retrospect*, without any commitments to prior intentions attributed to the user. What is appropriate can be operationally defined in terms of user acceptance, performance gains or any other utility. Even so, different meanings point to different degrees of *constructive validity* regarding how implicitness translates into other utilities. For instance, whether an interface results in better task performance because it frees up users' attention through automation or because the action is done unconsciously through habituation points to different expectations about user skill. In some cases, what is appropriate can be defined in terms of benefits to other parties. It these cases, we find it necessary to establish whether the expected benefit *depends* on users' unawareness such as when the interaction involves a trade-off (assuming that the users will adjust their behavior once they become aware of the trade-off). Additionally, to ensure unawareness or unintentionality, researchers might want to avoid setting clear goals or disclosing their evaluation criteria to their participants. This differs from many controlled studies where experimental tasks act as proxies for user intentions.

Scoping Design Problems

We use the word "scope" to denote the design problem of deciding which interactions should be targeted as implicit. Previous work stressed the foundation of implicit interactions on existing use patterns [52, 83] or actions the user "would have had to perform anyway" for a primary task [41, p. 33]. For example, public displays can facilitate implicit interactions by sensing people's naturally occurring presence and orientation in physical space [7, 96]. Or, consider eye movements that have long been identified as an input for implicit interaction [60, 95, 106]. An argument for their use in many applications is their "naturalness" [106]; people need to monitor the environment to guide their actions. A subsequent design strategy has been employing eye movement data for implicit interactions (e.g., moving the mouse cursor [107] or personalizing search results [14]). Yet a designer can also approach the problem from a different perspective, by acknowledging that eye movements are largely shaped by existing design decisions such as attention-demanding GUIs. This can in turn lead to various alternative design strategies that decrease the need for visual attention. Thus, designers are confronted with a practical choice of whether they treat the existing use patterns as pregiven or modifiable.

Another issue related to the design scope is determining which particular interactions should *not* be targeted as implicit interactions. A design prediction from early research is that, for many applications, implicit interactions will occur alongside with explicit interactions [51, 83]. Previous theorizing provides at least two possible reasons for the continued existence of explicit interactions.

First reason is the aforementioned foundation of implicit interactions on a purposeful or attention-demanding primary activity [21, 41, 83]. In some cases, this activity can be external to a system, thus not part of the interaction. For example, navigation in physical space is often external to an interactive system, but can be utilized by a mobile service for providing contextual data. At the same time, as our interaction with the world is increasingly being mediated by computers, we can expect to encounter many cases where a primary activity is part of the interaction, such as in computer-mediated communication or many productivity tasks. For example, implicit feedback for search systems can rely on actions that users perform anyway to examine or share information [2, 76, 99]. In these cases, explicit interaction becomes a prerequisite for implicit interaction.

The second reason is the potential failure of design assumptions or system inferences. In HCI, it is generally acknowledged that system inference can fail or design decisions can prove inadequate during interaction [8, 9, 45]. The inference mechanisms and design assumptions that implicit interactions rely on are no exception. Consider auto-rotation of the screen content in mobile interfaces based on the device orientation. While helpful in many cases, this adaptation can be inappropriate when the user is lying down [41]. In information retrieval, a user's inferred interest does not always match with what the user finds relevant. Thus, researchers turned to quantify the prediction accuracies for different types of implicit feedback [e.g., 32, 50]. The challenge can to an extent be addressed by developing better models to decrease failures. When near-perfect accuracy is not possible, relying solely on implicit interactions can be impractical, leading to their combination with interaction methods that facilitate explicit interactions.

4 DEPLOYING AN UPDATED DEFINITION

We reviewed various meanings of implicit and identified their consequences in regards to the entity, motivation and the constructive validity of implicitness. In this section, we provide and deploy an updated definition based on the understanding of implicit interaction in terms of intentionality. We define implicit interactions as interactions in which *the* *appropriateness of a system response to the user input (i.e., an effect) does not rely on the user having conducted the input to intentionally achieve it.*

Implicit interactions thus differ from explicit interactions where the appropriateness relies on the assumption that the user has performed an action to intentionally achieve a particular effect or, conversely, has abstained from performing an action to avoid a particular effect. For implicit interactions, appropriateness of a particular effect is instead *understood from the user input, but does not rely on the user's intentionality.* An input refers to any kind of data that originates from the user that is available to the system. An effect refers to any outcome that is facilitated as a result of this user action or data, either with or without system mediation. For example, walking into a room facilitates navigation in space, but can also cause the lights to turn on in the presence of a motion sensor. The formulation of interaction in terms of causal input–effect relationships is not new (see [22, 23]), but has not been previously used to study implicit interactions. Below, we illustrate how specifying an input–effect relationship (or shortly an input–effect pair) as the entity of interaction can help us address the previously identified challenges.

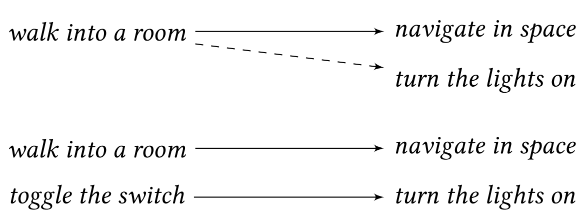

Figure 1: Depiction of implicit (above) and explicit (below) ways of turning on the lights. The dashed line shows an input–effect pair that is expected to be implicit. A common pattern in implicit interactions is the co-occurrence (or bundling) of multiple effects as a result of the same input, eliminating the need for additional actions.

Combining Input–Effect Relationships

The previous section, without going into the details, made the case that implicit interactions will exist alongside explicit interactions. Here, we elaborate on various possible combinations by specifying the entity of implicit as an input–effect pair. Let's start with our observation that implicit interactions often assume the presence of a primary and intentional activity. When viewed through the lens of input–effect pairs, this translates into situations in which an *input leads to multiple effects.* Some of these effects are intended by the user and can explain why the user has conducted the action in the first place. Other effects can be unintentional but still appropriate for a given situation. The expected benefits of implicit interactions can then be attributed to the decreased user effort that is achieved through this bundling (Figure 1) instead of an effect being unintentional.

What is appropriate for a given situation is not always known in advance, a consideration that calls for various additional interactions. First, reaching a particular effect can involve a complementary input–effect pair. For example, Buscher et al. utilize eye movements to model user interests when interacting with a search system [14], but their system retrieves the actual search results only after a typed query to manage the low accuracy of the user model that is inferred from eye movement data (Figure 2a). In another example, Buschek et al. reinforce "explicit" authentication methods (i.e., typing a password on a mobile device) with less accurate "implicit" authentication methods (i.e., using biometric data) as an additional layer of security [13]. In these examples, the ultimate execution of a particular effect (retrieving search results or logging into a mobile device) requires an additional interaction that is expected to be intentional.

Secondly, the system can allow falling back to a corrective input–effect pair when the design assumption or the system inference proves to be wrong. Unlike the previous case, this involves modifying an effect that is designed to be implicit *after* it has been executed. For instance, an intelligent whiteboard can organize a user's sketched notes as visual clusters, but the user can intentionally "override" these clusters if he or she disagrees with the system interpretation [51] (Figure 2b).

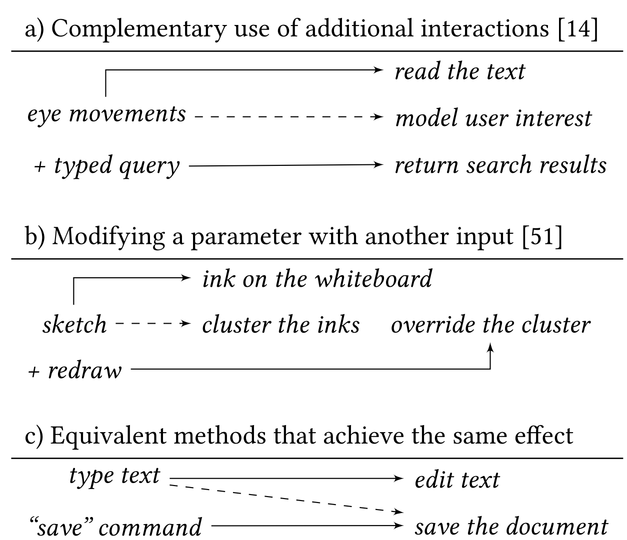

Figure 2: Diagrams showing an interaction that is designed to be implicit (dashed lines) within the context of other interactions.

Finally, there can be cases of false negatives, namely situations in which the system fails to provide an appropriate response when needed. For example, a text editor can utilize a user's editing actions as a trigger for auto-saving the document, but the user might also want to save the document without having to wait for the auto-save functionality (Figure 2c). These situations require the presence of an equivalent method in the interface that achieves the same effect.

Determining the Implicitness of an Effect

Specifying the entity of implicit also directs us to the more precise question of whether prior expectations of implicitness matches with users' reported mental attitudes toward an input–effect pair. Let's illustrate this by reviewing previous work through the lens of the updated definition. In their study of messaging applications, Hoyle et al. initially designate "read receipts" (i.e., visual notices that inform the sender that the receiver has opened the message) as "implicit" effects that occur as a by-product of viewing the message [47] (Figure 3a). Yet their interviews show that read receipts can be an explicit effect, such as when users abstain from opening messages to avoid informing the other party of their action.

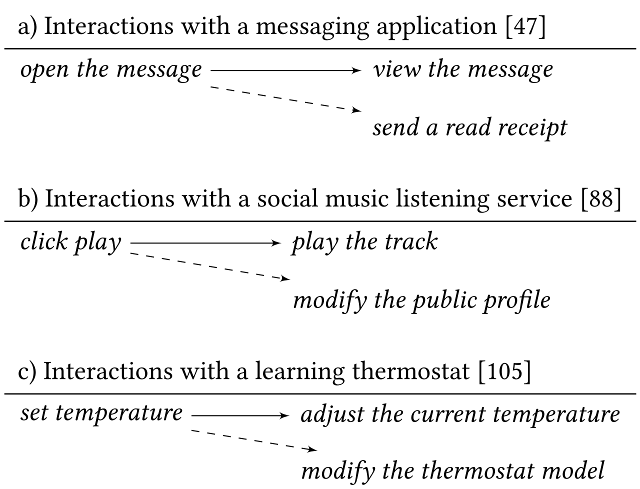

Figure 3: Depictions of input–effect pairs that are expected to be explicit and implicit (respectively shown as solid and dashed lines). The implicitness of a particular input–effect pair contradicts prior expectations in each example.

Outside implicit interaction literature, interviews have shown that users can put extra effort to achieve or modify seemingly implicit effects. Silfverberg et al. report a particular social media-linked music listening practice in which users hit the "play" button, but for presenting themselves as listening to a particular track in their social media profile instead of actually listening to it [88]. In this case, the input (hitting the play button) results in two effects, playing the music track and changes in the user's social media profile (Figure 3b). Contrary to the expectations, it is the latter effect that is intended by the user. Yang and Newman investigate the use practices that emerge around a learning thermostat [105]. When a user sets a new temperature, the thermostat facilitates both the instant effect of changing the temperature and the long-term effect of building a model of user preferences (Figure 3c). A finding from their interviews is that users can adapt their behavior of setting the temperature to prevent unwanted adaptations once they realize the limitations of the device's learning capability. Note that, in the above-mentioned cases, the explicitness of the interaction is not negative per se; the observations rather exemplify situations in which users adjust their mental attitude to compensate for the inappropriate system behavior.

Finally, we see a more precise definition helpful for reasoning about implicitness through interface properties, by expanding the scope of analysis from isolated "implicit interactions" to the *application context* an input–effect pair is situated in. For instance, among different effects that result from the same input method, some can be more visible, thus more likely to be noticed and intended by the user. Or, among equivalent input methods that lead to the same effect, some can require less interaction steps than others or require less skill, increasing the likelihood of that particular input for intentionally producing the effect.

The reasoning can be developed further by paying attention to the combination of different input–effect pairs. Consider our observation that implicit interactions are often enabled by other effects that are caused by the same input; bundling of multiple effects is a source of uncertainty for attributing user intentions to observable behavior. On the other hand, lack of an equivalent method for achieving a certain effect increases the likelihood that a particular input–effect pair becomes explicit. For example, a text editor can utilize users' editing actions as a trigger for auto-saving the document, but in the absence of a "save" command, users can resort to editing the document as a means to trigger an auto-save. Previous work documents such instances in which interactions that were designed to be "implicit-only" turned out to be intentional and at the focus of users' attention because they were the only means to reach a specific outcome [31].

5 DISCUSSION: ADDITIONAL CONSIDERATIONS FOR RESEARCH

HCI has long acknowledged that interactional achievements can depend on external conditions that have no mental counterpart in a user's mind. Designing for implicit interactions represent a constructive take on this insight by expanding the scope of design to unintentional and by potentially increasing the role of external dependencies even further. We identified the particular methodological challenges of this

Table 2: A list of additional considerations for research.

Determining implicitness by design: Do users' mental attitudes match with prior research or design expectations (if so, in which cases)? How do they adapt over time in relation to a design intervention?
Establishing criteria for design and evaluation: What are the assumptions about what is appropriate (from the perspective of the designers and the users)? To what extent do users' prior intentions represent what is appropriate? Does the expected benefit of a design intervention depends on the interaction being implicit (i.e., if a targeted implicit effect turns out to be explicit, is it still beneficial)?
Scoping design problems: Which effects are bundled together (co-occur as a result of the same input)? How does the bundling of effects make certain interaction outcomes harder? Are there any equivalent methods for achieving the same effect or correcting it? How does designing for implicit interaction can reinforce or modify existing use practices?

constructive orientation and showed how an updated definition can be deployed to address them with greater precision. While our analysis focused on the diverse uses of the term implicit interaction, we find the exposed challenges representative of more general concerns in HCI, namely the conceptualization of user and system agencies through design and the role of user intentions in research. Below, we discuss the broader implications of our analysis and identify additional considerations for design and evaluation. These are presented as a checklist of actionable research questions in Table 2.

Taking Implicit "Interaction" Seriously

First of all, framing implicitness as an interaction quality emphasizes the aspect of situational accomplishment; implicitness is not a design feature but an empirical claim about users' state in a given situation. Beyond terminological precision, what is the value of this insight for how we design and evaluate interfaces? If interfaces themselves are not implicit or explicit, what are they? And if implicitness is accomplished through interaction, how does it inform design?

For design, what is more consequential than the explicit–implicit dichotomy are the assumptions they rely on, namely designer's expectations about users' goals and what is appropriate for a given use case. These assumptions guide the practical design problems of bundling different effects or providing complementary input–effect relationships. Thus, even though interfaces themselves are not implicit, they can be expressed in the intention-agnostic language of different input–effect relationships. Distinguishing designers' assumptions from the actual interface properties is important as it exposes the role of interface in promoting or precluding different interaction outcomes. For example, an understanding of implicit as predetermined by design puts emphasis on the decreased user effort achieved through bundling multiple effects. Yet it can obscure how bundling multiple effects can make certain interaction outcomes harder, such as opening a message without sending a read receipt or adjusting the room temperature without changing the user model of the thermostat.

For evaluation, framing implicit as a quality of interaction calls for paying attention to users' actual mental attitudes and their long-term adaptations. Systems that are designed to facilitate implicit interaction often build on users' existing action routines to facilitate additional appropriate effects. The implicitness of an effect is then grounded on the expectation that user goals or actions will remain unchanged after a design intervention. What is missed in this conception is how design interventions can invalidate such expectations if users reformulate their goals in relation to these effects or avoid certain actions to prevent what they perceive as unwanted effects.

While our discussion focused on the term implicit, the relevance for similar concepts should be obvious. Distinctions between "user-controlled" versus "mixed-initiative"[3], "proactive" [59, 80, 104], "adaptive" or "automatic" often restate user intentionality in terms of system properties. Yet whether a system proactively adapts its behavior in response to the user input, or whether the users intentionally exploits the system adaptation cannot be stated independently from their knowledge and goals in a particular situation. Here, our emphasis parallels previous insights on foreground–background as situational properties [92], the accomplishment of meaning through interaction [24], and more recent criticisms against the use of qualifiers such as "natural" or "intuitive" [11, 68, 98] to describe interfaces. Thus, part of the problem can be attributed to a confusing mixture of experiential and system properties. That said, we distinguish this mixture from the more productive efforts of anticipating and designing for implicitness. And this is where we see the value of conceptual precision; a testable definition enables researchers to specify why implicitness is pursued and how prior design assumptions can be validated.

User Intentions from Normative to Descriptive

Finally, we frame designing for implicit interactions as part of a broader change in attitude in HCI that prioritizes appropriateness of action outcomes over their intentionality. Accompanying this shift is the changing role of user intentions from normative (i.e., as setting the evaluative standard of interaction [44]) to descriptive: Intentions can explain why the user has performed an action or found a system response appropriate, but as mental antecedents they provide incomplete resources for activity completion and can be negotiable. Thus, instead of taking the normativeness of user intentions for granted, *researchers should treat the extent user intentions become a measure of user acceptance as an empirical question* by taking situational factors such as users' capacity to model and control system behavior into account. Consequently, we argue for the need to expand the scope of evaluation from performance metrics and observable breakdowns to assessing how different interface configurations subtly influence user behavior and lead to qualitatively different outcomes.

Interface mediation in turn emphasizes the *normative aspect of designing* and the role of the designers in conceptualizing what is appropriate for a given situation. In HCI and design, similar thoughts led some to expand the notion of normative intentionality to artifacts under the phrases "material intentionality" [94] or "design with intent" [58]. Yet we observe that these discussions have been relatively absent in the context of implicit interactions. Normative aspect of designing becomes particularly relevant when user intentions are treated as incentives for end goals that are designed to benefit other parties. Potential trade-offs in these situations point to ethical questions related to users' informed consent and the distribution of burden and benefit.

6 CONCLUSION

In the wake of increased sensing capabilities and complex inference mechanisms, the concept of implicit interaction is ever more relevant. In this paper, we have drawn attention to the present ambiguity of the term and analyzed the consequences of different meanings for establishing why we facilitate implicit interactions and how we validate its benefits. In the most general level, our investigation is a call for researchers and designers to specify their particular use of implicit interaction instead of treating the term as self-evident. Our review provides a reference for future work by clarifying the differences between various meanings. We see the conceptual clarity brought by as a necessary step for larger, more systematic reviews.

In more particular, we call for paying closer attention to the implications of defining explicit–implicit distinction through intentionality and as a quality of an input–effect relationship in order to address the methodological challenges with greater precision. Importantly, we stress implicitness as something accomplished through interaction, which highlights the need to critically examine what prior distinctions of implicit and explicit presume about users' goals, their capacity to model the system behavior and what is appropriate for a given situation. We expect the additional considerations to be helpful as interfaces that aim to facilitate implicit interactions increasingly go beyond proof-of-concept and are deployed in more complex settings.

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