Design for the Periphery

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Abstract

In everyday life, we are able to perform various activities simultaneously without consciously paying attention to them. In line with Weiser and Brown s [25] vision of calm technology, we see major opportunities to leverage these skills in interaction with technology by designing interactions that can take place in the periphery of our attention. In order to design such interactions however, a detailed understanding of human attention skills is important. This paper therefore provides an extensive theoretical background on attention theory and links this to the design of interactive systems. The aim is to lay a basis for design-research on interaction design for the periphery.

1 Introduction

With the upcoming of pervasive technologies, the computer is becoming ubiquitous in everyday life. As a result, intelligence and thus information can be everywhere nowadays. However, with the traditional methods of human computer interaction (screens, beeps, keyboards, mouses and the like), we are at risk being overburdened with information. Emails, reminders, advertisement, the news, recommendations, all are trying to attract our attention. When we look at the physical world, a lot of information is present here too; the weather, the time of the day, street-signs, the activity of people around us. This information however, does not overburden us in any way. We can monitor it in the periphery of our attention, but also attune to it in the center of our attention if we wish. This allows us to be aware of what s going on around us without specifically attending to it. This human skill is frequently used in everyday life, but not often leveraged in interaction with technology (exceptions are [8, 15]). Therefore, we see major opportunities for this skill to be leveraged in order to avoid information overload. This direction is closely related to the vision of calm technology, which engages both the center and the periphery of our attention, and in fact moves back and forth between the two [25, p. 79]. We think this is a valuable approach to fitting new technologies into our lives, by leveraging human interaction skills gained in the real world.

From the second half of the twentieth century on, several theories of human attention skills have been developed. Though developed to gain insight in human capabilities from a psychological or neuro-scientific point of view, these theories also provide valuable insights for designers of interactive systems that leverage these skills in interaction. Currently only few studies in the area of calm technology are grounded in theory on human attention skills. However, in order to effectively design systems that can be perceived in the periphery as well as in the center of the attention, a detailed understanding of such skills may be valuable. This paper therefore aims at laying a basis for design-research on interaction design for the periphery, by linking an extensive theoretical background on attention theory to the area of calm technology and the combination of audio and physical interaction in particular.

2 Calm Technology

Most current computing technology is designed to be in the center of the attention. Particularly audio is frequently used for alerts, alarms and reminders [23] which are meant to attract the attention of the user. Weiser however, envisioned the interaction with the computers of the future vanishing into the background, so that we are freed to use them without thinking and so to focus beyond them on new goals [24, p. 3]. In other words, when we can perceive and interact with information from the computer in the periphery of our attention, computing technology can fit into our everyday life the way everyday information sources fit into our lives. This is what is meant with the term Calm Technology [25], which enables users to monitor information without specifically paying attention to it, while at the same time facilitating them to focus on it if desired. Weiser and Brown [25] use the inner office window, which connects the office to the hallway, as an everyday example of calm technology. This window allows all kinds of small informative clues: a lot of motion in hallway subtly informs you of an upcoming event and a light shining into the hallway late at night says that someone is working late. These clues are part of the ambience of the environment and are usually in the background but may be focused on if desired. Similarly, the aim of calm technology is to form a part of the ambience so that presented information can be perceived in the periphery. Some other terms have also been used to describe similar concepts. For example, Matthews et al. [12] use the term Peripheral Displays to describe computing applications that allow a person to be aware of information without being overburdened by it (p. 247). Ishii [7] uses the term Ambient Media to describe a class of interfaces that is designed to smooth the transition of the users' focus of attention between background and foreground (p. xx).

An early example of a calm technology design is the Dangling string [25], a plastic spaghetti string that hangs from the ceiling in an office context. The string is connected to a motor that will spin based on the information sent through the Ethernet cable. If the network is busy, the motor spins fast and if the network is not busy it will spin slowly. Therefore a visual and sonic representation of the business of the network is provided. Motion Monitor [12] is an example of calm technology that uses only visual information to engage the periphery; it is a ball that lights up in different colors resembling the amount of activity at a remote location, providing users with a sense of connectedness to friends and family. Other calm technology systems primarily use the auditory modality, for example audio aura [15], a system that informs office workers of information such as the availability of co-workers through background auditory cues. Birds Whispering [6] uses bird-sounds to subtly reveal information about the activity in the office. AmbientROOM [8] explored background monitoring of information through light, sound and movement in an office. The activity level of people on a distant location is displayed through shadows of rippling water on the ceiling or through light effects. Other information (e.g. the number of unread emails or the value of a stock portfolio) is displayed through a subtle soundscape of bird and rain sounds.

3 Attention Theory

In the 19th century, James [9] stated that everyone knows what attention is (p. 403), referring to the many different ways the word attention is used in everyday situations. Attention can be devoted to stimuli that we perceive through our senses (*sensorial attention*), but also to cognitive processes or thoughts (*intellectual attention*) [9]. The world around us is constantly full of stimuli that we can potentially attend to. Furthermore, our memory and reasoning capabilities add a large number of potential cognitive processes to undertake. As we cannot fully appreciate all that takes place at any one time [16, p. 6], a process of selective allocation of attention is needed to make sense of the world. As a result of this process, attended stimuli or thoughts will always be just a small fraction of all available streams [28].

Throughout the past decades, several models of this process of attention management have been developed in the areas of cognitive psychology as well as neuropsychology. Although various different functions of attention are distinguished in literature, the two most important functions described are *selective attention* and *divided attention* [17, 19, 27]. Selective attention is the process of selectively focusing the attention on one stimulus while intentionally ignoring others [19]. Models of selective attention therefore describe attention by analogy with a mental filter [27] that selects certain stimuli to attend to and rejects others. Such models are therefore often referred to as filter-models. Divided attention is the process in which we carefully divide our attentional resources over multiple attentional tasks at once [19], e.g. when multitasking [27]. Models of divided attention therefore see attention as a finite mental resource that can be divided over several sensorial or intellectual processes. Although these two functions of attention may not be mutually exclusive, we will first separately review literature on both functions. At the end of this section, we will present a model that captures our current understanding of the theory and that can be used to inform design-research in the area of calm technology.

3.1 Selective Attention

Selective attention theories usually only concern sensorial attention [17] and are often grounded in research on speech perception (e.g. [2, 14, 21]). In almost any given situation, several stimuli of multiple modalities will reach our senses simultaneously. These stimuli however, must be processed before they can be perceived. This processing, for example, enables us to distinguish our friend s voice from the voice of a passerby. In psychoacoustics this is called *auditory scene analysis* [1], which takes place when incoming signals are grouped into different streams based on the likelihood of them coming from the same source. Stimuli in other modalities are likely processed in a similar manner [1]. It is generally accepted that this form of processing is performed at an unconscious level of awareness, and happens before the process of attention starts to take place [28]. The attention theories we will describe in this paper therefore assume that incoming stimuli have been grouped into streams that can be attended to.

Selective attention theories describe attention as a mental filter. Influential early work by Cherry [4] forms the basis of a series of theories of selective attention [16]. Cherry s experiments [4] address the problem of selective attention, which he called the cocktail party problem referring to the situation at a cocktail party where one stands in a room full of sounds and is able to focus attention on a single conversation [19]. Cherry presented subjects with two spoken messages simultaneously and instructed them to attend to one message by directly repeating, or *shadowing* it. The other message had to be ignored, or *rejected*. As a result, Cherry found that subjects were able to almost entirely separate the two messages. Furthermore, the subjects did not remember any words mentioned in the rejected message. They could only recall that another message was present. Many researchers performed experiments similar to the ones performed by Cherry [4], which lead to a series of models of selective attention.

3.1.1 Early Selection Theory

Early selection theories suggest a limited capacity channel in the perceptual process that is only capable of handling one perceptual stream at a time [17]. The first well-known early selection theory was proposed by Broadbent [2], who suggested a selective filter in the brain that allows only one channel of information to pass and rejects others. One stream is selected based on the subjective attributes of the sound (e.g. pitch, volume). As became clear from Cherry s experiments, words in the rejected messages are not remembered. Broadbent s model [2] therefore assumes that the meaning of words is extracted after one stream has been selected [16]. The selection thus takes place early in the process, see Figure 1.

Late Selection Theory

In shadowing experiments similar to the ones performed by Cherry, Moray [14] showed that words that are important to the person in question (e.g. one s name) are consciously noticed when present in a rejected stream [16]. Counter to early-selection theory, this shows that the meaning of at least some words may be extracted before one channel is selected. Based on such evidence, an alternative theory was proposed by Deutsch and Deutsch [5], who suggest that the selection of attention is located later in the process, at a moment in which the meaning of all incoming streams has been identified [16, 19], see Figure 1. This late selection theory proposes that the identification process happens involuntarily and below the level of awareness.

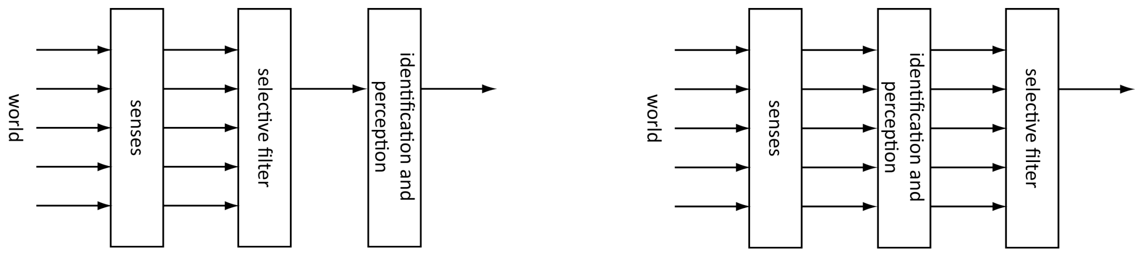

Fig. 1. Simplified illustration of an early selection model (left), adapted from [19, p. 94], and of a late selection model (right), adapted from [19, p. 96].

3.1.2 Attenuation Theory

Around the same time Deutsch and Deutsch [5] proposed their late-selection theory, Treisman [21] found that when words in the rejected channel are relevant to the information in the attended channel, they consciously or unconsciously influence the perception of the information in the attended channel. For example, listeners did notice words of the message in the rejected channel when the information was related to that in the attended channel [16]. Given the results of her experiments, Treisman [21] suggests that the selection process is among other things influenced by the relevance of the information in the incoming channels. She suggests that this happens through activations of the detector units for related concepts. This process is called *priming*. Based on the content of the information in the attended channel, related concepts are primed and therefore the threshold for identifying them is lowered. For example when having a conversation about a concert, related words such as the location of the concert, or the name of the performer may be primed. When a passerby says any of these words, one is more likely to recognize them and attend to this channel than when words with a less relevant meaning are heard.

Different from late-selection theories, Treisman proposes that the meaning of words in rejected channels is not identified before reaching the selective filter. Counter to early-selection theories however, Treisman [21] proposes a filter that attenuates unattended channels rather than completely blocking them. This way, a weakened version of these unattended channels is passed on [19]. Given the lower threshold for detecting primed stimuli, even an attenuated version of them is enough to be recognized and attended to. The idea of priming could also explain Moray s finding[14] showing that listeners tend to notice their own name in rejected channels; detectors for one s own name are primed, see Figure 2.

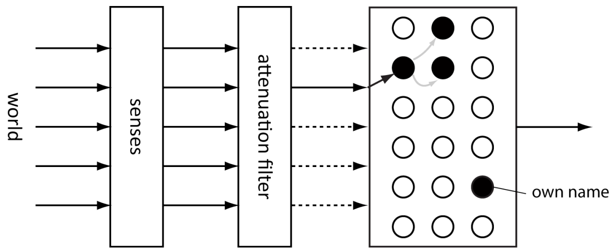

Fig. 2. Illustration of an attenuation model, adapted from [20, p. 25]. Representations of words in memory are illustrated by circles. Primed words, that have a lower threshold for being recognized, are illustrated by black circles.

The process of priming was already noticed by James [9], who referred to it as preperception. He illustrated this phenomenon by giving the following example. If I have received an insult, I may not be actively thinking of it all the time, yet the thought of it is in such a state of heightened irritability, that the place where I received it or the man who inflicted it cannot be mentioned in my hearing without my attention bounding, as it were, in that direction, as the imagination of the whole transaction revives [9, p. 449]. In other words, we may not only be primed for topics related to our current attentional focus or for stimuli that are generally relevant to us (such as our own name), we may also be primed for topics that are in the back of our minds for other reasons. Similar to the concept of priming is a process that Shallice and Burgess [18] call the supervisory attention system , when describing the selection of action and thought processes rather than perceptual stimuli. The supervisory attention system is in charge of top-down activation of schematic representations of actions or thoughts which increases the probability of them being selected.

Knudsen [11], who recently investigated attention in terms of neurobiological components, mentions top-down sensitivity control as one of the component processes fundamental to attention. Though describing a neurobiological phenomenon, this is rather similar to Treisman s idea of priming. The process of top-down sensitivity control increases the sensitivity of neural representations of attended information, which increases the chances of high signal strength at these representations. Knudsen [11] furthermore describes a bottom-up salience filter . Stimuli that are highly salient to us, such as a loud noise or a sudden flash of light, will pass this filter and can be attended.

Most psychology literature that summarizes attention theory address both early and late selection theories (e.g. [17, 20]). However, early selection theories cannot explain why relevant words in rejected channels are recognized. The amount of processing required to identify all incoming information in late selection theory on the other hand, does also not seem likely as most of the information is never used. Therefore, attenuation theory is often seen as the most plausible explanation of results of shadowing experiments ([17, 20]).

3.2 Divided Attention

As mentioned before, theories of selective attention usually only concern sensorial attention. Furthermore, most previously mentioned theories are grounded in research on the auditory modality only. Taking a broader approach, divided attention theories explain how we can perform multiple attentional tasks at once. These tasks may involve sensorial and/or intellectual attention and may include multiple modalities. Divided attention theories describe attention as the division of a limited amount of mental resources over different activities [19].

According to divided attention theory, the extent to which we can perform multiple tasks at once depends on the mental effort required for each task. The amount of mental effort needed decreases with practice and experience [27]. For example walking; when learning how to walk this activity requires a lot of mental effort and cannot be performed simultaneously with other activities. However, when we get more experiences, less effort is required and more can be done simultaneously. Highly trained processes such as walking require hardly any resources and are therefore called *automatic processes*. Such processes need little mental effort, involve no conscious control and many of these processes can be performed in parallel. On the contrary, *controlled processes* are processes that do require conscious control (such as reading a book). Only one controlled task can be performed at once.

A theory of divided attention proposed by Kahneman [10], suggests that resources can be allocated to any of the possible activities that one can perform as a result of information input (sensorial or intellectual). The amount of required resources may vary based on various aspects of the activity such as difficulty or automation. The distribution of resources over activities depends on a person s own intentions, as well as on so called *enduring dispositions*. This refers to relevant words such as our own name, or salient sensorial stimuli that attract our attention immediately such as a loud noise.

Furthermore, Kahneman [10] suggests a link between arousal and attention. The more aroused we are, the narrower our focus of attention will be. This means that as arousal increases, the attention to controlled processes increases, but also implies that the attention to automated processed decreases. For example, when we are highly engaged while reading a book, we may not notice any other streams of information, even when highly relevant information is present such as our own name. Another example: normally we are able to read (controlled process) and walk (automated process) at the same time, but when the reading task requires deep thought or causes high levels of arousal, we will often stop walking to focus on the reading [16]. This indicates that automated processes may require some attentional resources, though much less than controlled processes.

Though Kahneman [10] proposes only one kind of resource available for all tasks, Wickens and McCarley [27] describe multiple attentional resources, which may explain why certain tasks are more easily performed simultaneously than others. For example, driving while reading a book is more difficult than driving while listening to the same book being read to you.

3.3 Overview

The purpose of this theoretical overview is to gain a better understanding of human attentional processes and abilities in order to inform design for the periphery . Such designs are interactive systems that leverage these abilities so that information can be perceived without specifically focusing your attention on it. For this purpose, we have created an illustrative overview of the parts of the attentional process that we think are important in everyday life situations, see Figure 3. This overview is primarily meant to structure our own understanding of the process and is based on the above-mentioned literature.

We have seen that one may attend to sensorial stimuli (sensorial attention) or cognitive processes (intellectual attention). In many everyday situations however, an attentional activity may involve both sensorial and intellectual attention. For example when in a conversation, one will attend sensorial streams (e.g. listening to conversational partners, looking at their facial expressions) and intellectual processes (e.g. speaking, recalling information from memory). We will therefore not refer to streams that can be attended, but to *potential activities* which may consist of several kinds of tasks as well as involve multiple modalities. At any given moment in time, there will be multiple potential activities that we can attend to. These potential activities emerge from sensorial stimuli (e.g. hearing music makes the activity of listening to this music available or hearing a passerby speaking about politics may elicit potential thought processes about this subject) or from intellectual processes (e.g. planning to go call a friend or to take a shower). These potential activities form the center of the overview in Figure 3 and are represented by vertical bars of varying height and opacity. To keep the overview clear, Figure 3 only illustrates ten potential activities, however at any moment many more will be possible.

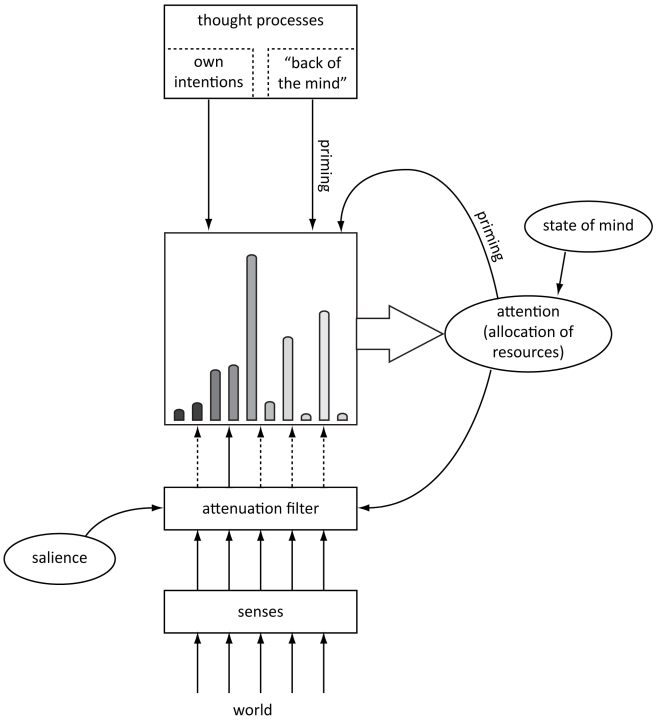

Fig 3. Illustrative overview of the attentional process, aimed to structure our understanding of this process to inform and support design for the periphery .

Obviously not all these potential activities can be performed at the same time. As suggested by divided attention theory, attentional resources have to be divided over these potential activities and only the ones to which resources are allocated will be performed. The height of the different bars indicates the resource demand of the activity, which is the amount of resources needed to perform the task. The opacity of the bars indicates the likelihood of recourses being allocated to that specific activity. The darker the bar, the more likely the activity is to receive resources. This likelihood is influenced by a person s own intentions (consciously deciding which activity to undertake) as well as by (unconscious top-down) priming which makes activities more likely to receive attentional resources. Primed activities are related to things that are generally relevant to us (e.g. our own name), things that are the current focus of attention or things that are in the back of our minds .

We discussed theories of both selective and divided attention proposed in literature. The difference between these two functions of attention is not straight forward. As a matter of fact, both selectivity and resource allocation characterize the attentional process [17]. Selectivity primarily seems to play a role in sensorial attention, whereas both sensorial and intellectual attention may involve resource allocation. We therefore suggest that the attentional process does involve a selective filter, but we define attention as the allocation of resources to one or more potential activities. In line with Treisman s attenuation theory, the filter illustrated in Figure 3 attenuates unattended incoming stimuli. This filter is influenced by the salience of incoming stimuli, for example a loud noise will pass the filter without attenuation.

The division of resources further depends on the state of mind of the individual, such as the level of arousal. Figure 4 illustrates the division of resources, and thus the attention, in two different situations. In these overviews, attentional resources are illustrated by white circles. In a situation is which one is highly engaged in reading a book, all attentional resources are allocated to this activity and no other activities can be performed (Figure 4a). A more frequently occurring everyday situation is illustrated in Figure 4b. In this situation, one s main activity is preparing dinner, but at the same time he is listening to the radio, looking at his watch and chewing chewing-gum. The other listed potential activities do not receive resources and are thus not performed. As illustrated in Figure 4b, not all recourses are used in this situation. At any moment one may (consciously) decide to call a friend or (unconsciously) be attracted to pay more attention to the radio as one s name is suddenly heard in that stream. This would change the recourse demand of some activities (e.g. carefully listening to the radio) as well as the priming of certain activities (e.g. when calling a friend while preparing diner, the relevance of monitoring the pans on the stove may become more relevant). This illustrates that the process of dividing resources over potential activities is highly dynamic and may in fact be at no moment a static overview.

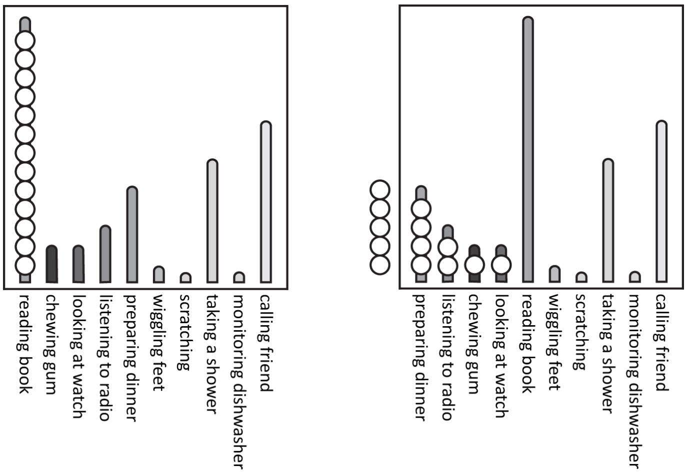

Fig. 4. Division of resources over different possible activities in two situations. **4a**: High attentional task reading a book (left). **4b**: A combination of low attentional tasks (right).

4 Center and Periphery of the Attention

In the previous section, we have presented an overview of our understanding of the attentional process, which may be useful to inform design for the periphery . This means, the design of systems that can be perceived or interacted with in the periphery of our attention, but also be focused on in the center of the attention. However, for such design processes to take place, it is essential to define what we mean by *center* and *periphery* of the attention.

In psychology literature reporting on attention [26, 27], the word periphery, which literally means external boundary or outward boundary [13], is generally used in the context of visual perception. In that area, the concept of peripheral vision refers to the parts of vision that occur outside the center of the visual field [26]. Vision in the center of the visual field is referred to as central or foveal vision [26]. Although visual displays are frequently used in calm technology designs, for example peripheral displays [12], authors in the area of ubiquitous computing often use the term periphery in a broader context. Brown and Duguid [3] describe how media contain peripheral cues that subtly direct users along particular interpretive paths by invoking social and cultural understandings (p. 131). These cues help us shape our expectations of the content. For example; by the cover, paper and typeface of a book we can determine if it is a novel or a study book. A little broader, Weiser and Brown [25] use the word periphery to name what we are attuned to without attending to explicitly (p. 79). Although this definition involves multiple modalities it is not yet very explicit, which we think is important to inform design processes.

As we describe attention as the division of resources over potential activities, we will explain the center and periphery of the attention in the same context, which is illustrated in Figure 5. What we see as the center of the attention is the one activity that most resources are allocated to. In the situation illustrated in Figure 5a, the center of the attention is the activity of reading a book, while Figure 5b illustrates preparing dinner as the center of the attention. The periphery of the attention consists of all potential activities that are not in the center, regardless of the number of resources being allocated to them. For example, in both situations illustrated in Figure 5, the activity of listening to the radio is in the periphery of the attention, while in situation 5a it is not performed and in situation 5b it is performed, be it with only a low amount of resources. However, the activity of listening to the radio is closer to the center in Figure 5b compared to Figure 5a, which means that it is more likely to shift to the center of the attention. As mentioned before, the attentional process is highly dynamic; the resource demand, priming and proximity to the center of each potential activity (represented by respectively height, opacity and location of each vertical bar) are subject to constant change. For example when driving a car and having a conversation with a passenger at the same time, both the activity of driving and the conversation will constantly move between the center and the periphery of the attention.

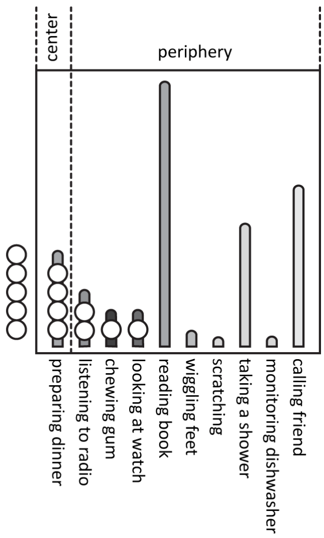

Fig. 5. Illustration of the center and periphery of the attention in two situations. **5a**: High attentional task reading a book (left). **5b**: A combination of low attentional tasks, in which not all available resources are used (right).

5 Design for the Periphery

As a result of the theoretical overview provided in this paper, we have defined attention as the division of attentional resources over potential activities. Furthermore we have described the *center* of the attention as the one activity to which most resources are allocated and the *periphery* of the attention as all remaining potential activities. Most current interaction with technology takes place in the center of the attention: screens, beeps, reminders, ringtones and keyboards are all designed to attract the attention. As information provided by the physical world is often perceived and interacted with in a much less obtrusive way, we see major opportunities for leveraging above describe human attention abilities in interaction with technology. This is what we refer to as design for the periphery .

The value of design for the periphery primarily lays in the idea that potential activities (related to interactive technology) can reside in the periphery of the attention, where they hardly require resources. However, when such an activity becomes relevant to the user, it may shift to the center of the attention and intentionally be performed. The weather is an everyday life example of this phenomenon. Information about the current weather will in most situations be available in the periphery, but when it becomes relevant (e.g. when one is about to go for a walk) or extraordinarily noticeable (e.g. a sudden storm), it will shift to the center of the attention. When designing the display of information that may shift between the periphery and center of the attention, it is important to think about how these intended shifts may be facilitated. A principle that may be drawn upon is that of salience, which ensures that extraordinary stimuli (e.g. loud sounds, sudden movement) are immediately noticed (see Figure 4).

Drawing upon salience however would not exactly contribute to technology being calm and unobtrusive. A more interesting principle to draw upon would be the idea of priming, which lowers the threshold for perception of stimuli that are relevant based on the current center of attention, things that are in the back of one s mind or intrinsically relevant stimuli such as one s own name. It would therefore be interesting for design-research in this area to address the design of stimuli for which priming may naturally occur or that may facilitate a learning process that could lead to priming after some experience has been gained.

Apart from stimuli that can shift from the periphery to the center of the attention, certain stimuli may never shift to the center even though they may influence the activities in the center of the attention. To take the example of the weather information again, one may never consciously attend to weather related information provided by the world around him, but still know that the sun is shining. This knowledge may influence his conscious activities such as deciding to go out for lunch. When designing this kind of peripheral stimuli, the principle of priming will not play a role, but the clarity of the designed stimuli will be of crucial importance as these stimuli likely need to be learned to reside in the periphery. An iterative design process could help in successfully designing such stimuli.

Since we have taken a broad definition of the term periphery, designing for the periphery may head into different directions. One of these directions could address the design of information displays that are intended to be perceived in the periphery of the attention. This direction relates to the area of peripheral display [12], which primarily uses the visual modality for information display, and in the area of calm technology [25], in which also examples that use audible information are known (e.g. [8, 15]). Furthermore, the tactile modality may be interesting to explore in the context of design for the periphery. Apart from perceiving sensorial stimuli, potential activities in the periphery may also be elicited by cognitive processes, such as tying your shoelaces in the periphery while watching TV in the center of the attention. An alternative direction may therefore address the design of interactions that can be performed in the periphery of the attention. As we are very skilled in manipulating objects with our hands, tangible interaction [22] seems to be a relevant interaction style for this purpose.

6 Conclusion and Future Work

In this paper, we have reviewed literature on calm technology and given an overview of attention theory. We have described our understanding of the attentional process, as well as of the center and periphery of the attention. Furthermore, potential directions for design for the periphery , which we see as a valuable approach for fitting new technologies into everyday life, have been discussed. We now have a detailed theoretical understanding of human attention abilities, which lays a basis for future design-research work in this area. Our next steps will therefore involve iteratively exploring the design space of the proposed directions.

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