Reflexive Interaction

Extending the concept of Peripheral Interaction

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ABSTRACT

Human-computer interaction (HCI) continues to evolve and interaction scenarios have to fulfill mobility, flexibility, and ad-hoc interaction where ever users are. To address this, traditional interaction concepts are being extended. While Peripheral Interaction was previously introduced, it still remains as a rather broad concept, intersecting with others, and thus creating space for further definitions. Therefore, this paper introduces the concept of *Reflexive Interaction*, which can be viewed as a specific manifestation of Peripheral Interaction. In contrast, *Reflexive Interaction* is envisioned to be executed at a secondary task without involving substantial cognitive effort. It allows the user to perform very short interactions, shorter than Microinteractions, without straining the user's main interaction channels occupied with the primary task. To clearly classify *Reflexive Interaction* in respect to previous interaction concepts, we use a taxonomy relying on an attention-based HCI model.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; *Interaction techniques*;

KEYWORDS

Reflexive Interaction, Peripheral Interaction, Taxonomy of HCI

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1 INTRODUCTION

This paper introduces and elaborates on the concept of *Reflexive Interaction*, namely its correlation to humans' use of technology. *Reflexive Interaction* can be seen as a specific manifestation of Peripheral Interaction and is envisioned to be executed without demanding great cognitive effort. It enables the user to enact an interaction as secondary task without interrupting the primary task. The idea emphasizes on utilizing quick, unobtrusive, and nonchalant interaction techniques to enable a new ubiquitous computing while disregarding the requirement of primary interaction modalities, such as visual attention. The concept of *Reflexive Interaction* exploits the humans' unique abilities of proprioception, motor-memory, peripheral perception, divided attention through separate cognitive processors, and the ability of conditioning reflexes.

In this paper, a definition of *Reflexive Interaction* is contributed, the concept is classified in relation to intersecting interaction concepts, and elucidated by a taxonomy relying on an attention-based HCI model. The concept is evidenced based on literature and enabler technologies are identified. Generic examples are used to demonstrate the ways in which *Reflexive Interaction* can manifest. At last, we provide an overview of more specific views on Peripheral Interaction.

2 REFLEXIVE INTERACTION

2.1 Overview

We can categorize the interaction between human and computer in three general classes: Focused Interaction, Peripheral Interaction, and Implicit interaction. Within this framework, a *Reflexive Interaction* is classified as a subcategory of a Peripheral Interaction, while slightly overlapping with Implicit Interaction. This aligns with Bakker et al.'s [7] view, due to the low attention demanded *(see Figure 1)*. Peripheral Interaction denotes any interaction that is occurring within the user's periphery in relation to their main task, for example, arranging tokens on a table while briefly interrupting work at the workstation. In a Peripheral Interaction, short attention shifts from the main task to a secondary task occur, to either perceive feedback or provide input. When adhering within a four seconds threshold, quantified by Ashbrook [4], this is known as a Microinteractions. Although Bakker [6], Hausen [41], and others provide several definitions on Peripheral

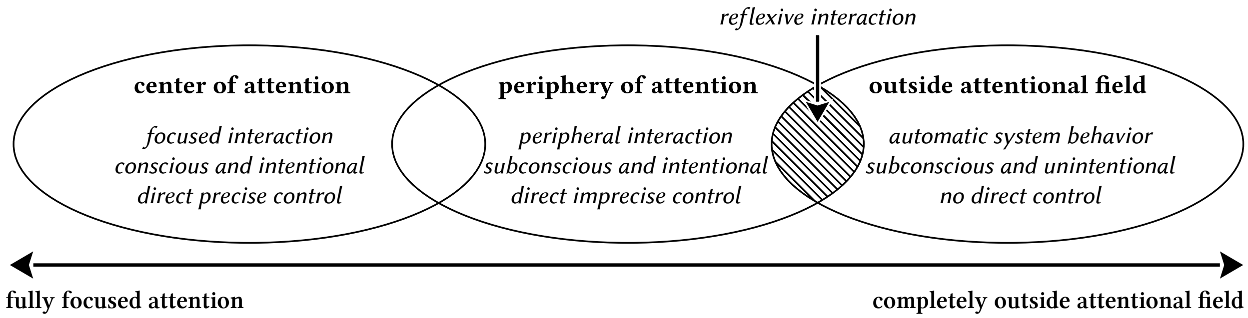

Figure 1: Illustration of the three types of interaction based on the user's involved level of attention by Bakker et al. [7].

Interaction, the current framework remains vague. In particular; when does a Peripheral Interaction end or become an Explicit Interaction? The only answer provided is the notion of floating transitions as also indicated by Ju [52] and in Figure 1. That is because human attention is dynamic and may even shift frequently to several other tasks. Existing research demonstrating a Peripheral Interaction, which Bakker [6], Hausen [41], Ashbrook [4], and Edge et. al. [27] present, all share a common underpinning. They work with either external or internal interruptions, while relying on Sequential Multitasking. Therefore, at the moment of interaction, the user's attention shifts to the secondary task, which can occur within several seconds. Although task interruptions are useful at times, they yield many negative consequences, such as increasing error rates [2]. It has also been demonstrated that an increased amount of task interruptions, forces the user to unconsciously interrupt more often in other daily routines [23]. Moreover, task interruptions are considered rather negative, both by society and HCI researchers. Technology should remain muted and gradually recede into the background [99], rather than become more distracting and increasingly louder, to compete for the user's attention [14]. Previous works by Hausen [41] and Ashbrook [4], attempt to counteract this by focusing on interruption management, while applying quick sequences of interaction during task interruptions. In contrast, *Reflexive Interaction* relies on a Concurrent Multitasking that enables tasks to truly exist in parallel. As task interruptions do not occur, the parallel secondary task would never exhaust the user's center of attention. A *Reflexive Interaction* should follow Brown's strict definition of a Peripheral Interaction, particularly that *«...the reflexive and reactive pre-attentive use of tools and techniques on the periphery of conscious attention»* [17]. Within Hausen's broad definition of Peripheral Interaction [41], the concept of *Reflexive Interaction* must be classified as a sub-concept of Peripheral Interaction, marginally intersecting with Implicit Interaction, which is happening pre-attentive (*see Figure 1*).

2.2 Definition

2.2.1 Classification: A *Reflexive Interaction* can be attributed to a reflexive and reactive pre-attentive variation of a Peripheral Interaction, which enables the user to interact in parallel with a secondary task without interrupting the primary task.

2.2.2 Enablers: A *Reflexive Interaction* is enabled due to the human's capability to complete tasks with divided attention. Divided attention exists because the human possesses several and separate processing systems for reflexes, reactions, and reflections. In addition, information can simultaneously be perceived in the sensor periphery, while actions can be executed in the motor periphery. Although the human's attention resources, such as cognitive resources, perception capabilities, and physical abilities are naturally limited, they can be regulated by our attention filters (*see also Figure 5*). By reducing the task's difficulty, the attention reduction allows for the extra attention span to be allocated to another task. For example, part of a person's attention can be directed to a secondary task when the mental and physical effort created by the task is minimal, when the user is highly motivated to accomplish a task, when environmental interference's are minimal, or when the tasks are highly familiar to the user.

2.2.3 Requirements: Interactions may occur subconsciously where information is perceived pre-attentively and when input is provided by a reflexive gesture. This requires a conditioning, including a long training phase, as well as an interaction design to operate on a standard basis of minor-complexity information, which is advisable to not exceed two bits. The interaction should also be accomplished within a fraction of a second. These boundaries are estimated based on literature (*see subsection: Evidencing Feasibility*), however, more sophisticated investigations may be required. Generally, input gestures are characterized as being very short. Feedback would rely on subtle notifications that are scaled to a level that is on the threshold of being non-disruptive, but still recognizable [5, 29]. Furthermore, the secondary task's feedback and input should be distributed to a secondary interaction modality and not to an already occupied channel. Moreover, the current context must be considered, such as the user's mental state and activity level, environmental changes, and temporal variables. These factors will help to determine the optimum time in which the user would be able to accomplish a secondary task in parallel, and coordinate which interaction modalities are occupied or available.

2.2.4 Benefits: A *Reflexive Interaction* would not allow an interruption of the primary task. Instead, it opens a quick parallel interaction on the basis of a Concurrent Multitasking, enabling the user to continue performing the primary task in an unhindered manner. The main focus of attention would remain on the primary task, while the *Reflexive Interaction* only requires peripheral attention. *Reflexive Interaction* does not interrupt the main directive, as it pre-attentively perceives the task and quickly accomplishes it in an automated way. For this reason, a *Reflexive Interaction* is also hardly to be interrupted. As quick gestures and short notifications often remain unnoticed by others, they are thus potentially socially acceptable in any environment.

2.2.5 Limitations: The concept of a *Reflexive Interaction* is not the ultimate solution to all interaction problems, as it may only be enabled with input and feedback no greater than two bits. The task complexity must be low and also demand low attention *(see Figure 2)*. Moreover, *Reflexive Interaction* requires the task to be conditioned closely. More complex and abstract tasks, greater than three bit, may be impossible to memorize in short-term [73]. However, an extensive training and conditioning may also enable the performance of more complex tasks in a reflexive manner. Greater research is required to determine the boundaries.

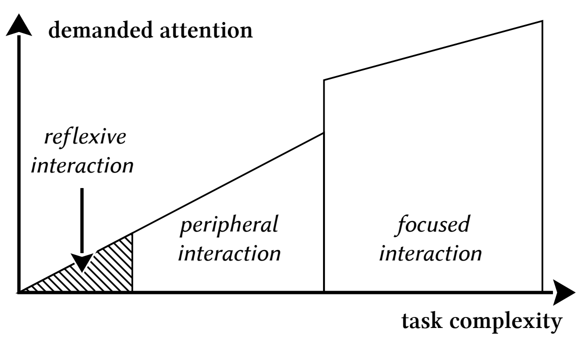

Figure 2: Demanded attention and task complexity. *Reflexive Interaction* can only happen during minor-complex tasks with low attention. (As shown in Figure 1, there is an undefined gap between focused and peripheral interaction.)

2.3 Example Implementation

To illustrate the workflow of a future system (*see Figure 3*), we assume a simple scenario in which a user rides a bike, while an incoming phone call notification occurs. Within the initial moment a call notification is received, the system would sense and analyze the current context, such as the environmental variables. Typical environmental variables are location, social aspects, infrastructure, conditions (e.g., light, temperature, noise, acceleration, ect.), and the user's physical activity and mental state. After evaluating these contextual variables, the system recognizes if a parallel task is possible and whether it could potentially enable a *Reflexive Interaction*. In the subsequent stage, the system determines, based on availability and pre-trained interaction, the optimal modality, namely our input and feedback abilities, To convey the notification, the system selects a body part that is not yet occupied by another task. Similar as envisioned by Horvitz et al. [44], the system scales the notification to an extend that it is just noticeable for the user, but without disrupting the current sequence of actions. For instance, a simple colour change appearing in the user's peripheral vision for a short moment would be a sufficient indicator. Moreover, we assume that the user already created a reflexive action, such as a foot-tapping or eye winking, which usually skips a request or mutes a disturbing notification, such as a call. As the feet are already performing the pedalling function, the user can either quickly respond with an eye wink to mute the call, a head-shake to decline the call, or nod to accept the call.

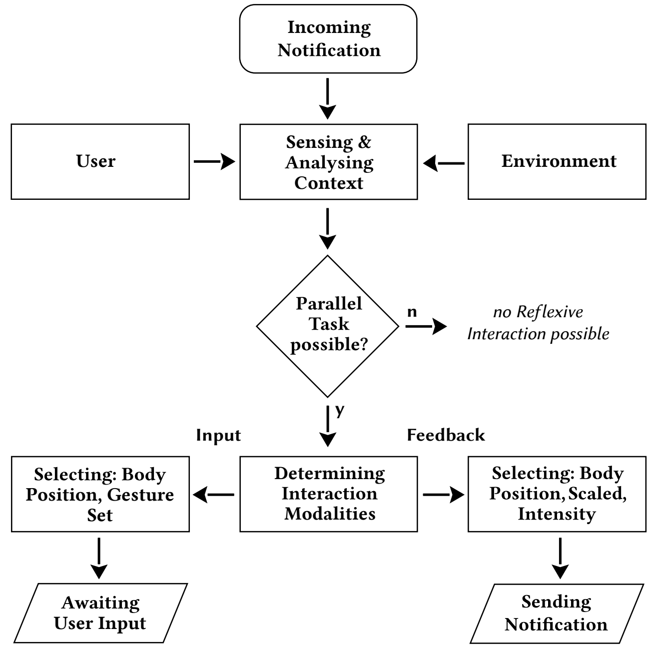

Figure 3: Flowchart of the theoretical workflow of a system.

The example shows that a *Reflexive Interaction* is context-dependent. It should consist of short, recognizable, yet non-disruptive scaled notifications, which include a short gesture set for a response. It makes sense to offer a gesture set that enables a response, such as an acceptance, a rejection, and the skipping of notifications. Using natural body language when assigning gestures, such as head-nodding, head shaking, or a heel kick, namely to "kill" a notification, seems intuitive and easy to internalize. However, other quickly executable gestures could be conditioned, but may require longer training periods. After internalizing a gesture, the interaction would take place without requiring an increased cognitive load.

However, a person may encounter an involuntary action. For instance, while the user is riding the bike, they may consider themselves too preoccupied and reflexively decline any incoming phone calls, only later changing their mind, once the call was disregarded. In this case, a designer may develop an option to revoke the user's decision, such as waiting for a second gesture to counteract the first negating gesture.

2.4 Evidencing Feasibility

This section introduces a small selection of fundamentals, which evidence the feasibility of *Reflexive Interaction*. As most fundamental we consider the mechanics of conditioning reflexes and multitasking.

2.4.1 Human Reflexes and Conditioning. Generally, a reflex is described as a near instantaneous reaction, such as a physical movement in response to a single or multiple stimuli. Human reflexes can be considered autonomous neuro-motor interactions, enabled by neural pathways. These are also called reflex arcs that act on an impulse-basis before reaching the brain [33, 96]. Therefore, reflexes do not initially involve conscious thoughts. However, the result of the reflex, such as a leg movement, is consciously perceivable.

We can distinguish between different forms of reflexes, such as Natural Reflexes, which are individually strong pronounced. There are also Primitive Reflexes, which only occur with newborns [19, 106] and and Myotatic Reflexes, which are being later developed in adults [58]. A reflex can be triggered by mechanical stimulation [18] and by nerves being stimulated (e.g., olfactory, visual ...) [70]. Aside from the type, none of the reflexes requires the individual to consciously draw attention. Moreover, for the first two groups, motor action is executed in an automated way, without requiring a conscious processing also. From 1928 to 1936, Pavlov's vast series of experiments led to the creation of another defined category of reflexes, conditioned reflexes [76]. These reflexes are not congenital but acquired during a lifetime. A good example of such a reflex is the well-known dog experiment, in which a bell rings immediately prior to feeding time. The experiment demonstrated that, at some point, solely ringing the bell would encourage the dog's digestive secretion production, although the food was not served. Building upon Pavlov's theory of Conditioning Reflexes, Skinner studied the behaviour of organisms more extensively [89]. This largely underpins the current theory of Associative Learning [60], which denotes the learning of Conditioned Reflexes as Classical Conditioning, while extending it within the concept of an Operant Conditioning [88]. *Reflexive Interaction* incorporates a set of somewhat Conditioned Reflexes which are utilized for interaction without creating high cognitive demand.

2.4.2 Multitasking. The human can be considered as an I/O system, which listens to the environment and is capable of action. That happens consciously when drawing attention to a task or unconsciously when responding with reflexes. As previously stated, our attention resources can be devoted to multiple tasks, which essentially underpins effective multitasking. In a prototypical multitasking scenario, we would have a main task with focal attention and a secondary task with peripheral attention (*see Figure 6*). Although most experiments utilizes Joula's theory [53], it is still questionable whether it is possible to divide an equal amount of attention into two equally demanding tasks. There are two theories demonstrating attention resource distribution; 1) Task Sharing: attention distributes among multiple tasks simultaneously, as illustrated in the *Figure 6*, and 2) Task Switching: attention switches rapidly between several tasks. The reality may involve a mixture between both: attention can be distributed but at a high frequency.

There are two types of multitasking [84], Concurrent Multitasking and Sequential Multitasking. The former, Concurrent Multitasking, describes a parallel execution of tasks when separate cognitive processors are used for separate processes. For instance, this involves an individual, who is walking, and interacts with a mobile device, while simultaneously answering a phone call. The neocortex develops responses to the conversation, while the cerebellum is coordinating the complex series of reflexes that enables the individual to walk. In this case, walking is peripheral to conversing. If the user reaches an unexpected obstacle, namely if the terrain is rough, the user may have to switch their conscious attention to navigating the terrain. Consequently, the conversation becomes peripheral, where the individual either switches into a passive listening mode or introduces filler statements and possibly loops of previously spoken phrases. One might say *«ummm»* or *«aahh»*, repeat previous words, or the last words spoken to them. At this point, the task of walking is brought to the center of attention, while the task of conversing is delegated to the periphery. Once the obstacle is past, the attention shifts back, which Weiser has also supported [98][1]. The latter type of multitasking, Sequential Multitasking, involves tasks which are executed in an interleaved way, over longer periods of time. This occurs in situations, such as assembling an IKEA shelf, where the user switches between reading the instruction manual and screwing the shelf. Essentially, multitasking is characterized by interruptions, which can be internal or external [71]. Internal interruptions are purely intrinsically motivated, such as by a user's change of mind. External interruptions, however, are caused by environmental factors, such as a phone ringing or receiving a notification. A *Reflexive Interaction* exploits the underpinnings of Concurrent Multitasking, to enable a successful accomplishment of multiple tasks in parallel.

[1] This is a modified example adopted from a personal correspondence with John N.A. Brown.

Figure 4: Depicting enabler technologies, which potentially enable a *Reflexive Interaction*.

2.5 Enabler Technologies

A *Reflexive Interaction* requires quick input mechanisms, including subtle and scalable notifications, as the user's current context is important to be considered. This section taps into the variety of enabler technologies explored in research.

2.5.1 Input Interfaces. Research proposes a variety of subtle input mechanisms, which could be performed quickly in a manner of *Reflexive Interaction*. Figure 4 – (A) shows an in-ear sensor enabling the detection of head movements and facial expressions. This is demonstrated by EarFieldSensing [67], InEar Biofeedcontroller [62], and CanalSense [3]. (B) shows Botential [65], which enables for quick on-body tapping and hovering gestures. Another method is to utilize the mouth (C), such as by a sip and puff [50], or biting on an intraoral interface [31]. In (D) quick thumb-to-finger gestures are demonstrated, such as by Ringteraction [32], Thumb-in-Motion [15], and Tip-Tap [55]). (E) Controlling a blinker by quickly raising the pinky finger, is demonstrated in WristFlex [24]. If hands are not occupied for a primary task, a *Reflexive Interaction* can be executed by a variety of finger and hand gestures like shown in FingerPing [107], Opisthenar [105], and BeamBand [48]. (F) As feet are usually not occupied, we can also use subtle foot tapping [85] and toe gestures [30].

2.5.2 Notification / Feedback Interfaces. Various channels, such as tactile on-body feedback [63], peripheral vision [22], and audio feedback [86] perceive feedback in a subtle manner. In Figure 4 - (G) a peripheral head-mounted display [64], such as Google Glass, can be used to perceive visual feedback in the periphery [21]. On-body feedback, such as a perceived pinch as shown in (H) Skin Drag Displays [47] or a (I) poking next to the spine [63] can trigger a reflex. (J) Utilizing Electrical muscle stimulation (EMS) can create a force feedback [59], which the user can become accustomed to with longer training. EMS notifications can also be conveyed in a subtle way, where increased task performance was also demonstrated in (K) [63]. (L) Deploying low-density information via on-body vibrotactile feedback, such as at the arm, hand [29], and foot [69] has shown to significantly reduce task interruptions and thus reduce stress when multitasking.

2.5.3 Context Aware Interfaces. The entire body constantly generates unique information, which can be utilized to draw inferences on the user's context, such as physical activity or emotional state. In particular, from the head and the face, the user's stress level (M) via a temperature sensor [104] and emotional state (N) using a mobile EEG [81] can be inferred. (O) Another common method to draw inferences on the user's mental state is using galvanic skin response, such as by implementing it into a shirt [45]. (P) Considering the user's current state, such if being in-/active, as well as analyzing the vital parameters [36] can be substantial in deciding the optimum time to confront the user with a potential interaction. (Q) Tracking the user's current physical state, such as the type of activity being performed [37] is another essential variable. (R) Additionally, one can utilize a pressure sensitive insole to identify the user's current posture [66] and using the center of pressure to infer on the body posture [28]. An insole can also be used to identify the user's environment, such as being indoors or outdoors [66].

2.6 Summary

The proposed idea of *Reflexive Interaction* must be viewed as an initial draft concept, which attempts to further define a segment of Peripheral Interaction. However, to implement a successful *Reflexive Interaction*, there are several matching preconditions. Interactions are required to be short and minor-complex, as they must be conditioned by training phases. The gesture set, which could be generally applicable to mute, decline, or accept an incoming notification, could be a general one, which has been internalized. *Reflexive Interaction* can also deploy application-specific gestures and notifications. The design of a notification is a crucial factor, as it can be either overlooked or generate excessive attention. Scaling those to a moderate level and determining a suitable feedback channel is challenging. The same challenges apply to the selection of the available input channel. Therefore, context aware interfaces, extracting important parameters to determine the user's state, and the environmental state, are necessary for an intelligent system to make such decisions.

3 TAXONOMY

As the term Human-Computer Interaction (HCI) was first mentioned in 1976 [20], many taxonomies were introduced to greater understand the interaction processes between humans and machines. The most important models include the *Gulf of Execution and Evaluation (1986)* [75], *The Structure of Multimodal Dialogue (1989)* [46], *A Unifying Framework for Interaction (1991)* [1], *Task Decomposition Model (2003)*, [56], *Human - Environment Interaction Model (2003)*, [56], *Cognitive System Engineering Model (2005)*, [103], and the model on *Understanding User Tasks (2011)* [95]. Within this time period, literature identified three waves that have informed this field of research [39]. Attempts were also made to organize new technology trends within alternative taxonomies [26, 34, 57], namely by introducing another viewing angle.

To set *Reflexive Interaction* into perspective to previous concepts, we utilize an elementary taxonomy based on the user's involvement of attention [53].

3.1 Attention-based HCI Model

3.1.1 Attention Theory. In 1890, James William originally defined attention as *«...taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others»* [49]. However, in contemporary society, attention is denoted as a behavioural and cognitive process that focuses on tasks. Within the past century, various theories on attention were investigated, which are mostly based on empirical research (1958: [16], 1959: [72], 1963: [25], 1964: [92], 1968: [74], 1980: [79], 1981: [51], 1984: [80], 1991: [54], 1992: [82], 1997: [83], ...). However, all contemporary theories concentrate on the selection process to maintain focus on the task at hand, while being able to accept interruptions. Attention shifts were later investigated in a broader manner by Strayer et al. [90, 91], who discovered the consequences of high task-switching.

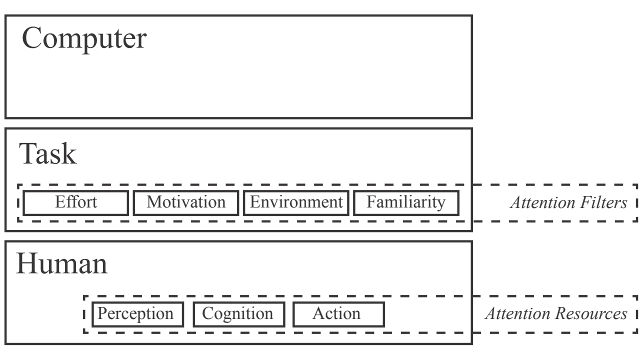

Figure 5: A simplified model showing four Attention Filters and the humans Attention Resources based on Wickens et al. [101] theory.

Task-switching at high rates can result in the loss of important information and a reduced reaction time. While early models only identify a single attention filter, decomposing a task into multiple attention filters are currently more common (*see Figure 5*). Attention filters such as Effort, Motivation, Environment, and Familiarity [101] are responsible for the level of difficulty, and thus for the amount of attention required to fulfill a task. Therefore, a *Reflexive Interaction* is favoured when the required mental and physical effort of both tasks are low, when the user is motivated, when environmental interference's are minimal, and when the tasks are highly familiar to the user. In terms of human attention resources, we distinguish between multiple attention resources, which are divisible into three categories; Perception, Cognition and Action. Current contemporary theories and models on human cognition agree that the capacity of cognitive processing is limited and individually pronounced. However, Wickens' Multiple Resource Theory [100] and Van Erp's Prenav Model [93] provides alternative assumptions. Following Wickens, each sensing modality allocates its own resources. The stronger the interference of two tasks, the more common resources are claimed. Therefore, it is suggested to distribute attention to several other modalities. For instance, should a car driver be required to follow traffic conditions, it would be less demanding having additional directional aids not relying on a visual basis.

3.1.2 Interaction Model. Although many attention theories exist, they all commonly agree that focal / focused attention is consciously directed to a primary task. At the same time, however, abrupt changes that occur within our peripheral perception are recognizable, such as environmental changes or internal changes, without requiring significant cognitive effort. More complex theories on attention, developed from Wickens et al. [101], explained these phenomena with five types of attention: focused, selective, switched, divided, and sustained attention. However, this paper will follow Juola's theory [53] in which, only two levels of attention are distinguished; focal attention, which is demanded by the main task (Focused Interaction) and peripheral attention, which may be demanded by a secondary task running alongside the main task (Peripheral & *Reflexive Interaction*). Moreover, interaction between humans and computers may be characterized by an Implicit Interaction in which the user's attention is not required – *see Figure 6*.

3.2 Elaborating Interaction Concepts

We introduced a taxonomy relying on an attention-based HCI model – *see Figure 6*, which is similar to the one used by Bakker et al. [7] *(see also Figure 1)*. In this section, we further elaborate the interaction concepts by making use of two different example scenarios.

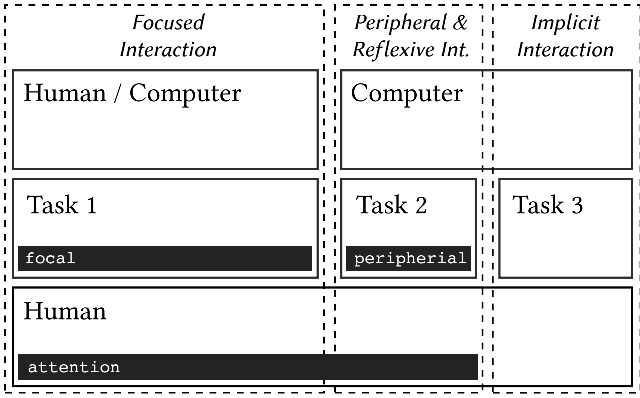

Figure 6: A model illustrating the relationship of Focused, Peripheral, Reflexive, and Implicit Interaction based on the user's involvement of attention.

3.2.1 Focused Interaction. When thinking of interaction, Focused Interaction is usually the first concept in mind. It is the most common interaction method within HCI. In a Focused Interaction, the user's focal attention is directed to a dedicated task.

Example 1: In an imaginative scenario, a stock-assistant in a logistics warehouse uses a hand scanner to scan the barcode of his chosen stock, a package (task 1). We assume that the package is being held in the left hand, while the scanner is carried and operated by the right hand. During the stocking and scanning process, the interaction process is monitored visually by the user. Perception, cognition, and action resources are fully devoted to the stocking task.

Example 2: In another scenario, we assume a pedestrian is walking along a path and intends to send a text message. Therefore, the phone is being taken out of the pocket and held by one hand, while the other hand may be used for text entry. Similar to the first example, the majority of attention resources are being demanded by the messaging task (task 1), while the hands and the eyes are preoccupied with the phone. A parallel task (task 2), such as walking, may co-exists, but does not receive focal attention.

3.2.2 Peripheral & Reflexive Interaction. Furthermore, there are possibilities to place a second interaction on the edge of the attention focus in the periphery, to minimize the cognitive load and to prevent distracting the user from the primary task. Since attention resources can distribute to those other than the primary tasks, peripheral attention can thus remain at a secondary task. While the term Peripheral Interaction was shaped significantly by the influence of Bakker [12] and Hausen [40], they allow a Peripheral Interaction to also attract full attention for short periods of time. However, in a *Reflexive Interaction* greater attention shifts would not occur, and the secondary task would remain within the peripheral attention only (*see Figure 6*).

Example 1: In re-using the scenario with the stock-assistant, a body-worn camera is used instead to identify the stock. An artificial intelligence, such as Alexa, would provide information about the stock via audio feedback. In a Peripheral Interaction, the user is still able to walk around, pick and place packages, while also providing input with voice commands. In this example, the user‘s attention would shift frequently between task 1 and 2, such as also to Alexa from time to time, particularly when giving voice commands. In another variation, a simple vibration under the foot would signal a wrong stock selection, while a quick foot gesture could confirm it. In this setup, the user‘s focal attention can always remain on the package, which is in their grasp, while keeping a record of their surroundings at any time. This scenario can be considered as a *Reflexive Interaction*, provided that the user already conditioned the interaction, and is thus able to quickly accomplish it with a certain automatism. These kinds of subtle interactions can be more convenient for the user. It may save time, increase efficiency, and be potentially safer, as the user's main interaction modalities, which are usually the hands and the eyes, are not being occupied. In this way, technology moves from the foreground to the background, of which Mark Weiser envisioned as a desirable technological interaction [99].

Example 2: In another mobile scenario, a user may use a Peripheral Head-Mounted Display (PHMD), such as Google Glass, while running a navigation application displaying a map. Small interruptions, by focus switches of the pupil from the real world to the displayed map, would still be considered a Peripheral Interaction following Hausen's definition [41]. In contrast, using a *Reflexive Interaction*, the user's pupil would not be required to focus on the PHMD and read the detailed information. Instead, a simple turn-by-turn path navigation could rely on colour changes of the display's background (e.g., blue=turn left; red=turn right), which are also perceivable by our peripheral vision (task 2). Moreover, pausing the application would be enabled by a quick eye-wink. In contrast, raising the finger to the glasses' frame using a sliding finger gesture and actively focusing the display would result in a Focused Interaction.

3.2.3 Implicit Interaction. The term Implicit Interaction was initially established by Albrecht Schmidt in 2000 [87] and exists as the polar-opposite to Focused Interaction. Implicit Interaction always incorporates an activity recognition component, which tracks the users' behaviour and the context. Collected data is subsequently processed and evaluated by an intelligent system and an output is generated. An Implicit Interaction thus occurs once the interactions are performed without demanding the user's attention. While the user may be conscious that an interaction may taking place in the background, an additional cognitive load is not created.

Table 1: Classifying interaction concepts into a 12-attribute taxonomy. This table aims to provide an overview, rather than being absolutely correct and complete. Sophisticated research is required to foster validation.

Criteria	Focused Interaction	Peripheral Interaction	Reflexive Interaction	Implicit Interaction
task complexity	high	moderate	low	any
attention & cognitive load	high	moderate – low	very low	non
interaction time	can be long	should be short	must be very short	any
multitasking	hard	easy	very easy	no restriction apply
task order	sequential	sequential & parallel	parallel	parallel
training required	not needed	helpful	necessary	non
awareness & consciousness	fully	partly	partly – non	non
interaction modalities	primary	primary & secondary	preferable secondary	primary & secondary
feedback	necessary	helpful	no need, but suggested	non
trigger	internal / system prompt	system prompt	environmental prompt	any contextual factors
context dependency	not needed	helpful	necessary	necessary
technical requirements	low	moderate	high	very high

Example 1: We again envision a logistics warehouse and a stock-assistant, who stocks packages on the shelf. While the logistics software is informed about the forthcoming stock, it also receives a broad stream of sensor data providing context knowledge, such as the current shelf the user is standing in front of. The system is capable of automatically registering the stock without requiring the user to explicitly scan the package's barcode, as the system fills up the electronic basket in the background (task 3).

Example 2: Again, in a mobile scenario, we envision a user typing a text message into their smartphone. While this action requires focal attention on the primary task (task 1), peripheral attention may be devoted to the user's surrounding to prevent accidents with other pedestrians (task 2). Based on the context information, such as the time of day and the user's vital parameter, an intelligent system may estimate the user's state. An estimation of the user's tiredness levels, for example, will thus result in an increased font size or a more sensitive auto-grammar-correction (task 3).

3.3 Classification

To better understand the concept of *Reflexive Interaction* in respect to common interaction concepts, we classified them in our introduced taxonomy based on 12 attributes *(see Table 1)*, which are:

Task Complexity: Focused Interaction occurs with tasks of a high complexity. Tasks that can be completed by Peripheral Interaction should be less complex. In contrast, *Reflexive Interaction* is only feasible with tasks of minor-complexity. The concept of Implicit Interaction allows any task complexities.

Attention & Cognitive Load: Therefore, the attention and cognitive load being created at a Focused Interaction is high. Peripheral Interaction aims to reduce attention to a moderate or low level. The cognitive load being created during a *Reflexive Interaction* is very low, which enables it to co-exist with other tasks. Implicit Interaction operates in the background and does not demand any attention and cognitive load, aiming to reduce them instead.

Interaction Time: The interaction time a Focused Interaction requires can be extensively long. In contrast, a Peripheral Interaction occurs in a short duration, such as within a moment. A *Reflexive Interaction* is executable in a fraction of a second. Implicit Interaction is not bound by any time constraints.

Multitasking: In a Focused Interaction, multitasking is hardly feasible. When being interrupted, we consider it as sequential multitasking, which is typical for a Peripheral Interaction. A *Reflexive Interaction* can co-exist by relying on a concurrent multitasking. In an Implicit Interaction, any type of multitasking is conceivable.

Task Order: In a Focused Interaction, as well as in a Peripheral Interaction, tasks are being completed in a sequential order. Both *Reflexive Interaction* and Implicit Interaction allow a parallel task completion.

Training Required: Tasks that are not internalized by the user require great attention, which results in a Focused Interaction. Training task executions favours an execution of tasks in a peripheral manner. To enable a *Reflexive Interaction* the task needs to be fully internalized, which requires a greater training and conditioning. This does not apply for Implicit Interaction.

Awareness & Consciousness: In a Focused Interaction the user is fully conscious and aware of their actions. While awareness can decreased in a Peripheral Interaction, the user is mostly conscious of their actions. In contrast, a *Reflexive Interaction* can be executed subconsciously or unconsciously. An Implicit Interaction occurs outside of the user's awareness.

Interaction Modalities: A typical Focused Interaction utilizes our primary interaction modalities, which demonstrate high information density (e.g., hands, eyes, ears,...). A Peripheral Interaction can rely on these primary interaction modalities, as well as on secondary channels, which demonstrate a lower information density (e.g., feet, limbs, nose,...). *Reflexive Interaction* preferably relies on these secondary interaction modalities. However, primary interaction modalities can also be used, once they are not occupied with the primary task. Implicit Interaction is not restricted to any interaction modality.

Feedback: A typical Focused Interaction requires a constant interplay of input and system feedback. Depending on the complexity of the secondary task, a Peripheral Interaction feedback is helpful, namely to increase precision. A *Reflexive Interaction* does not necessarily require additional feedback at the secondary task. However, a quick feedback is suggested. As Implicit Interaction is already providing feedback to the primary task, it does not employ additional feedback to draw attention to a deployed action.

Trigger: Focused Interaction can rely on an attention drawing system prompt or on an internal wish, which both trigger an explicit human intention. Similarly, Peripheral Interaction utilizes a system prompt or feedback as it can result in a series of user's reactions. In contrast, *Reflexive Interaction* is triggered by subtle environmental prompts, resulting in a quick user reaction only. Implicit Interaction cannot be explicitly triggered by the user, instead contextual factors are being utilized.

Context Dependency: A Focused Interaction does not need to utilize context information to demand the user's full attention. Utilizing context for a Peripheral Interaction, can be helpful to adjust the input and feedback strategies. A *Reflexive Interaction* heavily relies on context information, namely to understand whether deploying a *Reflexive Interaction* is feasible and which interaction modality to occupy. An Implicit Interaction heavily depends on context information to make adjustments and decisions on the user's task involvement.

Technical Requirements: A Focused Interaction can be implemented using any type information presentation and input interfaces. These do not need to be sensitive to the user's state or the environmental state. Peripheral Interaction requires more intelligent interfaces, being at least sensitive to the user's multitasking capabilities and aware of the status of other systems. Deploying a *Reflexive Interaction* is a greater technical challenge, since the device should be context-sensitive. This requires a variety of sensors and a certain intelligence. The technical challenge is even greater for implementing an Implicit Interaction.

4 RELATED WORK

We see *Reflexive Interaction* being a part of Peripheral Interaction, and thus finally introduce more background and alternative perspectives on Peripheral Interaction.

The research on Peripheral Interaction was largely influenced by Saskia Bakker and Doris Hausen with their dissertations [6, 41], numerous papers [10, 11, 42, 43]..., panel discussions, workshops [8], and books [7, 9]. In 2014, Hausen [41] defined Peripheral Interaction as the interplay between several tasks similar to multitasking, although there is a great difference. In the research field of multitasking, one usually focuses on interruption management, such as finding an opportune moment to interrupt the primary task with a secondary task [68]. *«In contrast, Peripheral Interaction can be applied to both, external and internal interruptions aiming at a reduction of cognitive and visual load and hence the effect of interruptions by embedding Peripheral Interaction into the user's daily routines»* as defined by Hausen [41]. Peripheral Interaction originated from Weiser's idea of calm technology, which envisions computers to be seamlessly integrated into all aspects of our everyday lives unobtrusively [99], and not in the center of our attention. When using computational devices, the user should be *«freed to use them without thinking and so to focus beyond them on new goals»* [98]. To achieve this, the idea of Peripheral Interaction places devices into the our attention's background, which is *«inspired by the way we fluently divide our attentional resources over various activities in everyday life... [while] the aim of Peripheral Interaction is to enable interaction possibilities with minimal attentional resources»* [7]. Thus, abrupt task interruptions can be minimized by seamlessly shifting the center of attention to a secondary task *«when relevant for or desired by the user»* [7]. A selection of other interpretations of Peripheral Interaction and its variations, is briefly introduced in this section.

4.1 Peripheral Tangible Interaction

In 2009, Darren Edge and Alan F. Blackwell introduced Peripheral Tangible Interaction to the HCI community [27]. Tangibles can be physical objects, which embody a digital system state that can be grasped for manipulation, while existing within the user's focus of attention. In contrast, the concept of a Peripheral Tangible Interaction, allows for an *«imprecise interactions with independently meaningful, digitally-augmented physical tokens»* [27]. These tokens can be freely arranged within the periphery of their workspace to be selected and fluidly engaged with, while existing away from the normal centre of attention. Edge's and Blackwell's goal was to *«design a TUI [(Tangible User Interface)] based on tangible objects that could drift between the focus and periphery of a user's attention according to the momentary demands of their activity»* [27] by combining the concept of a Peripheral Interaction and engaging tangible interactions. Still, when interacting with tokens, although being arranged on the desk in the periphery of the user's workstation, in the moment of interaction the focal attention can easily shift over to the tokens. This should not occur with *Reflexive Interaction*.

4.2 Microinteractions and Microgestures

In 2010, Ashbrook proposed the concept of "Enabling Mobile Microinteractions" to minimize interruptions [4]. He envisioned a tiny burst of interaction with a device lasting no longer than four seconds, to enable the user to return to the primary task [4]. Ashbrook considered motion-based gestures, such as finger gestures on a touchscreen of a wrist-worn device, while engaged in mobile situations. Although Ashbrook did not explicitly mention the term of Peripheral Interaction at that time, Microinteractions still fit into that continuum following Hausen's [41] definition. In 2011, Wolf [102] envisions Microgestures to be executable in the motor periphery, while the hands are performing a non-precise action, such as holding a mobile device, a digital camera, or grasping a steering wheel. Microgestures include the execution of finger movements, which are comparably quick gestures and often remain unnoticed by others. Microgestures yield the potential to be executable in a *Reflexive Interaction* when the fingers remain unoccupied by the primary task.

4.3 Casual Interaction

In 2013, Pohl et al. [77] proposes the idea of a Casual Interaction, being somewhat related to Peripheral Interaction as the user is engaged in multiple tasks. The core difference between both concepts is that a Casual Interaction can gradually shift from a focused task to a casual execution method, while reducing focal attention. Accordingly, the precision of the task execution is subsequently reduced also. To illustrate this concept, Pohl et al. describes a touch-sensitive colour picker that can be: (1) touched for fine-grained control, (2) hovered for setting at least the brightness and hue, and (3) gesticulated in greater distance for an abstract control. Another difference to Peripheral Interaction is that the user can make an active choice of engagement level, and therefore, *«the system is relieved from determining that level itself»* [78].

4.4 Peripheral Proxemic Interaction

In 2016, Vermeulen, Houben and Marquardt [94] summarize how to facilitate transitions between interaction outside the attentional field, the periphery, and center of attention by means of a so called "Proxemic Flow peripheral floor display". In their research, the authors combine Peripheral Interaction with Proxemic Interaction. The term Proxemic Interaction was mainly shaped by Ballendat et al. [13], Marquardt [61], and Greenberg et al. [35]. Proxemic Interaction means an extension of the classic vision of context awareness and the user's proxemic relationships (distance, orientation, movement, identity, location) to mediate interaction between people and digital devices, such as hand-helds and public displays. The authors designed Proxemic Interactions, to possibly enable the system to move fluently between the periphery and the center of attention. Similar to Bakker et al. [7], Vermeulen et al. [94] point out the overlap between Peripheral Interaction and Focused Interaction. In contrast to other research on Peripheral Interaction, Vermeulen et al. mainly concentrate on the user's ability to perceive visual information in a peripheral way, such as demonstrated with ambient light cues on the floor. Also visual peripheral perception can be utilized for *Reflexive Interaction*.

5 CONCLUSION & FUTURE WORK

In this paper, we introduced the idea of *Reflexive Interaction*, which in contrast to Peripheral Interaction, is bound to minor-complex input gestures and scaled notifications, which do not interrupt the user in his primary task. Therefore, considering context factors, such as the user's current state is imperative. The concept's feasibility is backed by literature, namely conditioning and multitasking (e.g., setting a car's blinker when arriving at the left turn lane demonstrates such the mechanism). Besides defining this previous blind spot *(see Figure 1)*, we also elaborated and precisely classified the existing interaction concepts based on 12 descriptive criteria *(see Table 1)*.

The manifestation of ubiquitous interactions within the future remains unclear. However, it is possible that alternative interaction techniques, involving more than the fingers and the eyes, will become the new norm. Mobile interaction will likely expand onto the human body, as envisioned by Harrison, who views the human body as an interactive computing platform [38]. On-body interaction yields a wide spectrum of advantages, such as two square meters of skin that can be manipulated in various ways (e.g., pressed, squeeze, inked etc.) [97]. *Reflexive Interaction* belongs in this continuum, as it offers a different perspective on mobile and ubiquitous interaction. Nevertheless, greater research needs to be conducted in the future to answer the following questions: What is the optimal number of assigned input gestures that can be internalized, while still enabling a *Reflexive Interaction*? How long will the learning phase be until a conscious execution of a gesture becomes internalized so it can be executed quick enough in a reflexive and reactive pre-attentive way? What would the context look like to prevent disturbances to the user, while presenting feedback and having the possibility to input gestures for a secondary task truly in parallel? What is the limit of complexity pertaining to gestures and notifications in order to still enable a *Reflexive Interaction*? How can notifications be conveyed to have a higher complexity but would not have a distracting influence on the user? How subtle can a feedback be to prevent distracting the user without being unintentionally ignored?

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