Move-it: Interactive Paperclips Turning a Passive Piece of Paper Into an Active Medium

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Hagenberg, am 26. September 2011

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Preface

At this point, I would like to express my gratitude to all the people, who gave me the possibility to complete this thesis. All those, who inspired, motivated, and supported me. All those, who had so much patience with me when I was bound up in my work yet again. All those, who helped me sort out my thoughts, and made me focus on the essential to find my way through the boundless possibilities of science and research. All those, who made me take my mind off things from time to time and brought me down when I had my head in the clouds. And further all those, who pretended interest so amiably when I told them stories from a world of metals with a memory, intelligent paperclips, and wiggling Post-it notes. Finally, let me conclude by quoting an ancient Far Eastern fable, dedicated to a special person, who supported me throughout the whole project:

> There was a frog that lived in a shallow well. *"Look how well off I am here!"* he told a big turtle from the Eastern Ocean. *"I can hop along the coping of the well when I go out, and rest by a crevice in the bricks on my return. I can wallow to my heart's content with only my head above water, or stroll ankle deep through soft mud. No crabs or tadpoles can compare with me. I am master of the smoking water and lord of this shallow well, What more can a fellow ask? Why don't you come here more often to have a good time?"* Before the turtle from the Eastern Ocean could get his left foot into the well, however, he caught his right claw on something. So he halted and stepped back then began to describe the ocean to the frog. *"It's more than a thousand miles across and more than ten thousand feet deep. In ancient times there were floods nine years out of ten yet the water in the ocean never increased. And later there were droughts seven years out of eight yet the water in the ocean never grew less. It has remained quite constant throughout the ages. That is why I like to live in the Eastern Ocean."* Then the frog in the shallow well was silent and felt a little abashed.

Kurzfassung

Viele Menschen verlassen sich heutzutage nach wie vor auf traditionelle Hilfsmittel wie Stift und Papier, um kurze Notizen zu machen. Besonders Post-it Haftnotizen sind eines der beliebtesten Papiermedien für informelle Notizen und können allein durch ihre Präsenz hervorragend als passive Erinnerungshilfen dienen. Leider bieten die Haftnotizen jedoch keine direkte Unterstützung für die aktive Erinnerung an wichtige Ereignisse und Aufgaben. Digitale Anwendungen können uns im Gegensatz dazu wichtige Informationen bei Bedarf aktiv bewusst machen, ziehen aber andererseits die Konfrontation mit Arbeitsunterbrechungen (Interruptions) nach sich, die ständig um unsere Aufmerksamkeit konkurrieren.

Diese Arbeit beschäftigt sich mit der Konzeption und Umsetzung von Move-it, einem aktiven Papier-Interface, das die Vorteile von traditionellen Papiernotizen und die Möglichkeiten computerbasierter Systeme miteinander vereint. Durch die Kombination von herkömmlichen Post-it Notizen mit einer technologisch optimierten Büroklammer, kann das System einem Benutzer aktive Rückmeldung durch subtile Bewegungsreize geben und auf diese Weise ein passives Stück Papier in ein aktives Medium verwandeln. Im Rahmen von zwei Laborstudien wird darüber hinaus die Einsatzfähigkeit von Move-it Sticky Notes als periphäre Displays für die Signalisierung von Arbeitsunterbrechungen untersucht und mit etabliertem Pop-Up Feedback verglichen, das vorwiegend in kommerziell verfügbaren Anwendungen eingesetzt wird. Die Studienergebnisse zeigen, dass die Signalisierung von Arbeitsunterbrechungen durch die beweglichen Post-it Notizen als deutlich weniger störend empfunden werden. Negative Auswirkungen auf das emotionale Wohlbefinden und die menschliche Leistungsfähigkeit werden deutlich reduziert, und macht das vorgestellte System somit zu einer vielversprechenden Lösung für die Signalisierung von Unterbrechungen des menschlichen Arbeitsflusses.

Abstract

A lot of people still rely on pen and paper for taking short notes. Especially Post-it notes are one of the most popular paper media for informal note taking and serve as an excellent medium for passive reminding due to their physical presence. Unfortunately, they do not provide direct support if active reminding is required. Digital tools on the other hand, can proactively keep us aware of important information, but bring along the challenge of interruptions constantly competing for our attention.

This work presents the design and implementation of Move-it, an active paper interface that combines the affordances of note taking on paper with the capabilities of computer-based systems. By combining common Post-it notes with a technologically enhanced paperclip, the system provides active feedback to the user through subtle motion cues and turns a passive piece of paper into an active medium. In two experiments, the applicability of Move-it sticky notes as peripheral displays for human interruption is investigated. Compared to well-established pop-up feedback used in existing commercially available tools, the experimental results show that the moving paper notes cause significantly less disturbance on an interrupted primary activity. Negative effects of interruptions on emotional state and human performance are reduced considerably and make the proposed system a promising solution for effective human interruption design.

Chapter 1

Motivation

Although we are nowadays surrounded by many mobile devices such as tablet PCs, netbooks, and smartphones, paper still remains a ubiquitous means for informal note taking in professional or private context [73]. Whether it is a to-do list stuck to a workplace monitor, contact information jotted down during a telephone call, a sudden idea while riding on a train, or a short message attached to a pile of documents passed over to a co-worker, paper is often the means of choice. Informal notes thereby can be used for a variety of purposes including temporary storage, cognitive support and reminding. Digital interfaces on the other hand, provide affordances such as active feedback, easy distribution, storage, or searchability, that can not be offered by traditional paper notes. Nevertheless, numerous investigations show that people still exhibit a strong preference for paper-based over digital media since existing commercially available tools do not adequately support user needs related to informal note taking [9, 11, 16, 20, 81].

1.1 The Myth of the Paperless Office

In 1975, a *BusinessWeek* article [79] featured the then head of Xerox PARC, George E. Pake, making a series of predictions about the "Office of the Future" envisioning that within a few years, his office would be completely different:

> There is absolutely no question that there will be a revolution in the office over the next 20 years. What we are doing will change the office like the jet plane revolutionized travel and the way that TV has altered family life. [...] I'll be able to call up documents from my files on the screen, or by pressing a button, I can get my mail or any messages. I don't know how much hard copy [printed paper] I'll want in this world.

Affordance	Paper Notes	Digital Notes
Ease of Capturing/Annotation	x	
Flexible Content	x	
Portability/Mobility	x	x
Duplication/Distribution		x
Searchability		x
Context-Sensitivity	x	
Reminding	x	x

Table 1.1: The affordances of paper-based and digital notes.

Ever since then, people have claimed the *Paperless Office* being just around the corner. In fact, this revolution in office life did never occur. Paper consumption actually kept rising in the following years and for a number of reasons paper documents still remain an integral part of today's office work environments [73]. Due to its numerous affordances (see Table 1.1), primarily the intuitive interaction, or fast and flexible capturing of information anywhere and anytime, paper is often the preferred medium for informal note taking. Sketches, meeting notes, reminders, driving directions, phone numbers, passwords, or grocery items. With a pencil at hand, any kind of information may be instantly scribbled down on a scrap of paper or Post-it note, scrawled on the corner of a napkin, or jotted down in a paper notebook. In contrast to that, digital tools often can not provide the expressive freedom of pen and paper [11, 20]. For example, Cook et al. [16] found that designers preferred to use paper for brainstorming, annotation, and communication, because it was quicker and easier to use, more portable, and more useful for face-to-face collaboration than computer tools.

As paper is also highly portable, it supports mobile usage: just as easy as jotting down a note on a piece of paper, this note can then be folded together, stuck into our pockets and taken with us. On the other hand, as informal note taking is often closely tied to mobile scenarios where pen and paper may not be at hand. Thus, for note capturing in the mobile context, people often rely on smartphones or PDAs since nearly all of them provide some basic freeform note taking functionality [9]. Moreover, these digital notes are superior to paper-based notes when it comes to duplication or distribution. A digital to-do list may be accessed and manipulated easily from different devices in arbitrary locations, while there is no chance to access a paper-based grocery list intentionally left at home before heading to the supermarket. Likewise, searching for a paper document in a large physical archive is far more cumbersome than locating a particular file in a digital file system, or scanning a physical paper document for a particular keyword is not as convenient as opening a search mask and performing a

Figure 1.1: Two examples for paper notes placed in location-sensitive context: on a workstation monitor to remind a user of saving his work regularly (left), or on a refrigerator to remind household members of grocery items to be bought (right), cf. http://www.publicis.be.

keyword search on a desktop computer [20, 28, 43, 56, 72].

Another considerable benefit of paper is the natural support for enrichment with context information, a functionality that can only hardly be provided by digital tools [84]. Seemingly irrelevant details in a paper notes appearance like handwritten remarks, dog-ears, or even coffee stains can be unique characteristics and help people to quickly identify a particular piece of paper [50]. By placing paper notes in particular locations, they can moreover be provided with location-dependent context information [9, 11, 22]. In this context, Lin et al. noticed that Post-it notes are still the most popular paper media for informal note taking [49], as they provide additional affordances such as adhesiveness, compact format and attention-attracting color. These inherent features make them a very prominent form of paper: to-do lists, shopping lists, and appointment dates are often written on Post-it notes and stuck to prominent places as reminders (see Figure 1.1). For example, Bernstein et al. [9] report that they observed Post-it notes adapted to deliver contextually-relevant information by being stuck in the places or to the physical objects to which they referred e.g., people sticking Post-it notes containing useful information right onto their workstation monitors. Similar to that, unorganized piles of paper on an office desk may serve as reminders of unfinished tasks, or a household list pinned to the refrigerator in the kitchen may serve as a reminder for pending home-related activities [78]. However, while paper-based notes provide excellent affordances for passive reminding due to their physical presence [23], they do not provide direct support if active reminding is required [3, 28, 41, 56]. A digital tool can proactively remind us of important information by presenting a pop-up window or playing an alert sound. Paper-based reminders on the other hand, are passive and thus reliant upon people noticing them at the right moment.

Given these affordances of paper and digital notes summarized in Table 1.1, we were motivated to combine the strengths of the real and digital world and propose an active paper interface to provide a seamless user experience.

1.2 Metals with a Memory

New materials are the core of new design and developments in material science inspire new ways in which we interact and communicate by transforming the boundaries of what is possible and imaginable[1]:

> Imagine a future where the only tool in an auto body shop was a hair dryer! Or a damaged mail box could pop back into shape on a sunny day. A future where safety relief valves, such as sprinkler systems, would work every time. And a future of morphing surfaces, where submarines and aircraft could alter their shapes to improve performance over varying flight conditions.

All of these scenarios are possible due to the ability of smart materials to respond to changes in their surroundings. A unique class of smart materials are *Shape Memory Alloys (SMA)* that possess the ability to "remember" a pre-defined shape and can be made to return to this original shape, even under high applied loads, when temperature is increased. SMAs, specifically the most commonly used nickel-titanium (Nitinol, NiTi) alloys, are currently the most versatile shape-changing materials. They have been adopted for various applications in mainly industrial domains like aircraft, spacecraft and medicine to be used e.g., in self-expanding solar panels, cardiovascular stents, artificial bone implants, or orthodontic braces [46]. Even in our everyday lives we are surrounded by SMA technology. For example, thanks to their shape-changing abilities, coffee makers and rice cookers stop heating at the right moment upon reaching a certain temperature, or the frames of our reading-glasses can easily return to shape even after accidental bending.

This shape recovery behavior is referred to as the *Shape Memory Effect (SME)*, which describes the ability of a material to be deformed at low temperatures and return to its original shape upon heating. This effect is a result of phase transitions that take place while the material remains solid.

[1] http://www.mide.com

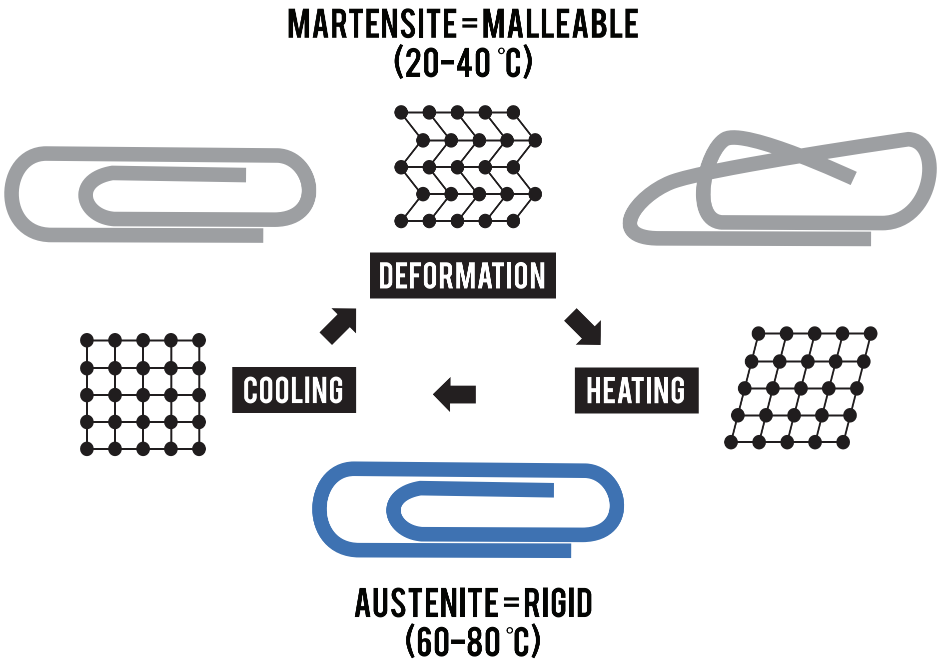

Figure 1.2: A shape memory alloy assuming different material and shape properties. Being malleable in the martensite phase, the SMA turns to austenite phase upon heating and recalls its memorized shape.

Normally, these phase changes occur when a material is heated to its melting resp. boiling point, like e.g., water changing its phase from solid over liquid to gas as temperature increases. However, in the case of SMAs, the phase transformation occurs at considerably lower temperatures through a rearrangement of the position of particles within the crystal structure. Thus, the metal does not change its aggregate phase, but instead retains its shape without melting. This solid state phase transformation is a transition from a *Martensite* to an *Austenite* crystal structure as illustrated in Figure 1.2. In martensite (low-temperature phase), an SMA is malleable and can be deformed into various shapes. Once heated above its transition temperature (60–80°C for a typical NiTi SMA), the crystal structure changes to austenite (high-temperature phase), the SMA becomes rigid and assumes its memorized shape. Finally, when the SMA cools down again (20–40°C for a typical NiTi SMA), it turns back to the malleable martensitic phase with no associated shape change, and the whole cycle can be repeated [46].

We think that shape-changing materials present exciting new opportunities and were inspired to exploit the dynamic properties of shape memory alloys to turn traditional paper into an active medium by equipping it with motion feedback capabilities.

In this work, we present the Move-it system, which combines the affordances of traditional paper and digital interfaces and extends it with active feedback functionality. To exploit the strength of both paper and digital devices, our setup combines common Post-it notes with a technologically enhanced paperclip, which can be moved and thus give active feedback to the user. Our contribution considers the design of an active paper interface, without modifying the paper itself. Rather than equipping the paper with various sensors [3, 15], our approach focuses on the development of a mechanism that provides the infrastructure to activate the paper to move, and thus preserves the fundamental affordances of paper as a low-cost medium for informal note taking. Our setup combines common Post-it notes *(Move-it sticky notes)* with a technologically enhanced paperclip *(Move-it ioClip)*, which can be moved and thus extend traditional paper with active feedback functionality. We illustrate the concept of giving active physical feedback with the design of three application scenarios in the context of reminding, information awareness, and localization support. Finally, we describe the results from two experiments, which evaluate the applicability of Move-it sticky notes as peripheral displays for effective human interruption.

Chapter 2

Related Work

2.1 Pen-and-Paper

The fact that traditional paper is still very popular yet partially inferior to digital systems [73], has inspired researchers to investigate the possibilities of enhancing paper with interactive features. Therefore, extensive effort has been invested in the research of finding ways to augment traditional paper by combining its unique affordances with affordances of the digital media, thus bridging the gap between paper and digital worlds. The *Paper PDA* project [33] is one of the first projects looking for ways to augment real paper with PDA-like functionality. It makes use of "paper widgets", which provide predefined areas for user input to invoke actions in the electronic world, e.g., sending e-mail messages or communication of contact information. *The Designers' Outpost* [42] shows a successful combination of paper and the physical workspace with the advantages of electronic media to support collaboration. The seamless integration of Post-it notes into a digital whiteboard and the digital annotation provide high level of flexibility and new ways of interaction with a traditional medium. Guimbretière [28] presents a concept of using paper and computers as two different ways to interact with *Paper Augmented Digital Documents (PADDs)*. Primarily used as digital documents, they are printed whenever the affordances of paper are needed and annotations to the physical documents are then synchronized with their digital representations. Similar to these examples, our system implements such a pen-and-paper interface to provide advantages such as light-weight note capturing, digital processing of handwritten strokes, and automatic synchronization in order to provide access to the functionality of digital tools.

Arregui et al. [3] have not only focused on linking printed and electronic content, but also the equipment of paper documents with sensors and communication abilities. Documents are tagged with RFID marks and can then be located easily or trigger alarms if certain conditions around the documents occur. Furthermore, other types of sensor such as accelerometers and magnometers are used to collect additional context information. However, despite the inspiring vision of locatable and traceable documents, feedback is still of digital nature only. Furthermore, comprehensive equipment is required to gather contextual information, which make the system lose the appeal of a low-cost paper interface. Unlike that, our system intents to preserve the fundamental affordances of paper. Rather than equipping paper with various sensors [3, 15], we seek to treat it as the cheap and lightweight medium that it is, which allows users to use commonly available Post-it notes as a cost-effective, convenient means of informal note taking. In this thesis, we focus on the utilization of an intelligent paperclip, which allows us to give active physical feedback rather than using digital feedback only. Once combined with an interactive paperclip, the Post-it notes are provided with additional I/O capabilities without modifying the paper itself.

Quickies [56] uses Post-it notes as an "input medium" for informal notes, which are digitized and processed automatically. Information is automatically integrated into Personal Information Management (PIM) tools like calendars, contacts, or to-do lists. In our setup, we aim to provide a similarly fluid transition between paper-based input and digital applications. Automatic synchronization and smooth integration into PIM tools are the key to provide standard paper notes with additional advantages of digital content such as easy searching or distribution. However, feedback provided by Quickies is of digital nature only as the paper notes remain passive. The *Smart Filing System* [72] on the other hand, demonstrates the connection of physical and digital documents and provides both digital and physical feedback. The system is composed of an electronically augmented physical filing cabinet containing interactive folders and a computer running a document management system. Feedback on a virtual folder matching the criteria of an enhanced search or currently viewed on the computer is indicated by a LED, which is attached to each interactive folder. Vice-versa, a button attached to the interactive folders enables navigation between virtual folders. Similar to this approach, our system tries to create affinities between physical Post-it notes and digital notes to invoke physical feedback if certain conditions are fulfilled. However, since perceptual research provides evidence that motion signals are more effective in attracting a user's attention than optical signals [7, 24, 61], we are giving feedback through physical motion cues.

2.2 Shape Memory Alloys

To provide the paperclip with the ability to generate kinetic movement, we make use of Shape Memory Alloy (SMA), an active material with actuation capabilities introduced in Section 1.2. The majority of HCI research involving shape memory alloys explores their use as actuators and presents new ways to generate motion, especially in architectural, artistic and robotic areas.

Kukkia and Vilkas [10] for example, are kinetic electronic garments deformed by integrated SMA wires. Playful scenarios like kinetic hemlines or animated flowers demonstrate the potential of animated clothes to function as e.g., interactive physical displays or reactive garments. *Caterpillar Locomotion* [80] describes the development of a "softbot" constructed from an elastic silicone rubber cylinder with SMA springs arranged in two serial rows on the sides of the soft body. Activating pairs of SMA springs makes the robot move in a simulated crawling motion of a caterpillar. Sugiyama et al. [77] propose a circular soft robot with a set of SMA wires inside, actuated to deform the soft body and thus create crawling and jumping motions. In contrast to these applications, our system deals with the motion of paper instead of textile or synthetic materials and thus proposes essentially different functional requirements regarding actuation force and frequency.

Another popular application of SMA actuators are three-dimensional displays [14, 57, 63] or SMA Motion Displays (SMD) [59]. Instead of changes in light as in visual displays, SMD replace the elements corresponding to light dots or pixels by SMA actuators. Triggering the actuators results in the motion of single "pixels" and can be used to display different three-dimensional shapes and textures. *Sprout I/O* [14] for example, is a haptic interface composed of an array of soft kinetic felt strands with the ability to sense human touch and move to display images and animations. Nakatani et al. [57] created a 3D shape display consisting of a 4×4 pin-rod matrix, where the height of each single pin-rod can be controlled individually to convey both visual and tactile information. Similar to that, *Lumen* [63] is an interactive visual and shape display that presents images through an array of movable light guides. Furthermore, interactive installations like the *plant* [59], *Himawari* [58] or *Hylozoic Soil* [8] investigate possibilities of moving robot plants, responding to human presence. Artificial leaves are controlled by SMA actuators and, combined with proximity sensors, react to movement of the human body with expanding and contracting motions. Inspired by these examples, we consider SMA technology as a lightweight, flexible and therefore promising alternative to conventional actuators such as servo motors [68] for the design of responsive physical interfaces.

For the construction of our intelligent paperclip, we moreover consider latest work of Koizumi et al. [44], who investigated ways of building moving paper prototypes. They developed an animated paper platform from paper and SMA, where small helix-type SMAs are attached to traditional Japanese Origami forms, shrinking and bending when heated and serving as actuators to create movement. The prototyping toolkit allows users to build their own creations and bring them to life by simply affixing actuators to the paper surface. Similarly, *Programmable Matter* [32] deals with self-folding Origami forms composed of a smart paper sheet with a triangulated flexible crease pattern. Triggering the attached thin-foil SMA actuators in a certain order, they demonstrate the paper sheet adopting basic three-dimensional Origami shapes. The *Sleepy Box robot* [71] is an interactive paper device constructed of two paper boxes resembling the body and head of a robot. The boxes are connected by an SMA wire that allows the robot to move its head in response to various stimuli. *Electronic Popables* [65] demonstrates the construction of paper-based SMA-driven Venus flytraps as part of an interactive pop-up book. In combination with a touch sensor, the flytrap can react to user touches with realistic open and close movements. Similar to most of these examples, our interactive paperclip uses a basic "bending style" [44] actuation, with the SMA shrinking and bending an attached sticky note when heated.

2.3 Peripheral Displays

Peripheral displays take advantage of the human ability to stay aware of things in the periphery and therefore provide users with awareness without distracting or disturbing them when engaged in a primary activity [85]. With Move-it sticky notes serving as peripheral displays, we move the information display off the screen into the user's physical environment and take the challenge of providing people with ambient awareness of such updates in the periphery of their attention. Numerous peripheral display designs provide awareness of diverse information sources manifesting themselves as subtle visual or auditory changes. For example, Matthews et al. [53] designed and implemented a *Peripheral Display Toolkit (PTK)* providing architectural support for key features of peripheral displays. They present a number of applications designed with the PTK, for example the *Bus Mobile* giving users a sense of how much time is left until a bus reaches a chosen bus stop, or a 'Social Guitar' providing an audible indication of activity levels in remote spaces. *AuraOrb* [2] notifies a user of incoming e-mail messages through a spherical ambient notification device. Sensing whether the user is attending to the notification device, it determines an appropriate notification strategy and delivers information by progressively changing between notification levels. These notification levels range from subtle colored light to announce incoming e-mails, over displaying subject and sender of the e-mail when the user looks at the notification device, to opening an e-mail message window when being touched. Motivated by this approach, we designed an application scenario for Move-it sticky notes to notify a user about scheduled meetings or deadlines and draw his attention by subtle wiggling motion of Post-it notes.

De Guzman et al. [21] explored the design of peripheral displays in the context of instant messaging. They designed four different physical clients embedded in everyday physical objects in the user's environment. An expanding ball, a spinner, a picture frame and a wind chime serve as tangible peripheral displays of awareness information and communicate IM contacts' availability. *LumiTouch* [13] is an emotional communication device, utilizing a traditional picture frame augmented with glowing lights to indicate remote presence of people. Similarly, *BuddyWall* [67], is an ambient wall-mounted communication device providing awareness of the presence of others. Tangible "Buddy" objects can be placed in a wall-mounted panel and communicate the availability of a remote friend by changing its brightness according to the friend being online, away or offline. Inspired by that, we designed another application scenario for Move-it sticky notes to represent the availability of a remote contact by physical deformation of Post-it notes.

However, among the multitude of peripheral display designs, there are only few displays mainly conveying information through motion. One of them is the *Infotropism* [35] project, which utilizes bending of artificial plants to represent contributions of recyclables to a recycle container to improve people's recycling behavior. Similarly, *Breakaway* [40] is an ambient display designed to improve people's sitting behavior. Their concept of using the pose of a small vellum sculpture as an abstraction of a user sitting for too long, indicates when it is time to take a break. Motivated by these examples, we seek to use our intelligent paperclip as an ambient notification device allowing users to maintain awareness of certain information. We designed three different application scenarios with the paperclip communicating information about scheduled events, changes in a remote contact's availability or the location of paper documents through subtle motions thus providing awareness and reminding users in an unobtrusive way. As proposed by Elliot et al. [23], our intelligent paperclip functions as *Location-dependent Information Appliance*, additionally providing the sticky note with location context. They introduce the concept of *Flexible Ambient Displays*, that allow different information sources to be mapped into their features. For example, the *Flower in Bloom* opens and closes, the *Glow Lamp* changes color by rotating its shade or the *Ambient Beads* move up and down the monitor to communicate information. In our case, the ioClip itself becomes such a flexible ambient display to be equipped with flexible information sources such as appointment notifications, to-do lists or contact information. Depending on the information source, the system chooses an appropriate actuation method, and generates kinetic movement turning the attached paper note into an active physical reminder.

Chapter 3

Application Examples

To demonstrate the versatility of the Move-it system, we have designed and implemented three different demo applications with three specialized types of Move-it sticky notes depicted in Figure 3.1.

- *Mind-it sticky notes* for active reminding,
- *Watch-it sticky notes* for information awareness, and
- *Find-it sticky notes* for interactive bookmarking.

Each of these applications was developed to cover a specific everyday scenario and solve common workplace-related problems by a novel approach of combining the advantages of both physical and digital interfaces.

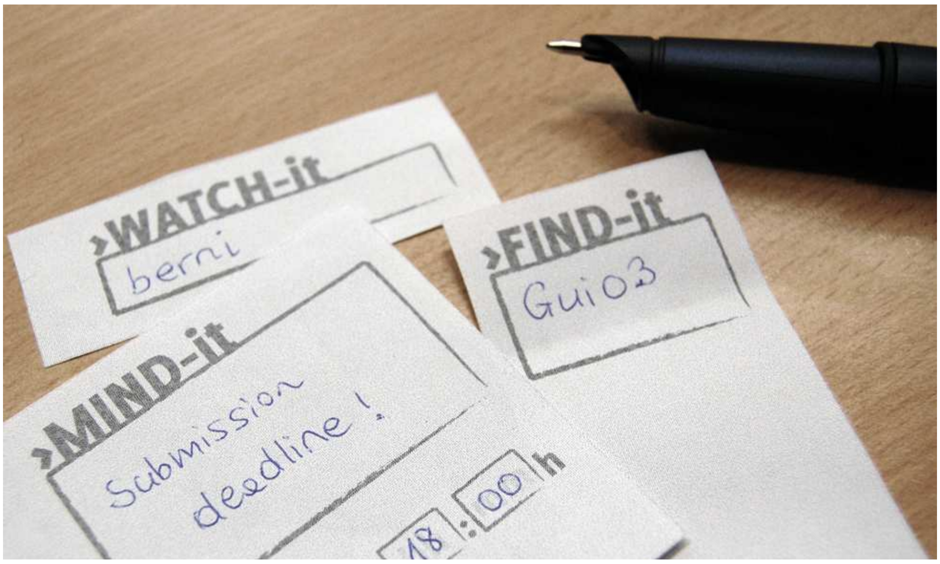

Figure 3.1: Move-it sticky notes for three exemplary application scenarios: Mind-it sticky notes for active reminding, Watch-it sticky notes for information awareness, Find-it sticky notes for interactive bookmarking.

3.1 Mind-it Sticky Notes for Reminding

The typical office worker is often confronted with a huge amount of information, tasks, and activities that he must remember to deal with. This results in growing lists of things to be done, often in parallel and in rapid succession. As a consequence, people use reminders as memory aids to inform them about some future activity that they should engage in. They use reminders to signal others and themselves that an approaching event needs to be attended, or that a task needs to be done. Over the course of time, this has led to the adoption of various memory-augmentation mechanisms ranging from traditional media such as paper notes, to digital representations such as e-mail, to-do lists, calendar entries, or electronic bookmarks [9, 11, 22, 25, 27, 29]. For example, a popular memory aid is the "note-to-self", traditionally embodied as a piece of paper that is annotated with information to be remembered and placed in the way of a typical routine to promote visibility. Likewise, people are also arranging printed documents in piles on their desk to serve as reminders of unfinished tasks. Unfortunately, these paper notes only serve as passive reminders and people are still responsible themselves to become aware of the reminder at the appropriate time. Investigations show that people exhibit a strong preference for paper-based reminders, mainly due to the intuitive and lightweight capturing process. Furthermore, the tangibility of paper makes it easy to position reminder notes in virtually any place, which lends paper-based reminders the unique advantage to be associated with context information. On the other hand, users currently have a number of electronic tools and strategies at their disposal to help them keep track of reminders. Personal information management (PIM) tools such as electronic calendars and to-do lists are especially designed to support reminding of tasks and events. Unlike the previously mentioned memory-augmentation strategies, PIM tools provide mechanisms to proactively trigger reminders at appropriate times. For example, dialog boxes pop up when a scheduled calendar event approaches or the due date for a to-do item is near. Moreover, PIM tools support digitally represented to-do items to be accessed anywhere and anytime in distributed working environments. However, despite the numerous advantages of PIM tools, the electronic capturing process is far from being as intuitive, flexible, and lightweight as scribbling a note on a piece of paper. For that reason, people often have difficulty dealing with electronic reminder systems and still exhibit strong preferences for paper-based reminders in many situations. Furthermore, researchers have found that people often develop practices with existing commercially available applications to support memory needs. For example, the e-mail inbox is often used as an informal to-do list. People are marking e-mails as unread, leaving them unorganized in the inbox, flagging them as to-do items, or even sending messages to themselves to remember things to be done. Unfortunately, similar to paper-based reminders, these rather unconventional practices lack the ability

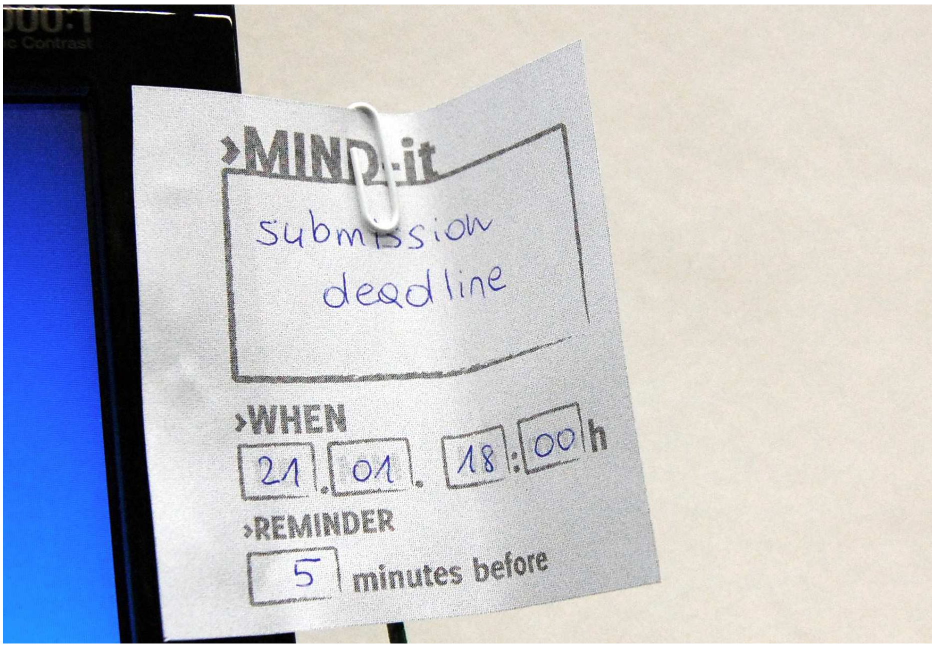

Figure 3.2: A Mind-it sticky note for active reminding. Once the deadline for a specified event approaches, the sticky note proactively reminds the user by a subtle wiggling motion.

to proactively remind people when e.g., a task needs to be accomplished.

Mind-it sticky notes are especially designed to help people reduce forgetting the details of important information throughout their busy lives, i.e., support them in reminding appointments, events, or tasks to be done. By combining a Mind-it sticky note with a Move-it ioClip, the sticky note becomes a location-based active reminder. So, for example, a Mind-it note can us five minutes before the start of a scheduled meeting by a subtle wiggling motion as depicted in Figure 3.2. Mind-it sticky notes follow a novel approach of merging physical and digital interfaces to combine the advantages of common memory-augmentation strategies mentioned before. Just like traditional sticky notes, Mind-it sticky notes are captured in a familiar manner through handwritten annotation, exhibit passive reminder functionality due to their mere presence, and can be placed in arbitrary places and associated with (location-based) context information. Even more importantly, the interplay of the physical Post-it note and the intelligent paperclip extend the passive reminder functionality with the ability to draw a user's attention by giving active physical feedback. Just like common PIM tools, Mind-it sticky notes are therefore able to proactively remind people at appropriate times, and their digital representations can be easily duplicated and distributed.

3.2 Watch-it Sticky Notes for Awareness

Another characteristic of modern professional work is that it is very communication intensive. A typical information worker has many spontaneous (virtual and real) communications with multiple individuals over the course of a working day and for this purpose often uses computer-mediated communication tools like e-mail or instant messaging (IM). The use of such communication tools goes hand in hand with an increasing amount of people's cognitive resources being allocated by constant monitoring activities to maintain awareness of incoming messages or online status updates. Consequently, to relieve the cognitive load of constant monitoring, it is often desirable to get notified whenever an incoming message arrives or a certain IM contact's availability status changes to "online". Unfortunately, these computer-mediated notification mechanisms are prominent sources for human interruption. This results in a huge amount of notifications constantly interrupting the user during his work, which is often perceived as disrupting and annoying. For example, e-mail preview windows usually pop up when a new message arrives or changing system tray icons may indicate new mail by changing their appearance. In the context of instant messaging, windows pop up when a conversation is initiated or small pop-up windows appear for a few seconds to inform a user of a changing IM contact's availability.

Addressing this problem, Watch-it sticky notes are designed to support support users by providing ambient awareness of the availability of another person. Once associated with an information source, the sticky note can provide an active status feedback by subtle movements. For example, Figure 3.3 shows that a Watch-it note can inform us about the online status of our favorite Skype contacts by changing shape accordingly. Similar to Mind-it sticky notes, Watch-it sticky notes provide a number of advantages over conventional awareness mechanisms provided by today's e-mail and instant messenger clients. First of all, the information is moved off the screen and represented by a simple Post-it note in the periphery of a user's environment. Thus, the Watch-it note becomes a peripheral display that informs a user about the availability of IM contacts without occupying any space on a user's working screen. Just as with Mind-it sticky notes, simple handwritten notes serve as information sources and are automatically associated with their digital representations. Especially in the context of instant messaging, Watch-it sticky notes furthermore provide the unique possibilities of selection and enrichment with context information. Since people are usually only interested in the availability status of a few IM contacts, Watch-it sticky notes can be used to pick a selection of a few particular contacts to be monitored to prevent information overload produced by status updates of other contacts. Furthermore, these contacts can be grouped by sophisticated spatial arrangement or color coding and thus provide additional context information. According to that, we can for example establish different contact

Figure 3.3: Two Watch-it sticky notes for information awareness. Each IM contact is represented by a Post-it note, once the contact's availability status changes to "online", the sticky note smoothly changes shape accordingly.

groups for work colleagues, clients, friends etc. by assigning the single Watch-it sticky notes an appropriate spatial position close by each other or same color. Finally, Watch-it sticky notes inform a user about status updates by subtle physical feedback represented as smooth changes in shape. Designed to be just as intuitive as looking out of the window to determine the current weather conditions, one glance at the sticky note allows us to determine the availability of the associated IM contact.

3.3 Find-it Sticky Notes for Bookmarking

As mentioned in the previous application scenarios for Move-it sticky notes, desktop-based applications like information management and communication tools become more and more popular and make their way into today's offices. However, despite the many past predictions envisioning a paperless office of tomorrow [73], paper still remains an integral medium of today's office work. Unfortunately, even though paper brings along a lot of advantages, there are still some problems to be dealt with. The mechanisms for storage and retrieval of paper documents have not changed over the past years and largely rely on the use of physical folders and filing cabinets, which makes them relatively cost- and time-intensive.

Find-it sticky notes try to address this problem, by combining the affordances of paper notes with features of digital interfaces like low-cost storage and searching. Just like common Post-it notes, Find-it sticky notes can be used as bookmarks in books, folders, or documents to highlight important sections and quickly retrieve them later on. Furthermore, Find-it sticky notes provide the ability to provide active feedback to the user upon request. The

Figure 3.4: Two Find-it sticky notes for interactive bookmarking. Once a search request matches a keyword written on the Post-it note, the sticky note provides active feedback to the user by a constant wiggling motion.

combination of a Find-it sticky note with a Move-it ioClip enables them to facilitate the retrieval process of paper documents by giving active feedback upon request. For example, a Find-it sticky note can help us to retrieve a particular bookmark in a book matching a requested keyword as shown in Figure 3.4. Since the physical notes are automatically associated with their digital representations, a search request can be performed conveniently using a common keyword search feature on a desktop computer. Find-it sticky notes matching the request may then support the document retrieval process by exhibiting a permanent wiggling motion to signal the match. This way, documents containing the relevant information can be found easily. In the fashion of the previous application scenarios, the annotation process remains as intuitive as with common pen and paper, physical and digital representations of a Find-it sticky note are associated automatically, and the note is clearly visible to the user through active physical feedback.

3.4 The Affordances of Move-it Sticky Notes

This chapter introduced just three of many possible application examples for the Move-it system. Nevertheless, the flexibility of the system allows virtually any information source to be captured on Move-it sticky notes and monitored to provide active physical feedback triggered by the occurrence of a specified event. Similar to the Mind-it scenario, sticky notes attached to the ioClip could notify a user of incoming e-mails, tweets, RSS feed updates, expiring online auctions etc. by a subtle wiggling motion. Likewise, the Watch-it scenario could easily be extended to areas like monitoring of information (e.g., e-mail inbox quota, computer memory usage, battery level, stock values, or weather).

Summarizing, all types of Move-it sticky notes have one thing in common: combining the advantages of physical and digital interfaces, they provide a number of unique affordances, the *Affordances of Move-it Sticky Notes*:

- *Lightweight note capture* through familiar handwritten annotation.
- Easy positioning in arbitrary places and consequent enrichment with (location-based) *context information*.
- Easy (re)arrangement and support for grouping through spatial arrangement or color coding due to the *tangibility of paper*.
- Digital processing of written input and *automatic synchronization* and integration with PIM and communication tools.
- The ability to provide *active physical feedback* and draw a user's attention, once associated with a technologically enhanced paperclip.

To go even further, our intelligent paperclip could be used as a kind of *Location-Dependent Information Appliance* and the Move-it ioClip itself could serve as *Flexible Ambient Display* to be equipped with flexible information sources [23]. We can very well imagine a home or office of tomorrow integrating numerous *Move-it Hot Spots*, providing the infrastructure of a Move-it ioClip to be equipped with Move-it sticky notes. These hot spots provide both valuable location context, while serving as both passive and active reminders. Move-it hot spots can be established in popular places near refrigerators, fixed phones, entrance doors etc. and provide active motion feedback. For example, imagine sitting at home on the sofa watching TV while being able to maintain awareness of the online status of your favorite IM contacts in the periphery, which are represented by several shape-changing Watch-it notes attached to a Move-it hot spot in the living room. Likewise, a wiggling Mind-it note attached to a Move-it hot spot in the kitchen could remind actively of the approaching expiration date of some food in the refrigerator. However, these are just a few real world examples for the usage of the Move-it system in the home and office domains.

Chapter 4

The Move-it Active Paper Interface

4.1 System Design

The Move-it active paper interface combines enhanced Post-it notes (*Move-it sticky notes*) supporting identification and processing of handwritten notes with an intelligent paperclip (*Move-it ioClip*) supporting recognition and movement of Move-it sticky notes attached to it. The Move-it desktop application combines these two components and enables the Move-it system to provide active feedback to the user. Figure 4.1 illustrates the workflow of the Move-it system, starting with Move-it sticky notes being annotated with handwritten notes right through to the Move-it ioClip being actuated upon occurrence of a specified event.

- First, handwritten notes are captured on traditional paper using a digital Anoto pen. The strokes are transmitted to the Move-it desktop application, processed using handwriting recognition, and then interpreted and synchronized with personal information management (PIM) tools. The recognition process is described in detail in Section 4.1.1.
- Next, the Move-it sticky note is ready to be combined with an intelligent Move-it ioClip, which identifies each sticky note uniquely by processing a graycode on the backside of the note. Once identified, the Move-it desktop application is able to establish a distinct association between the digital notes and the physical paper note. The identification process is described in detail in Section 4.1.2.
- Finally, upon occurrence of a specified event (e.g., at a particular point in time, upon request) the Move-it ioClip gives active motion feedback by actuating the shape memory alloy attached to the paperclip. The actuation process is described in detail in Section 4.1.3.

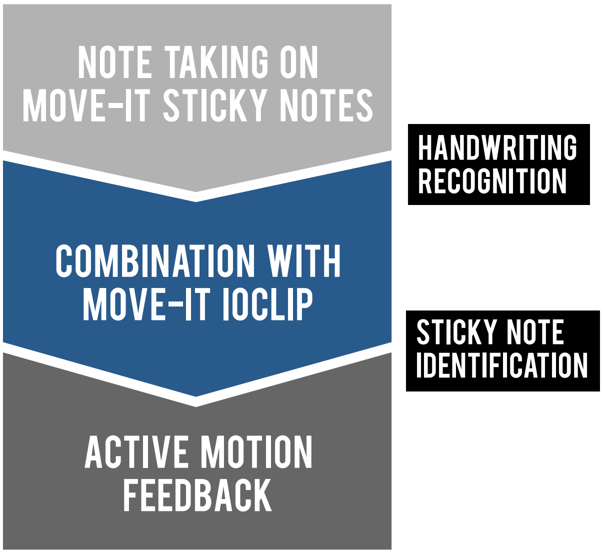

Figure 4.1: The Move-it workflow. Handwritten notes are taken on traditional paper (and digitally processed using handwriting recognition), Move-it sticky notes are then combined with (and uniquely identified by) the intelligent paperclip, which finally triggers active motion feedback upon occurrence of a specified event.

4.1.1 Tracking the Handwritten Notes

With Move-it sticky notes, the note taking process is as convenient and familiar as with traditional pen and paper as depicted in Figure 4.2. Notes are captured using a digital Anoto pen, with an embedded infrared camera, processesing a unique dot pattern that each Post-it note is covered with. The digital pen looks and feels like using its normal ballpoint counterparts, but provides additional abilities of capturing and converting ink to digital data, which is then transferred via Bluetooth to the Move-it desktop application for further processing. The application converts the strokes to text using Microsoft's handwriting recognition SDK and classifies the written strokes, which are then synchronized with a PIM tool, i.e., Microsoft Office Outlook. Consequently, the note is visible in the calendar or to-do list of Outlook as well as on the physical Post-itİn our current implementation, Move-it sticky notes structure information by defining a printed input layout with distinct input areas (e.g., subject, content, due date) to be filled with written notes. As a result, the reliability of handwriting recognition and note classification is maximized and definition of all required information is ensured while at the same time preserving the simplicity of note taking on traditional paper. Implementation details of the recognition, classification, and synchronization processes are discussed in Section 4.3.

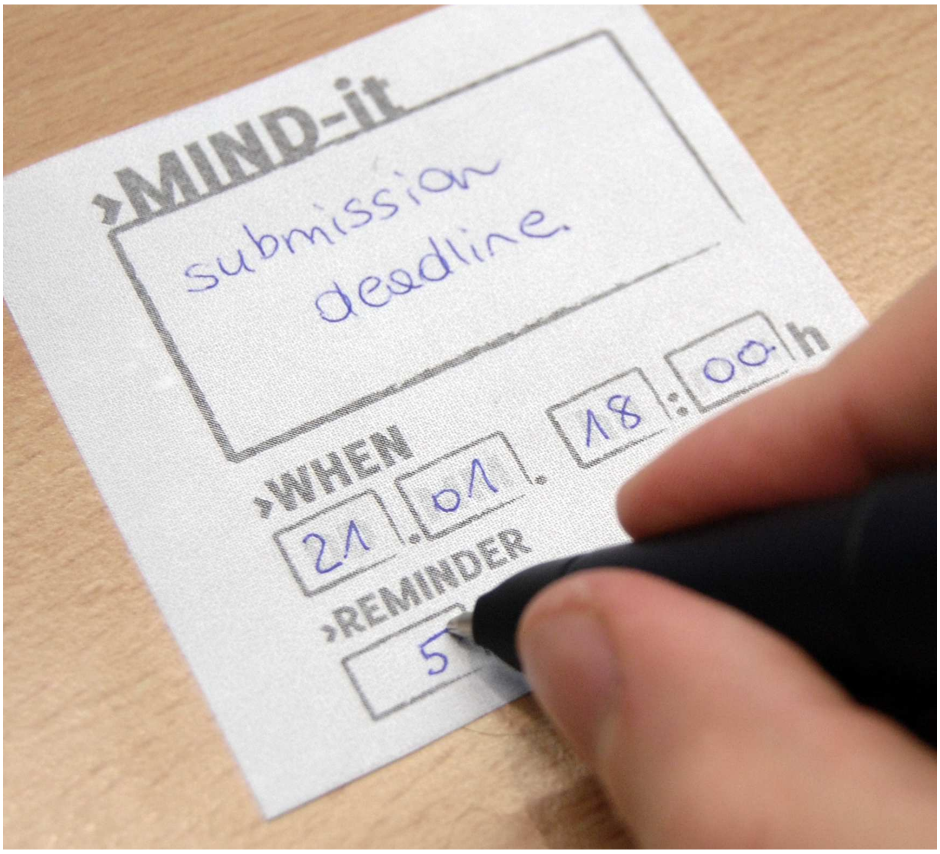

Figure 4.2: Move-it sticky note annotation using a digital Anoto pen.

4.1.2 Identifying the Sticky Notes

To determine which Move-it ioClip needs to be actuated once a specified event occurs, it is necessary to establish a distinct association between the digital and physical Move-it notes resp. the Move-it ioClip they are attached to. In our first version [64], all paperclips were color-coded, i.e., a pink clip had to be connected with a pink Post-it note, a blue clip had to be connected with a blue Post-it note, and so on. In the current version, we added reflective sensors[1] that combine an infrared-emitting diode (IRED) and photo transistor in a small package attached to the paperclip. As depicted in Figure 4.3, the photosensor tracks the reflected infrared light bounced back from a unique graycode printed on the backside of the Move-it sticky note. If the graycode is almost black, the reflection tracked by the sensor is low, if the graycode is white, the reflection is high. In our current implementation, we use two different types of Move-it ioClips (see Figure 4.4).

[1] http://www.datasheet4u.net/download.php?id=487289

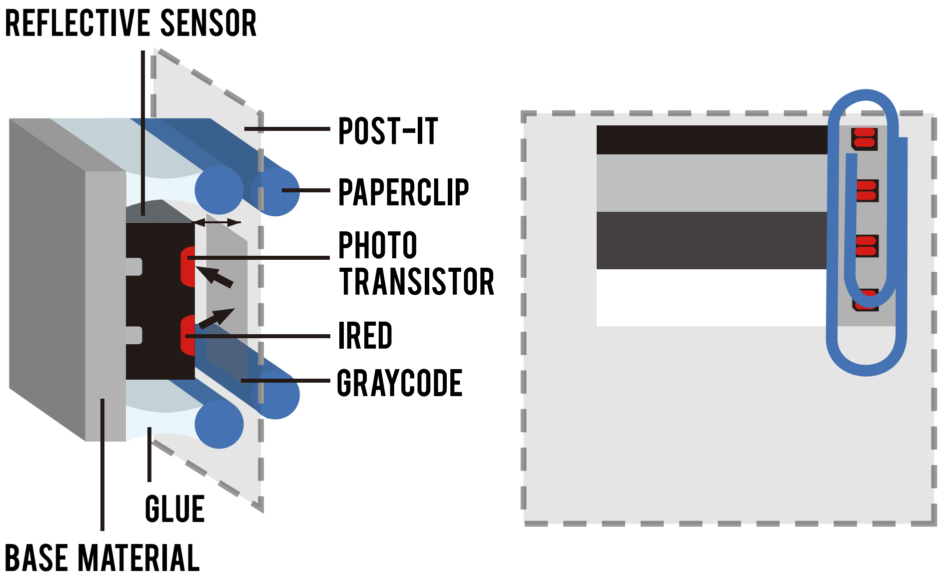

Figure 4.3: A schematic drawing of a Move-it sticky note with a unique graycode printed on the backside (right), which is recognized by four reflective sensors attached to a Move-it Multisensor ioClip (left).

- *Move-it Monosensor ioClips* (26 mm) use one reflective sensor that tracks a graycode consisting of a single strip colored in a specific shade of gray. Unfortunately, this design is susceptible to ambient light interference and the number of distinguishable shades of gray is limited to a maximum of ten.
- *Move-it Multisensor ioClips* (50 mm) use a sensor unit consisting of four reflective sensors. To provide robust tracking results, the sensors track a graycode consisting of four strips with a black and a white bar for the first and last strip and two gray-coded strips in between. Each photo sensor tracks a specific section of the graycode, the black and white strips are used to track the ambient light to adjust the tracking results of the inner sensors. In this design, we can distinguish up to 10×10 graycodes, i.e., 100 different Move-it sticky notes.

In either case, reading the graycode on the backside of the paper enables the Move-it system to provide each Move-it sticky note with a unique numeric identifier. This id is then associated with the digital notes recognized in the previous step and serves as the connecting link to determine which Move-it ioClip needs to be actuated in the next step.

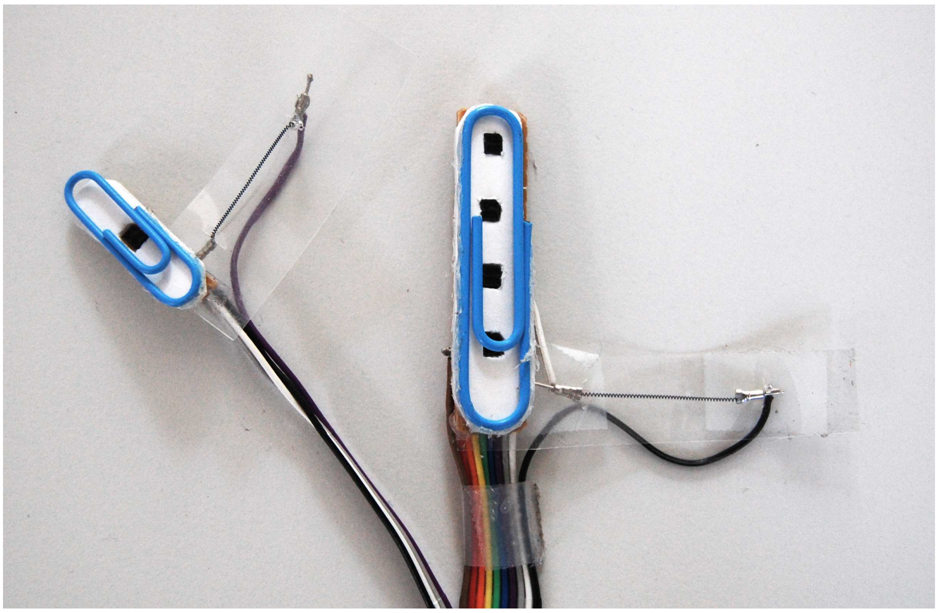

Figure 4.4: A Move-it Monosensor (left) and Multisensor (right) ioClip with reflective sensors for sticky note identification and a shape memory alloy for sticky note movement.

4.1.3 Moving the Sticky Notes

Once a previously specified event occurs (e.g., at a particular point in time, upon request), the Move-it sticky notes are then actuated by the Move-it ioClip and give active feedback to the user. To create the motion feedback, the Move-it ioClip makes use of the *shape memory effect (SME)* described in Section 1.2. On each active paperclip, we attached a Nickel-Titanium (NiTi, Nitinol) shape memory alloy (SMA) spring[2] with a length of 20 mm and a wire diameter of 0.15 mm that is connected to a small piece of polyester film. Once heated to 50–60°C, the SMA shrinks and bends the whole surface of the connected polyester film as depicted in Figure 4.5. By attaching the intelligent paperclip to a regular Post-it note, it becomes possible to actuate any paper note without enhancing the paper with wires [3, 15]. The bended polyester film distorts any Post-it associated with the paperclip. Once the SMA cools down, it returns to its original shape and the Post-it folds back again. Consequently, heating and cooling the SMA can produce arbitrary patterns of kinetic movement. In our current implementation, we use two different modes of motion (bending).

[2] http://www.toki.co.jp/biometal/download/downloadfiles/BMX_eng.pdf

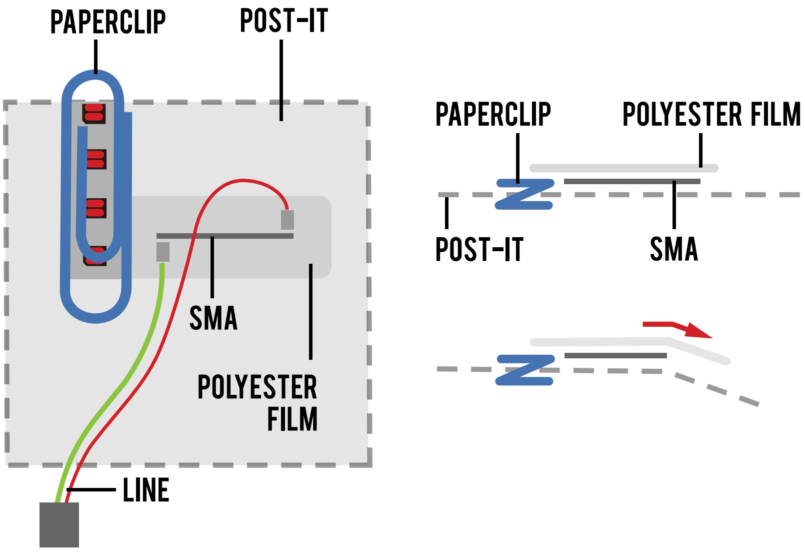

Figure 4.5: Schematic drawing of a Move-it ioClip with attached shape memory alloy (SMA) and a polyester film (left), which are shrinked resp. bent when heated (right).

- In the first mode, the Post-it note is moved repeatedly to create a subtle wiggling motion. Every few seconds a single actuation impulse is released to the SMA resulting in a fast heating (less than one second) and consequent shrinking of the SMA, initially followed by a longer cooling period of about three seconds until the SMA returns to its original shape. However, the actual results may vary and especially the time needed for the SMA to cool down is substantially dependent on the temperature of the environment. In our final implementation, we were able to achieve 0.5 Hz with a bending range of 45°.
- In the second mode, the Post-it is moved once and the bending angle is then maintained for a longer period of time. To hold the bending state, we added small resistors for each attached Move-it ioClip and implemented a pulse-width modulation mechanism for limiting resp. controlling the flow of current. In our final implementation, we were able to keep a maximum angle of 45° for several hours.

These types of movement correspond to the application examples described in Chapter 3, and cover the needs of Mind-it and Find-it sticky notes for drawing a user's attention through wiggling motion effects, as well as the needs of Watch-it sticky notes for awareness support by shape changing effects and consequent bending state maintenance.

4.2 Hardware Setup

Summing up, the Move-it system smoothly integrates Move-it sticky notes as input medium with the Move-it ioClip as output medium, connected and mediated by the Move-it desktop application. Figure 4.6 shows an example for a typical Move-it setup, while Figure 4.7 shows a schematic illustration of the interconnected system components.

Figure 4.6: The Move-it system consisting of Move-it sticky notes (enhanced Post-it notes supporting identification and processing of handwritten notes), the Move-it ioClip (an intelligent paperclip supporting recognition and movement of Move-it sticky notes attached to it) and the Move-it desktop application (running in the background).

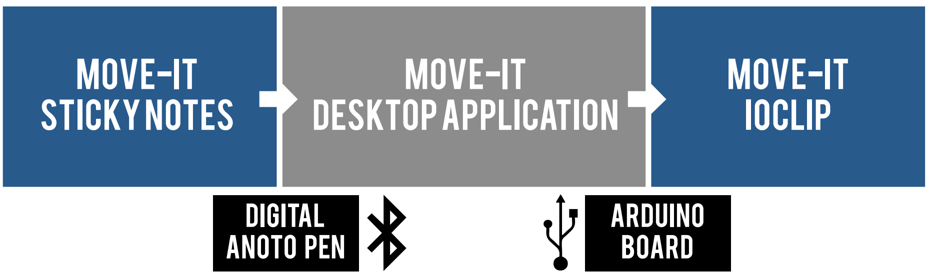

Figure 4.7: The structure of the Move-it system setup with Move-it sticky notes as input medium and Move-it ioClip as output medium, connected by the Move-it desktop application.

With this design, the Move-it system provides an active paper interface, with the ability to turn a passive piece of paper into an active medium.

- On the input side, a digital Anoto pen is connected to a computer running the Move-it desktop application via Bluetooth and transmits the input strokes in real-time while a user takes handwritten notes on a Move-it sticky note. In our current implementation we use ADP-301[3] digital pens, which, in contrary to other pens, supports real-time data transmission instead of storing the strokes in an in-built memory unit.
- The Move-it desktop application runs in the background, processes the input data from the digital pen and integrates the notes in PIM tools like calendars, to-do lists or address books. In our current implementation we integrate the notes with Microsoft Office Outlook, which is described in detail in Section 4.3.
- On the output side, an Arduino board is connected to the computer via USB, which receives actuation signals triggered by the Move-it desktop application and transforms them to resistive heating (300 mA, 5.0 V) of the according Move-it ioClip. In our current implementation, we use an Arduino Mega 2560[4] microcontroller that can address up to four Monosensor resp. two Multisensor Move-it ioClips.

4.3 Implementation

Figure 4.8 depicts the structure of the Move-it desktop application, the core component of the Move-it system. Basically, the application is responsible for handling the input from connected Anoto devices during the annotation of Move-it sticky notes as well as converting the handwritten notes to text, which is classified and associated with corresponding digital representations.

- **Input Manager:** Each Move-it sticky note is covered with a unique dot pattern that is captured and processed by a digital Anoto pen during annotation. By registering the pen's movement across the paper, the Input Manager generates a series of input events, which are then forwarded to the Stroke Manager for further processing. The `MoveItInputManager` is described in detail in Section 4.3.1.
- **Stroke Manager:** The notes are translated into machine-readable text by interpreting the strokes with handwriting recognition algorithms. By identifying the region on the paper the strokes are written on (e.g., inside the "Reminder" region of a Mind-it sticky note), the notes can be classified and interpreted accordingly for further processing. The `MoveItStrokeManager` is described in detail in Section 4.3.2.

[3] http://www.anoto.com/digital-pens-1.aspx
[4] http://arduino.cc/en/Main/ArduinoBoardMega2560

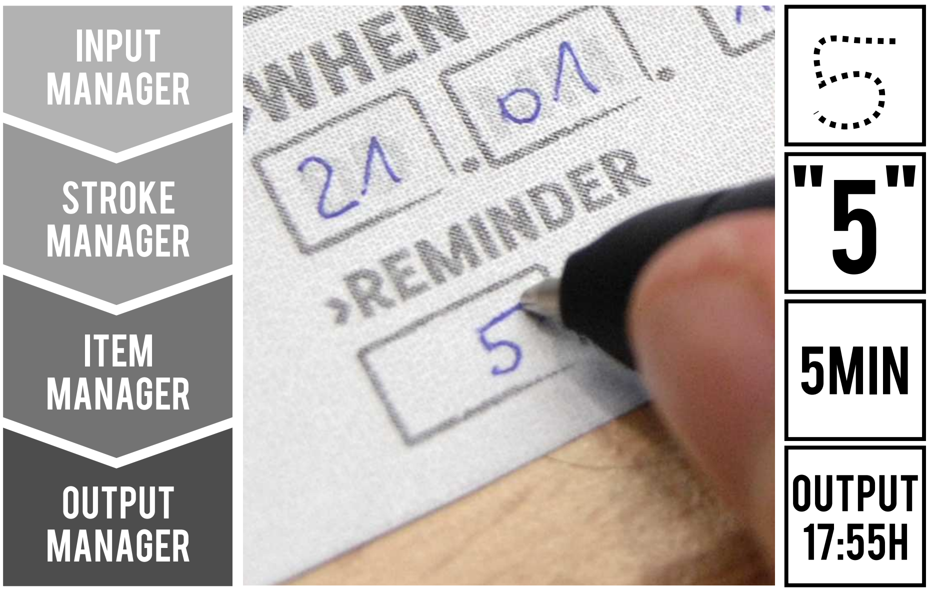

Figure 4.8: The structure of the Move-it desktop application. 1) The Input Manager handling input events from connected Anoto devices, 2) the Stroke Manager classifying the input strokes and converting them to text, 3) the Item Manager creating digital representations of Move-it sticky notes, and 4) the Output Manager triggering active physical feedback on time.

- **Item Manager:** The resulting datasets are used to create a corresponding digital representation of a Move-it sticky note, which is automatically synchronized with a PIM tool or IM application. The `MoveItItemManager` is described in detail in Section 4.3.3.
- **ioClip Manager:** Furthermore, each Move-it sticky note is printed with a unique graycode on the backside. Once a sticky note is attached to a Move-it ioClip, the graycode is read by the reflective sensors attached to the ioClip as described in Section 4.1.2. Subsequently, the graycode is mapped to a unique numeric identifier, which is used to establish a distinct association between a physical Move-it sticky note and its digital representation.
- **Output Manager:** Once the digital representation of a Move-it note is created, events associated with this note (i.e., reminder events in Microsoft Outlook, contact status changes in Skype) are handled to trigger active physical feedback. By resolving the association between the digital and the physical representation of a Move-it sticky note, the Output Manager can trigger motion feedback of the physical note by writing a corresponding serial signal to the Arduino board connected to the computer running the Move-it desktop application.

4.3.1 The MoveItInputManager

Our Move-it sticky notes consist of ordinary Post-it notes provided with a unique dot pattern that is virtually invisible to the human eye. As depicted in Figure 4.9, the pattern consists of small dots (0.1 mm in diameter) arranged with a spacing of approximately 0.3 mm on a square grid. The dots are slightly displaced from the grid in one of four possible positions, thus forming the proprietary Anoto pattern, which enables a digital Anoto pen to calculate the exact location on the page one is writing on. Each dot carries two bits of information and since the pen registers positions by reading an area of 6×6 dots, a unique pattern is ensured on a very large area[5]. Therefore, the displacement of the dots makes it possible to uniquely identify each pattern area and to extract what has been written and where it has been written on the paper. In our current implementation, we make use of the Anoto SDK 3.2 for PC Applications[6], which provides low-level handling of pen input signals that are passed to the `MoveItInputManager`. The Input Manager is responsible for the management of Anoto devices connected via Bluetooth to the computer running the Move-it desktop application, as well as the abstraction and forwarding of incoming pen input signals.

- **Pen Connected**: Once an Anoto device is connected to the computer running the Move-it desktop application, a new `MoveItInputDevice` instance identified by a unique serial number is created and added to the application's internal list of connected devices.
- **Pen Down**: When a connected Anoto device touches the paper, this input event is handled by the Input Manager and forwarded as high-level `MoveItPenDown` event.
- **New Coordinate**: When a connected Anoto device is moved across the paper, it captures the unique dot pattern with its in-built camera, processes the image in real-time to two-dimensional coordinates, and generates a corresponding input event. This input event is handled by the Input Manager and forwarded as high-level `MoveItPenMove` event, which encapsulates the horizontal and vertical pen coordinates along with the unique ID of the page written on.
- **Pen Up**: When a connected Anoto device is lifted from the paper, this input event is handled by the Input Manager and forwarded as high-level `MoveItPenUp` event.
- **Pen Disconnected**: Once an Anoto device is disconnected from the computer running the Move-it desktop application, the corresponding `MoveItInputDevice` instance is removed from the application's internal list of connected devices.

[5] http://www.anoto.com/filearchive/4/4192/general_development_guide.pdf
[6] http://www.anoto.com/filearchive/1/12007/PDS_SDK.pdf

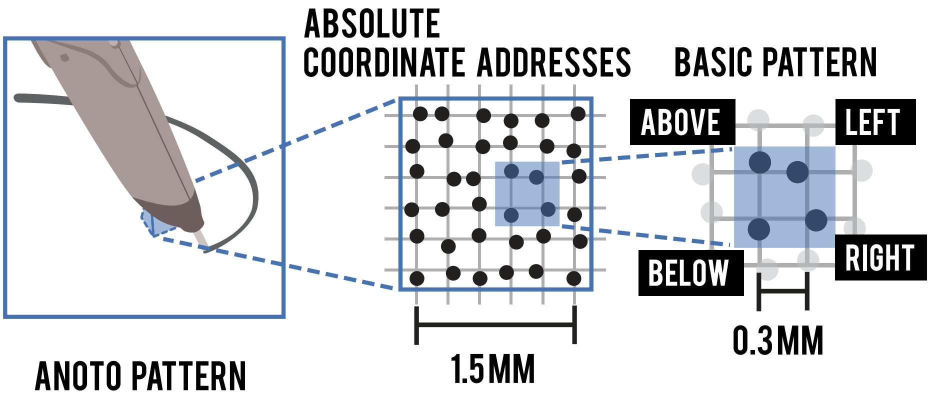

Figure 4.9: A unique Anoto dot pattern consisting of small dots slightly displaced from a square grid, which makes it possible for a digital pen to identify the pattern area and calculate the exact location on the paper.

4.3.2 The MoveItStrokeManager

The `MoveItStrokeManager` is responsible for converting the pen input coordinates to strokes, classifying the strokes based on the input region they are written on, and translating them into machine-readable text. First of all, the Stroke Manager catches events triggered by the Input Manager and pen coordinates are converted to points, which are then connected to strokes for further processing. Whenever the digital pen is lifted from the paper, the strokes are classified by identifying the input region on the sticky note, the strokes are written on (e.g., strokes inside the "Reminder" region of a Mind-it note are classified as reminder time). Correspondingly, an associated `MoveItConfigurationManager` manages a series of XML-based layout configurations for every type of Move-it sticky note, which specify the location and dimensions of the different input regions in Anoto coordinates. For example, the following code snippet describes a `MoveItConfiguration` defining the input regions (title, due date, reminder time) for the Mind-it sticky note depicted in Figure 4.10.

```
<?xml version="1.0" encoding="utf-8"?>
<MoveItConfiguration>
  <MindIt pageid="70.0.10.28">
    <MoveItInputRegion bounds="850,1050,2400,1900" name="title"/>
    <MoveItInputRegion bounds="850,2100,1150,2350" name="dateday"/>
    <MoveItInputRegion bounds="1200,2100,1550,2350" name="datemonth"/>
    <MoveItInputRegion bounds="1600,2100,1950,2350" name="datehour"/>
    <MoveItInputRegion bounds="2000,2100,2350,2350" name="dateminute"/>
    <MoveItInputRegion bounds="850,2500,1200,2700" name="reminder"/>
  </MindIt>
</MoveItConfiguration>
```

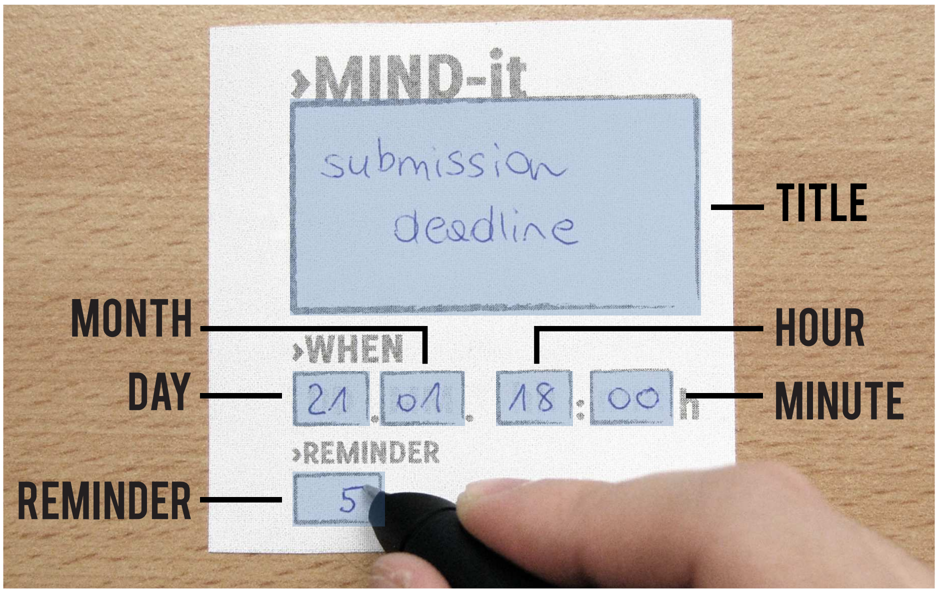

Figure 4.10: A Mind-it sticky notes with predefined input regions for title, due date (day, month, hour, minute) and reminder time.

Subsequently, the strokes are translated to machine readable text using Microsoft's handwriting recognition SDK. Based on the input region identified by the Configuration Manager, the strokes can be assigned to a corresponding `MoveItInputType` and interpreted accordingly (e.g., as literal, numeric, or generic input). After successfully interpreting the handwriting on a Move-it sticky note, the Stroke Manager triggers a `MoveItStrokeEvent` encapsulating the ID of the sticky note and the result of the text analysis.

In the first version of our implementation [12], we did not provide a layout structure for the notes and users were able to sketch them on a blank Post-it note. This caused a lot of problems with the recognition, because almost every user sketched the contents in a different way and the stroke recognition engine often failed. Not surprisingly, in the current version, we achieve a much higher recognition rate (actually the successful stroke recognition rate was almost 100%). Since input with digital pens lacks real-time feedback, we chose to use this form-like solution rather than a gesture-based approach (similar to [48, 56]). Although a free-form entry of notes might have been more attractive in terms of input flexibility, it raises numerous problems (e.g., automated distinction between text-based and numeric content, automatic recognition of time and date declarations in various formats), thus potentially suffers from drawbacks in terms of recognition reliability, which is crucial for the overall workflow and user acceptance.

4.3.3 The MoveItItemManager

The `MoveItItemManager` is responsible for the creation of digital representations of physical Move-it sticky notes, the establishment of a connection between them, and the subsequent synchronization with a PIM tool (i.e., Microsoft Office Outlook) or IM application (i.e., Skype). The Microsoft Outlook integration is realized by implementing an add-in using Outlook's Interop framework based on C#. More precisely, Mind-it notes are synchronized with the digital calendar as `Outlook.AppointmentItems`, Watch-it notes are integrated with the digital address book as `Outlook.ContactItems`, and Find-it notes are stored as `Outlook.NoteItems`. For example, Figure 4.11 shows a Mind-it sticky note and its corresponding digital representation in the Outlook calendar. In combination with Microsoft Exchange Server, items created on the Move-it system can then easily be used in distributed systems or shared with others. The Skype integration is done by utilizing the Skype API[7] to access contact information. The connecting link between a physical Move-it sticky note and its digital representation is realized by adding a custom property containing the unique numeric ID of a sticky note to the corresponding Outlook item. Likewise, the original stroke data obtained by the Stroke Manager is associated with the synchronized Move-it sticky note items to preserve the handwritten notes and their drawing order.

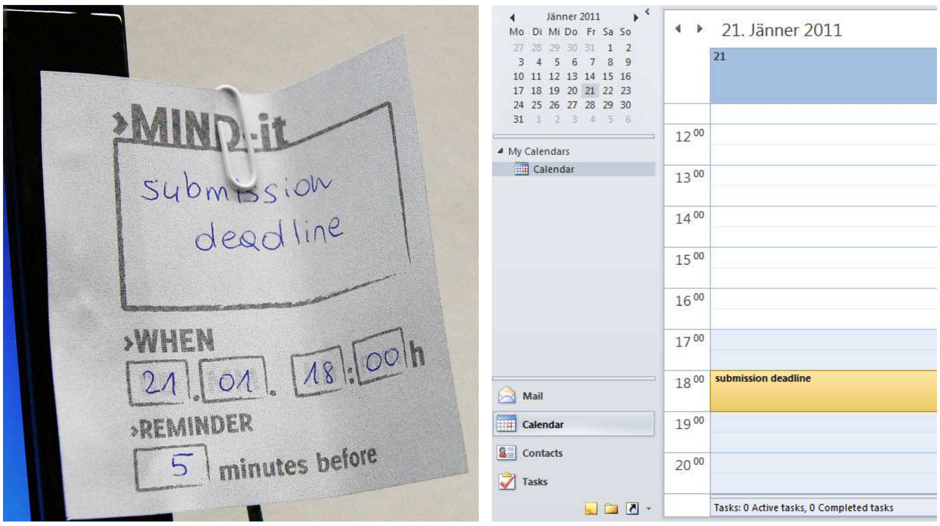

Figure 4.11: A physical Mind-it sticky note (left) and its digital representation as Microsoft Office Outlook calendar appointment (right).

[7] http://developer.skype.com/accessories

4.4 Challenges and Limitations

As mentioned in the introduction, we think that the enhancement of a paperclip provides a lot of advantages. Our primary consideration was to preserve the fundamental affordance of paper being a light, cheap, and disposable material. In our approach, the sophisticated technological components are integrated in the Move-it ioClip and sticky notes can therefore be discarded unhesitatingly after serving their purpose, while the clip itself can be reused anytime in order to be combined with a new sticky note. Enhancing the paper itself on the other hand, would bring along high costs for various electro-active materials to be embedded into the pulp during the papermaking process [15]. Thus, the appeal of paper notes as a disposable medium for informal note taking would be lost. However, while the combination of a common paperclip with SMA is relatively simple from a design perspective, both the implementation and handling rise up several challenges and required substantial fine mechanical engineering skills. In addition, SMA technology comes with its limits and has some constraints that have to be considered, including heating problems, limited force, and power.

- One of the challenges in combination with SMA is to avoid heating problems. As mentioned before, the SMA can get a temperature up to 80°C. We noticed no problems if the time of resistive heating was less than five seconds. However, longer resistive heating needs a method that prevents our hardware from getting too hot. Therefore, we used pulse-width modulation for controlling power to the SMA, which results in a high-frequency series of modulated pulses switching between on and off states. Furthermore, we added resistors for each connected Move-it ioClip (see Figure 4.12) to limit the flow of current. Consequently, temperature can be kept stable and the SMA can maintain its bending state for virtually any length of time without overheating.
- Another problem is the limited speed of movement. Since SMA-based movements are based on heating, it is almost impossible to heat and cool down the material immediately. This results in a non-linear, asymmetric motion (contractions and expansions). In other words, the SMA can be quickly contracted if it is heated resistively, but cooling speed strongly depends on environmental parameters such as ambient temperature, length of the SMA wire, or flexibility of the attached material.
- Besides the heating problems, we also found that force is limited, and the SMA spring used in our current implementation is only able to produce a maximum force of 20–40 gf. While this is adequate for bending the polyester film and a standard Post-it note, additional strain caused by e.g., thicker paper notes could not be handled appropriately. In addition, the service life of a SMA is closely associated with the magnitude of the load and the kinetic distortion.

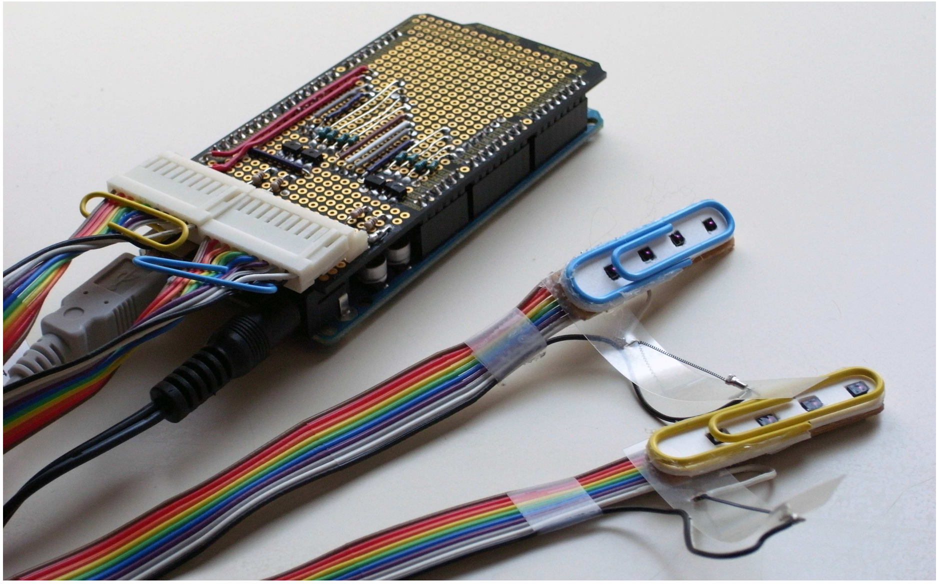

Figure 4.12: An Arduino microcontroller with resistors for each Move-it ioClip, limiting the flow of current to prevent overheating of the SMA.

- Finally, the possibly biggest limitation when dealing with shape memory alloys is the need for some kind of external heating source to produce the required thermal energy to make the metal assume its memorized shape. In our current implementation, we use resistive heating to actuate the Move-it ioClips. Thus, an external power supply is necessary, which unfortunately limits the portability of the whole setup. As an alternative to resistive heating, Koizumi et al. [44] propose the use of wireless energy sources such as sunlight, heaters, or lasers. However, these technologies are not optimal either, as they suffer from other shortcomings like low actuation speed, low precision of control, limited practicality, or security issues.

Nevertheless, we consider shape memory alloys as a flexible and therefore promising alternative to traditional actuators such as servo motors etc. for the design of responsive physical interfaces. The goal of this thesis is not to develop the ideal technology for providing active motion feedback, but to demonstrate the possibilities offered by lightweight SMA material as a potentially interesting alternative for user interface design.

Chapter 5

Move-it Sticky Notes for Human Interruption

Today, interruptions are omnipresent in our daily lives. Whether it is in private or in working context, interruptions are common to today's multitasking environments characterized by continuous switching between different tasks. People have become connected to increasing numbers of information sources and are therefore challenged to deal with notifications about various types of information such as incoming e-mails and instant messages, or latest news, weather, and stock reports. Consequently, many applications compete for the users' attention to notify them of important events or to provide information awareness. With Move-it sticky notes serving as peripheral displays, our goal is to provide a means of announcing interruptions that achieves the optimal tradeoff between attracting a user's attention and trying not to be disruptive [5]. By providing subtle motion cues in the periphery of a user's field of vision, we aim at supporting awareness in a sufficient way, while at the same time reducing the negative effects of interruptions.

5.1 Basics of Human Interruption

An interruption can be defined as any *randomly occurring event, that breaks the attention of a human on a primary task and forces him to turn his attention toward the interruption* [75]. Interruptions are mostly externally generated by various sources such as other persons, events, or applications introducing information updates, tasks, or advice. Interruptions typically require a human's immediate attention and partially insist on action. They create breaks in the workflow, force users to suspend their current activity, and require them to regain context of the original task to resume the suspended work later on. As a result, interruptions are often perceived as annoying and frustrating, since they keep people from their work and negatively affect human performance and emotional well-being.

To characterize the nature of human interruption, several theoretical models have been proposed in the course of the last years. These models provide an overview over the potential influences on the problem of human interruption, the cognitive mechanisms of interruption processing, and the effects of human interruption. Furthermore, they provide guidelines for the design of systems that support interruption management. Latorella's *Interruption Management Stage Model (IMSM)* [47] illustrates the stages of cognitive information processing that people exhibit when confronted with an interruption. The IMSM describes interruption management as stages of cognitive information processing that people exhibit when confronted with an interruption: detection of an interruption announcement, interpretation of the announcement, integration of the interruption into the current task, and finally resumption of the ongoing task. Furthermore, the IMSM specifies four general effects of interruptions: diversion (attention is redirected from the primary focus to the stimulus of the interruption announcement), distraction (momentary redirection of attention to interpret an interruption announcement), disturbance (efforts to either immediately execute or schedule the interrupting task), and disruption (efforts to regain context and resume the ongoing task) [55]. McFarlane developed the *Taxonomy of Human Interruption* [54], which describes the problem of human interruption by looking at it from different independent viewpoints. The taxonomy specifies eight major dimensions of the problem: source of interruption, individual characteristic of person receiving interruption, method of coordination, meaning of interruption, method of expression, channel of conveyance, human activity changed by interruption, and effect of interruption. Based on the requirement that interruptions occur whenever a continuous primary task is paused by an interrupting task a user is requested to switch to, McFarlane identifies three phases of human interruption: before switch, during switch, and after switch. Furthermore, he gives guidance how to best support these phases by appropriate user interface design. According to that, the goals of effective human interruption design are to present interruption announcements in the best possible way in the before switch phase, to maximize the overall performance in the during switch phase, and to facilitate resumption of the original task in the after switch phase.

5.1.1 The Interruption Lifecycle

Based on these models and other sources of research on human interruption e.g., [39, 47, 54, 82], the interruption process can be generalized to an interruption lifecycle consisting of the following phases (see Figure 5.1).

Interruption Occurrence: An interruption is annunciated and the user's focus of attention is redirected from a continuous primary task to the interruption announcement (*diversion*). This phase includes the effort needed to interpret the interruption announcement (*distraction*).

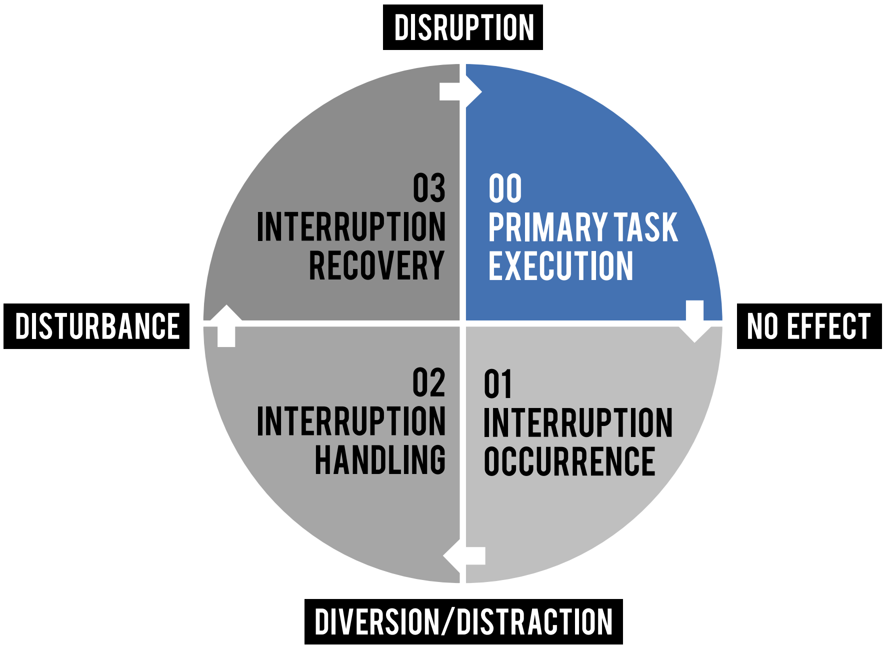

Figure 5.1: The phases of the interruption lifecycle and associated effects of interruption. 1) Interruption occurrence signaled by the announcement of an interruption, 2) interruption handling making a user pause a continuous primary task and process the interruption, 3) interruption recovery shifting back the focus of attention to the original task, cf. [39, 55, 82].

Interruption Handling: The continuous primary task is paused and the user's focus of attention is shifted to the interruption in order to process the interrupting task. This phase includes the time needed to bring the primary task to a stable point from which the primary task can be resumed later on (*disturbance*).

Interruption Recovery: The user's focus of attention is shifted back to the original primary task. This phase includes the time needed to regain context of the original task and return to the point in the work at which the interruption occured (*disruption*).

5.1.2 Effects of Human Interruption

The nature of human interruption has been investigated by numerous research groups so far as well as the many effects on user behavior and task performance. Most of them highlight the negative impacts that interruptions have on users working in a multitasking environment. They have found that users perform less efficient on an interrupted task than on an uninterrupted task, i.e., that interruptions can cause people to make mistakes and reduce their efficiency. A number of research efforts have been aimed at better understanding the effects of interruptions on computer-based tasks by manipulating features such as interruption length, frequency, complexity and similarity to the primary task. One consistent finding is that interrupted work environments lead to reduced task performance and that users almost always performed slower on an interrupted task than on a non-interrupted task [6, 26, 45, 75]. Experiments revealed that interruptions affect human behavior and researchers have empirically observed that interruptions induce personal stress, annoyance, and frustration [1, 6, 60, 86]. Consequently, interruptions are often regarded as annoying and frustrating because they keep people from their work and affect their emotional feeling negatively. Another robust finding is that interruptions of higher complexity (in terms of information processing or memory demands) or greater similarity to the primary task were found to exhibit more disruptive effects than others [6, 26, 34, 38, 45]. Furthermore, there is evidence for a negative relationship between interruption frequency and human performance [75, 86]. Other related work has shown the difficulty that users have with returning to disrupted tasks following an interruption. According to that, task completion time may be increased significantly in terms of a *resumption lag*, which is defined as the additional time needed for reorientation and reestablishment of primary task context after an interruption [6, 18, 19, 38].

The results of this research sound a warning for notification systems such as electronic mail, instant messaging or reminder systems supposed to enhance productivity in many working environments. Such tools have been widely adopted to support information workers and provide effective means of communication and task organization. Consequently, findings from this research highlight the need for effective interruption management to prevent negative effects on human performance, behavior, and emotional well-being. Although interruptions are ubiquitous in todays multitasked working environments, the extent of their negative impact is substantially dependent on *when* and *how* an interruption occurs. Thus, the development of methods to support people in dealing with interruptions promises to be valuable.

5.1.3 Human Interruption Tradeoffs

Whenever dealing with interruptions, there is a fundamental tradeoff between drawing a user's attention and trying not to be disruptive: *information awareness vs. intrusion* [5]. Information awareness refers to the amount of attention attracted by the announcement of an interruption and can be thought of the efficiency of information delivery. Intrusion refers to the amount of disturbance caused by the interruption announcement entailing negative effects on task performance and cognitive state. Figure 5.2 illustrates the tradeoff between information awareness and intrusion and highlights the optimal balance of high information awareness and low intrusion that Move-it sticky notes for human interruption aim at.

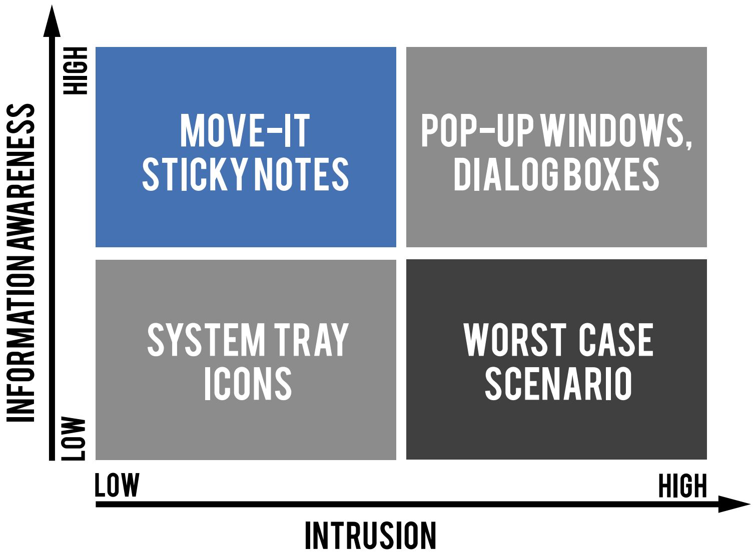

Figure 5.2: The tradeoff between information awareness and intrusion of common user interface techniques for the announcement of interruptions and the optimal balance of high information awareness and low intrusion, ideally to be exhibited by Move-it sticky notes, cf. [5].

Common user interface techniques like pop-up windows, dialog boxes, or system tray icons are undeniably ubiquitous in current notification systems and inform users of incoming e-mails and instant messages or remind them of scheduled meetings and tasks to be done. Unfortunately, each of these techniques achieve either high awareness or low intrusion, but not both. While pop-up windows and dialog boxes achieve high information awareness, research on the effects of pop-up interruptions e.g., [1, 18, 38, 66, 76] shows that the level of intrusion is also very high and results in negative effects on task performance and human behavior (see Section 5.1.2). For example, Storch [76] found that on-screen interruptions caused significantly higher disruptive effects than telephone or walk-in interruptions, probably due to the abruptness of the interruption announcement prohibiting user's from completing the ongoing primary task. System tray icons, are more subtle and keep the level of intrusion relatively low because only a small portion of the screen is occupied by the interruption announcement. Unfortunately, the information awareness exhibited by this user interface technique is also very low [5]. Thus, the goal for the application of Move-it sticky notes for human interruption is to achieve the optimal tradeoff between information awareness and intrusion to reduce negative effects of human interruption and *support the announcement of interruptions in the best possible way.*

5.2 Coordination of Human Interruption

Researchers found a fundamental tension between the disruptiveness of interruptions and their potential benefit, which makes people struggle with finding the balance between entertaining useful interruptions and avoiding distracting ones [37]. Although interruptions are perceived valuable at times, they are generally characterized as annoying and frustrating because they keep people from their work. These findings suggest a high potential for increasing the efficiency of interruption management systems.

McFarlane and Latorella [55] suggest five basic strategies to support effective interruption management in a multitasking environment: training, incentives, personnel selection, completely replace person with automation and design HCI support. Experiments have shown [34] that the harmful effects of interruptions can be reduced over time by training and experience. However, the potential benefit of training, incentives or personnel selection is limited, because people's cognitive capabilities are limited and can only be enhanced to a certain degree. Automation on the other hand, seeks to control disruption by providing individuals with intelligent filtering mechanisms to control the volume and nature of interruptions [36, 69]. However, this requires consideration of a multitude of environmental conditions to successfully manage incoming demands for an individual's attention. In addition, the intelligent filtering of interruptions is a one-sided automated decision process and may keep people from receiving potentially beneficial information.

Numerous computer-mediated interruption management systems have tried to improve the balance between information awareness and intrusion (see Figure 5.2) using different strategies: appropriate timing, multimodal presentations ,or novel visual representations. One consistent finding is, that the disruptiveness of an interruption substantially depends on the point in a computing task the interruption is presented at. Researchers developed models to predict better and worse moments for interruptions and experiments showed that triggering interruptions at opportune moments produced less negative effects on human behavior and task performance [1, 17, 18]. In McFarlane's experiments, participants performance improved when they were given the opportunity to control the timing of the interruptions. According to that, McFarlane suggests four solutions to the problem of coordinating human interruptions [54]: immediate (requiring an immediate user response), negotiated (user chooses when to attend), mediated (an intelligent agent determines when best to interrupt), and scheduled (interruptions come at prearranged time intervals). Experimental results showed that none of these methods was found to be the single best way to interrupt users for all kinds of human performance measures but instead there are tradeoffs between the coordination methods and different kinds of human performance. If forced to acknowledge the interruption immediately, users in his study got the interrupting task processed promptly, but were less efficient overall. On the other hand, giving people control to negotiate for interruptions resulted in enhanced performance. Though, McFarlane also points out that users may indefinitely postpone (or even forget) interruption processing in these cases. Mediated coordination of interruptions implies the need for some kind of attention management system capable of detecting opportune moments for interruption and interacting with the user at that time. Many researchers envision such systems to minimize the disruptive effects of interruptions. However, similar to intelligent filtering, identifying opportune moments for interruption in a user's task sequence is a complex problem and requires comprehensive knowledge about a user's working context.

Other research has shown that different modalities of interruptions such as sound, light, heat vibration or smell can also be a determining factor for the disruptiveness of interruptions [4]. They come to the conclusion that there is no single best modality for interruption, but instead suggest that previous personal experience of individuals confronted with different feedback modalities plays a key factor in their reaction. Again, finding the modality that is the most efficient while being the less disruptive, requires the development of a complex multimodal system capable of adapting output modalities according to the feedback about disruptive effects of an interruption. Future systems would have to become multimodal adaptive interfaces, selecting the appropriate output modality based on comprehensive contextual information about the individual and its working environment.

Finally, finding ways to best gain people's attention by designing HCI support seems to have the most potential for improving human performance. Multiple studies have shown that especially the nature of the display used to announce interruptions, substantially influences performance on a primary computing task [5, 51, 83]. According to that, Move-it sticky notes were chosen to serve as novel strategy for visual representation of interruption announcement (see Section 5.2). Rather than filtering interruptions or manipulating the timing of their occurance, we decided to move the information off the screen and use Move-it sticky notes as peripheral displays providing subtle motion cues to attract a user's attention resp. support information awareness. Furthermore, Move-it sticky notes feature negotiation of interruption coordination as suggested by McFarlane [54]. When interrupted while performing a continuous primary task, a user can decide autonomously when to attend to the moving sticky note and process the interruption. Thus, we expect interruption announcement by Move-it sticky notes to exhibit less disruptive effects and better performance than immediate coordination methods like pop-up windows or dialog boxes. Furthermore, the risk of negotiated interruption coordination for indefinite postponement of interruption processing may be eliminated by the inherent passive reminding feature of Post-it notes due to their mere presence.

5.3 Evaluation

We conducted two experiments to evaluate the applicability of Mind-it and Watch-it notes for human interruption as compared with common UI solutions such as dialog boxes or pop-up windows. The effects of interruption in each of the phases of the interruption lifecycle (see Figure 5.1) were measured based on Latorella's Interruption Management Stage Model [47]. The results were evaluated to determine and compare the tradeoffs between information awareness and intrusion (see Figure 5.2) exhibited by the different expression modalities. Furthermore, according to McFarlane's Taxonomy of Human Interruption [54], the results were assessed to meet one of the main goals of effective human interruption design: to present interruption announcements in the best possible way. Both experiments were especially designed to assess the interruption tradeoff (see Figure 5.2) achieved by interruptions announced through Move-it sticky notes in comparison to common notification mechanisms like dialog boxes or pop-up windows. The first experiment evaluates the applicability of *"Mind-it Sticky Notes for Alerting"* (Chapter 6), and is particularly focused on the amount of intrusion caused by feedback from moving sticky notes. The second experiment evaluates the applicability of *"Watch-it Sticky Notes for Awareness"* (Chapter 7), and highlights the information awareness provided by shape-changing sticky notes. Experimental results are discussed in detail in the following chapters.

Chapter 6

Experiment 1: Mind-it Sticky Notes for Alerting

Reminding people of upcoming appointments is one of the typical application scenarios for Mind-it sticky notes. Thus, Mind-it notes are used as alerting displays, which remain in the periphery at most times but grab a user's attention as soon as important information arrives [52]. For example, a Mind-it sticky note supposed to remind the user of a scheduled meeting five minutes before the specified date serves as a passive reminder due to its mere presence. As soon as the specified reminder time is reached, the Mind-it will be actuated by the interactive paperclip and thus become an active reminder grabbing a user's attention. Based on this application scenario, the goal is to achieve an optimal tradeoff between information awareness and intrusion by exhibiting a high level of information awareness while at the same time keeping the level of intrusion as low as possible (see Figure 5.2) to draw a user's attention in the most effective way. According to Matthews et al. [53], this goal corresponds to the "interrupt" notification level, defined as the demand to represent information of high importance and grab a user's full attention, i.e., *alerting* the user of some critical information. To evaluate the applicability of Mind-it sticky notes for alerting, we compared them with common Microsoft Office Outlook reminders, which are usually represented as common dialog boxes appearing in the middle of the screen.

6.1 Feedback Modalities

For interruption feedback, we compared Mind-it feedback with common Microsoft Outlook reminders, which resulted in three feedback modalities.

- **No feedback (control condition):** Under this condition, participants are not interrupted at all while performing a continuous primary task. Attention is fully focused on the primary task and performance in this condition serves as a benchmark for the other feedback modalities.

- **Microsoft Outlook pop-up feedback (pop-up condition):** Under this condition, interruptions are communicated by standard Microsoft Office Outlook reminders, represented as a dialog boxes appearing in the middle of the screen. The participant's attention is drawn from the primary task to the Outlook notification until the reminder window is dismissed manually by the user.
- **Mind-it sticky note feedback (sticky note condition):** Under this condition, interruptions are communicated by a wiggling Mind-it sticky note attached to the right side of the monitor. The participant's attention is divided between performing the primary task and sticky note feedback in the periphery.

6.2 Hypotheses

We expected that Mind-it feedback modality would demonstrate a less disruptive effect *(H1)* and exhibit better task performance *(H2)* than Microsoft Outlook standard pop-up feedback modality. More specifically, we explored the following hypotheses to address critical questions like:

- How do the different feedback modalities affect task performance?
- How does the interruption modality influence people's perception of the task load? How disturbing do participants perceive the different feedback modalities?
- How long does it take people to process an interrupting task after noticing an interruption? Do participants wait for an opportune moment to start processing an interrupting task?
- How long does it take to resume the primary task after the different interruption modalities? Do participants experience a resumption lag?

H1: Interruptions are less disturbing under the sticky note condition than the pop-up condition.

As described in Section 5.1.2, research on human interruption provides evidence the timing of interruptions can affect task performance: interruptions occurring at a point of higher mental workload exhibit a higher disruptive effect. Corresponding to that, Salvucci and Bogunovich [70] claim that users interrupted at points of higher mental workload exhibit a strong tendency to postpone the processing of an interruption until they have reached a desirable stopping point in the primary task. In line with that, other research on human interruptions found that users exhibit a strong tendency to switch tasks at points of lower workload and postpone interrupting task processing [17, 70]. They tend to complete conceptual and motor subtasks before switching and responding to an alert, presumably to leave the primary task in a stable state that allows for more efficient resumption later on [39]. Since in our experiments participants had the possibility to autonomously decide when to initiate the interrupting task, we wanted to see if they would exhibit *chunking behaviors* [74] or execute the interrupting task immediately. Therefore, we logged any keyboard input events on the primary task window after announcing an interruption and expected participants to exhibit one of the following *awareness strategies* [5]:

- **Immediate:** Suspending the current transcript task to process the interruption immediately.
- **Postponed:** Completing the current subtask (e.g., finishing typing a word or phrase) and bringing the primary task to a stable state before switching to the interrupting task.

Contributing to our first hypothesis, we expect that participants exhibiting the postponed awareness strategy would be less stressed by the interruptions and thus perceive them to be less disruptive. Measures taken to validate this hypothesis were:

- Task workload perceived by the participants, defined as ratings in the modified NASA-TLX survey (see Section 6.3.5 for details).
- Distraction, disruption and disturbance perceived by the participants, defined as ratings in the final questionnaire.

H2: Task performance is better under the sticky note condition than the pop-up condition.

According to the findings on the negative effects of human interruption on human behavior and task performance (see Section 5.1.2), we expected performance in both the primary and the interrupting task to degraduate under the sticky note and the pop-up condition as compared to the uninterrupted control condition. Particularly, we expected performance to degraduate less under the sticky note condition due to the fact that the subtle motion feedback in the periphery would induce a less disruptive effect than the pop-up feedback. As well associated with the stress level induced by the interruption feedback, we expected that it would take participants less time to recover from the interrupting task under the sticky note condition. Altogether, we expected the sticky note condition to leave users more freedom to choose an appropriate moment for switching from the primary to the interrupting task and therefore be deemed by users more respectful due to the fact that less annoyance, frustration and time pressure are produced [1]. Performance measures taken to validate this hypothesis were:

- Progress on the transcript, defined as the number of typed characters (*primary task performance*).
- Number of errors in the transcript, defined as number of missing, redundant, or misplaced words (*primary task error rate*).

- Time needed to start the interrupting task, defined as the timespan between announcement of the interruption and the user starting the interrupting task (*start time*).
- Time needed to solve the calculations during the arithmetic training (*interrupting task performance*).
- Number of errors on the calculations solved during the arithmetic training (*interrupting task error rate*).
- Time needed to return to the primary task, defined as the timespan between interrupting task completion and first occurring user interaction on the transcript document or media player window (*return time*).

6.3 Experimental Design

18 undergraduate and graduate students from the local university were recruited to perform a laboratory user study. Participants were asked to perform a time consuming primary task of writing a transcript based on a video clip. While participants were performing this primary task, interruptions were triggered regularly and participants were asked to perform a short task of solving basic arithmetic calculations. Summarizing, the study was a 3 (feedback modality) $\times$ 3 (interruptions), counterbalanced within-subjects design, which took about 30 minutes (10 minutes for each condition). In the study, we measured the participant's performance on the primary task in terms of progress on the transcript and number of errors in the text. Performance on the interrupting task was measured in terms of time needed to solve the calculations, and correctness of the results.

6.3.1 Participants

18 participants (15 male, 3 female) aged between 21 and 27 years (average age was 23.8 years) were recruited for the user study from the local university. All participants had good experience with both Microsoft Windows and used Microsoft Outlook (or similar applications) on a daily basis.

6.3.2 Primary Task

The primary task was adapted from that used by Adamczyk et al. [1] and consisted of three media clips from a German technological TV broadcast[1]. The video clips were about 4.5 minutes in length and very similar in structure, speaking rate, and narration density. The task was timed to four rounds of transcript writing (separated by three interruptions), each lasting 90 seconds and resulting in a total 6 minutes Time On Task *(TOT)*.

[1] http://www.wdr.de/tv/aks/zursendung/angeklickt.jsp

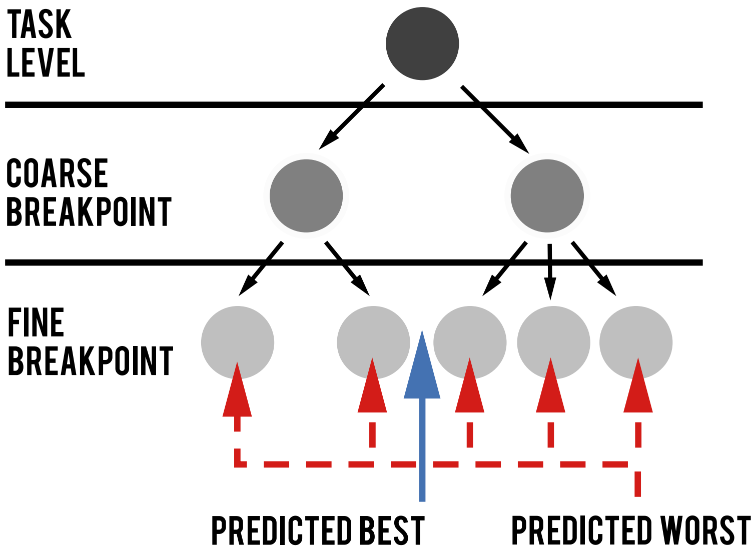

Figure 6.1: Task model hierarchy, cf. Adamczyk et al. [1], with predicted best points for interruption corresponding to moments between coarse breakpoints and predicted worst points for interruption corresponding to moments during fine breakpoints in a task execution sequence.

The task was chosen to cover a variety of demands, while still constituting a meaningful example of a commonly performed everyday task. First of all, it was supposed to induce a relatively high cognitive load on mental resource. Since the speaking rate of the narrator was too high to write the transcript in parallel to watching the media clip, participants had to pause video playback regularly and memorize the last portion of the narrator's text before writing it down in the Word document. Consequently, participants also had to deal with two different desktop applications in parallel (see Figure 6.3) and switch between them continuously. The interruptions were designed to occur at stages when cognitive load imposed on the participants was highest, immediately after switching from the media clip to the transcript document. According to the task model hierarchy of Adamczyk et al. [1] depicted in Figure 6.1, this corresponds to a predicted worst moment for interruption since the interruption is triggered during the execution of fine breakpoints in a task execution sequence. We chose this points of interruption because we expected that annoyance, frustration and time pressure induced on the participants would be highest at these moments and consequently there would be a high potential for reducing these negative effects. Figure 6.2 illustrates the workflow of constant switching between the transcript and video applications in the primary task. Whenever an interruption was triggered, participants had the choice of immediately performing the interrupting task (*Immediate* awareness strategy), or postponing task execution (*Postponed* awareness

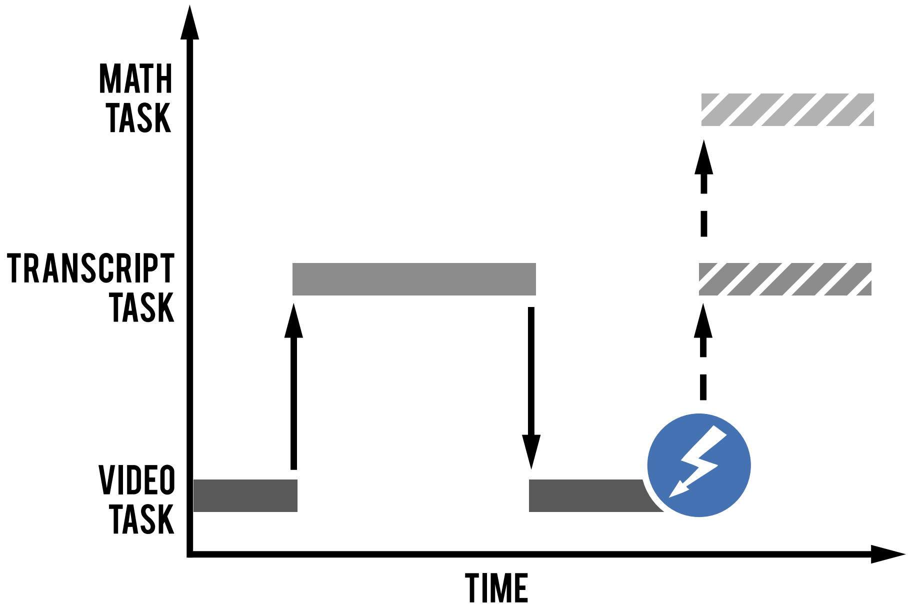

Figure 6.2: Primary task workflow with interruptions being triggered at moments of high cognitive load, immediately after switching from the media clip to the transcript document. Participants then had the choice between immediately processing the interruption (*Immediate* awareness strategy), or postponing the interruption (*Postponed* awareness strategy) and finish writing a word or sentence from the previously memorized text.

strategy) and finish writing some of the previously memorized text. In either case, the arithmetic training was started by the participants pressing the 'ESC' key on the keyboard when they were ready to process the interruption. After finishing the interrupting task, participants returned to the primary task and continued writing on the transcript document.

6.3.3 Interrupting Task

The interrupting task consisted of ten basic arithmetic calculations. Participants were shown a form asking them to perform additions between two-digit numbers (e.g., $37 + 98$), type the result in a textbox and confirm by pressing the return key or a corresponding button below the textbox as shown in Figure 6.3. The entered results were validated and incorrect entries had to be repeated until the calculation was solved correctly.

The task was chosen to be different from the primary task in order to prevent disruptive effects caused by task similarity as suggested by several experiments on human interruption [26]. Furthermore, the task depicts an everyday situation of mental arithmetic that people are familiar with.

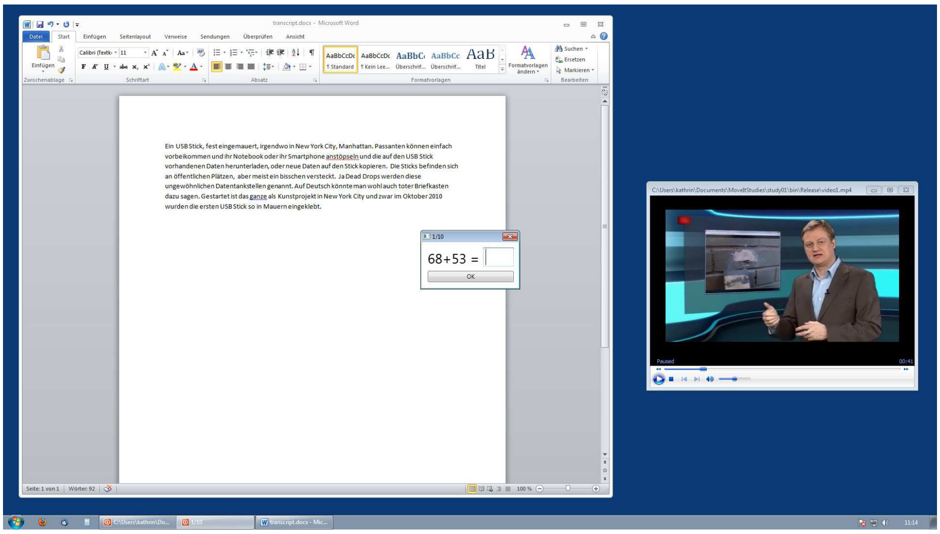

Figure 6.3: Desktop screenshot of the primary transcript task and interrupting arithmetic task.

6.3.4 Apparatus

The study was conducted on an Intel Core i7 machine with 8×2.8 GHz and 8 GB RAM running Windows 7. All tasks were performed using a 23" TFT monitor with a screen resolution of 1920×1080 pixels. For the sticky note feedback modality, a Mind-it note with the subject "Training" was placed on the right side of the monitor as shown in Figure 6.4. A Windows desktop application displayed task instructions and implemented custom logging mechanisms to record performance measures in the background. Furthermore, participants' screen interaction was recorded for subsequent analysis.

The experiment was conducted in a separated, calm office environment with all potential sources of interruption such as mobile phones, e-mail clients etc. deactivated to prevent any external distractions.

6.3.5 Procedure

At the beginning of the experiment, participants were welcomed, introduced to the purpose of the study, and given instructions on the task they had to perform. The participants were told to do the task exercises as fast and accurate as possible. Subsequently, participants partook in a short practice round with a one-minute sample media clip to become accustomed to the task. After performing the task under the control condition, participants were informed that they would be interrupted periodically in the following conditions. They were introduced to the interrupting task by performing a short training session solving 30 arithmetic calculations similar to the ones

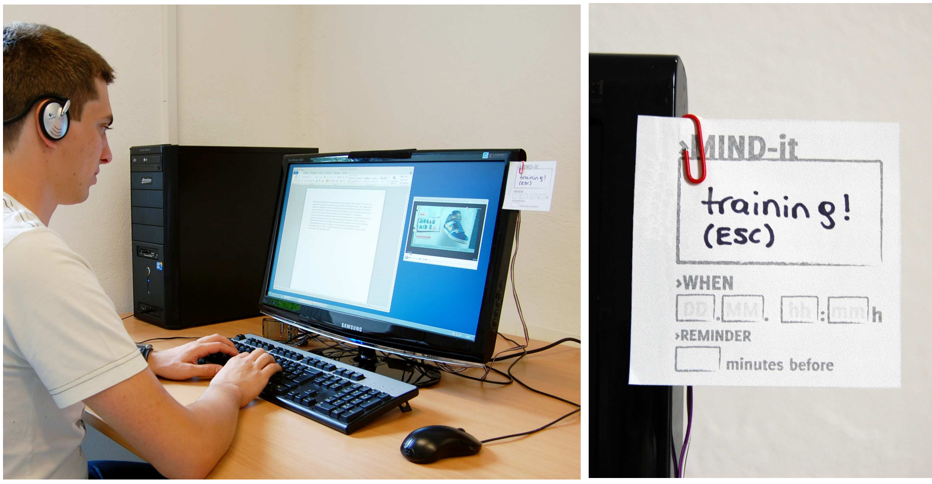

Figure 6.4: The apparatus of the Mind-it experiment *(left)*, with a Mind-it sticky note announcing the interruptions *(right)*.

they would encounter later. Thereafter, the primary transcript task and the interrupting arithmetic task were combined and participants performed them under the pop-up and sticky note conditions. To prevent any learning effects, the interrupted conditions were alternated after each participant.

To measure the effect of the interruption on the emotional state, participants were were shown a modified NASA Task Load Index (TLX) survey [31] after each task. While the NASA-TLX was originally meant to assess the subjective workload experience, its scales are also relevant to the experience of interruption [1]. The modified version used in this study was derived from the German translation of the TLX [62], which includes six 20-point scales (mental demand, physical demand, temporal demand, performance, effort, frustration). While the physical demand scale was skipped, we added the following two items under the pop-up and sticky note conditions to obtain more specific information on the perceived impact of the interruptions:

- How disruptive was the alert for the workflow? (*workflow*)
- How disruptive was the alert to perform the training? (*interruption*)

As well, after completing all tasks, participants were given a follow-up questionnaire specifically comparing the sticky note and pop-up feedback modalities. In this concluding questionnaire, participants were asked to estimate on a 10-point scale the severity of the experienced effects of interruption (see Section 5.1) caused by the two different feedback modalities:

- To what extent did you feel distracted from the primary activity you were engaged in? (*distraction*)
- To what extent did you feel disrupted by the feedback? (*disruption*)
- To what extent did you feel disturbed in your workflow? (*disturbance*)

6.4 Results

6.4.1 Emotional State Measurement Results

NASA-TLX Ratings

The ratings in the NASA-TLX survey assessing the subjective workload induced by the experimental task are depicted in Figure 6.5. A two-way within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of feedback modalities on the individual task load. For all tests an alpha level of 0.05 was used, the Greenhouse-Geisser correction was used when the assumption of sphericity was violated. The results are presented in Table 6.1. Post-hoc analyses consisted of paired-samples t-tests with familywise error rate controlled across the test using Holm's sequential Bonferroni approach. Significant differences between the means of pairs are presented in Table 6.2.

NASA-TLX value	***F***	***p***
Mental Demand*	$F_{2,34} = 14.866$	0.001
Temporal Demand	$F_{2,34} = 1.862$	0.171
Performance	$F_{2,34} = 4.141$	0.025
Effort*	$F_{2,34} = 4.714$	0.031
Frustration	$F_{2,34} = 1.460$	0.246
Workflow	$F_{1,17} = 26.751$	0.000
Interruption	$F_{1,17} = 26.613$	0.000

Table 6.1: Main effects for feedback modality on perceived task load (NASA-TLX). Starred (*) results indicate Greenhouse-Geisser corrected values.

NASA-TLX value	**Pair**	***F***	***p***
Mental Demand	Control – Pop-Up	$t(17) = -4.053$	0.002
	Control – Sticky Note	$t(17) = -3.695$	0.005
Performance	Pop-Up – Sticky Note	$t(17) = -3.189$	0.016
Effort	Pop-Up – Sticky Note	$t(17) = 2.961$	0.026
Workflow	Pop-Up – Sticky Note	$t(17) = 5.172$	0.000
Interruption	Pop-Up – Sticky Note	$t(17) = 5.442$	0.000

Table 6.2: Significant mean differences along perceived task load (NASA-TLX) between pairs of feedback conditions.

According to that, participants perceived the experimental task to be significantly more challenging (*mental demand*) under the interrupted pop-up and sticky notes conditions than the control condition, which might clearly be a consequence of the additional mental demand induced by the interrupting arithmetic training. Furthermore, the task was perceived to be accomplished

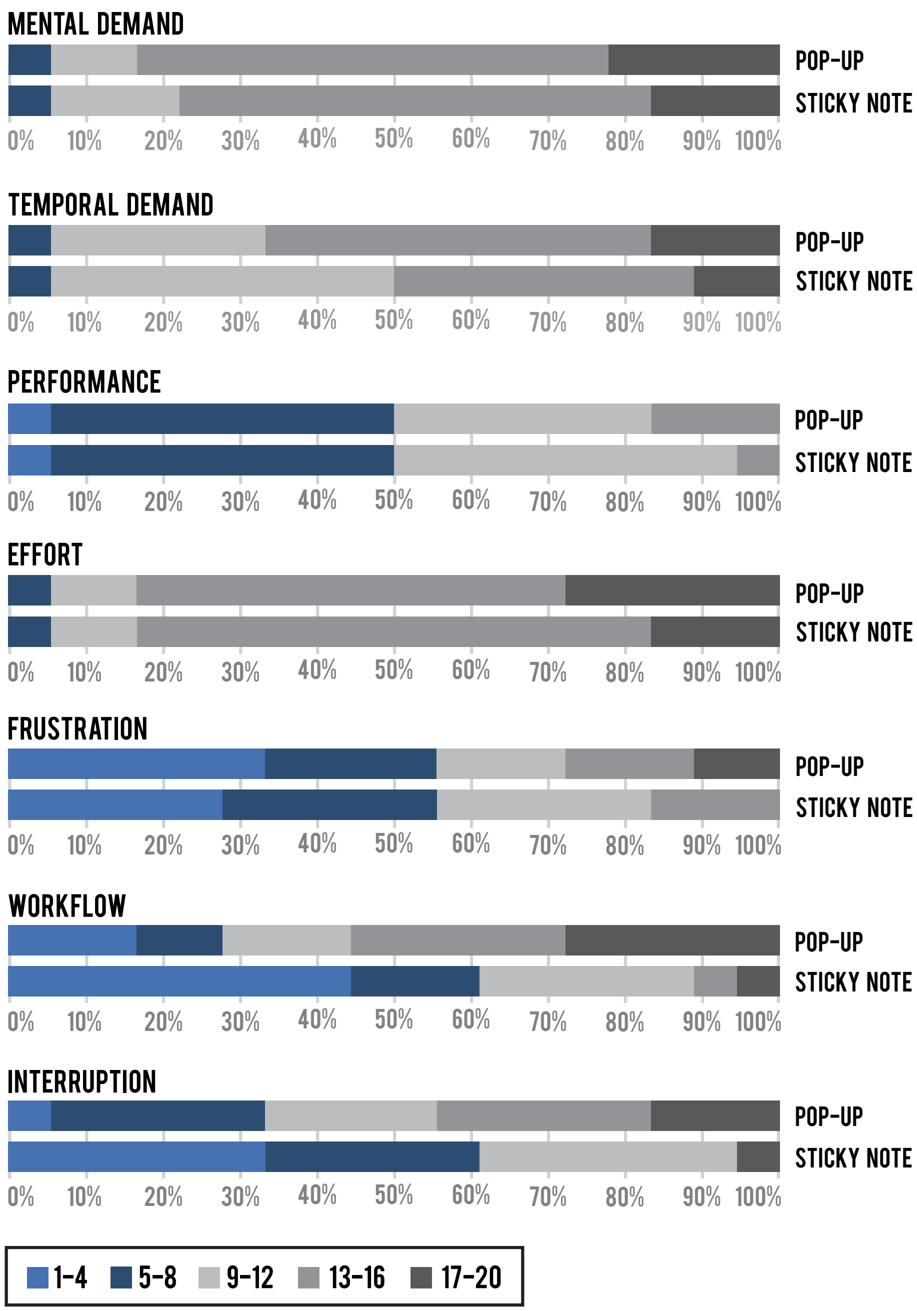

Figure 6.5: Ratings in the adapted NASA-TLX survey assessing seven workload-related factors (*mental demand, temporal demand, performance, effort, frustration, workflow, interruption*) under the pop-up and sticky note feedback conditions.

less successfully (*performance*) and with more *effort* under the pop-up condition as compared to the sticky note condition. Most interestingly, there was a highly significant effect of the feedback modality on the perceived impact of interruption. The notifications requesting the participants to perform the arithmetic training were perceived to be more disturbing under the pop-up condition than the sticky note condition, which is clearly evident from the ratings for our custom *workflow* and *interruption* scales.

Final Questionnaire Ratings

Ratings in the final questionnaire assessing the effects of interruption under the pop-up and sticky note conditions are depicted in Figure 6.6. A two-way within-subjects ANOVA revealed a highly significant effect of the different feedback modalities on perceived effects of interruption on all three scales, as listed in Table 6.3. In other words, participants felt less distracted from the primary task (*distraction*), felt less disrupted by the feedback (*disruption*), and felt less disturbed in their workflow (*disturbance*) under the sticky note condition than the pop-up condition.

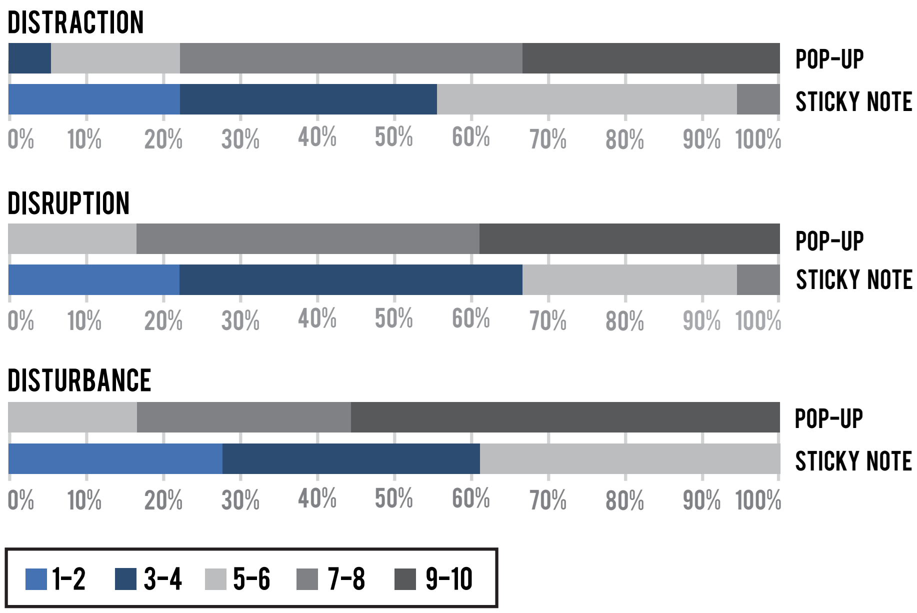

Figure 6.6: Ratings in the final questionnaire assessing the effects of interruption (*distraction, disruption, disturbance*) during the pop-up and sticky note feedback conditions.

Effect of Interruption	***F***	***p***
Distraction	$F_{1,17} = 66.649$	0.000
Disruption	$F_{1,17} = 61.416$	0.000
Disturbance	$F_{1,17} = 70.508$	0.000

Table 6.3: Main effects of the feedback modality on perceived effects of interruption (final questionnaire).

6.4.2 Performance Measurement Results

The results of the time measurement show that the Total Working Time (TWT) for one complete task consisting of Time On Task (TOT), *start time*, Time On Interruption (TOI), and *return time*, was on average 578 seconds ($SD = 59.68$) under the pop-up condition and 588 seconds ($SD = 54.34$) under the sticky note condition. Although there was no main effect on the TWT, these findings indicate that participants needed slightly longer to perform a task under the sticky note condition than the pop-up condition. Provided that, we took a closer look at the single components counting for the TWT. Since the primary transcript task was timed on 4×90 seconds, the major portion of TOT remained constant for each feedback condition. Analyzing the times to start the interrupting task (*start time*), we found that participants took significantly longer under the sticky note condition ($M = 11.28$, $SD = 3.95$) than the pop-up condition ($M = 7.40$, $SD = 3.43$). These results show that the time to start the interrupting task was significantly affected by the type of feedback, $F(1, 17) = 7.30$, $p < .05$. In the interrupting task, participants needed about equally much time ($M = 62.00$) to solve the five arithmetic calculations (TOI) under the pop-up condition and the sticky note conditions. Looking at the times to return to the main task after an interruption (*return time*), we found surprisingly short time spans. Again, there was no main effect for the type of feedback. The time to return to the main task was only slightly longer under the pop-up condition ($M = 3.15$, $SD = 1.00$) than the sticky note condition ($M = 2.78$, $SD = 0.57$). Average time measures for a single interruption are summarized in Figure 6.7. Provided that, we can conclude that the time to start the interrupting task is the crucial component influencing the differences in total working time between the two interrupted feedback modalities.

Primary Task Performance

In the primary transcript task, participants typed on average 1012 characters ($SD = 212$) under the control condition, 1144 characters ($SD = 220$) under the pop-up condition, and 1154 characters ($SD = 250$) under the sticky note condition. The analysis of variance showed a main effect for the feedback type on primary task progress, $F(2, 34) = 17.59$, $p < .001$. Nevertheless,

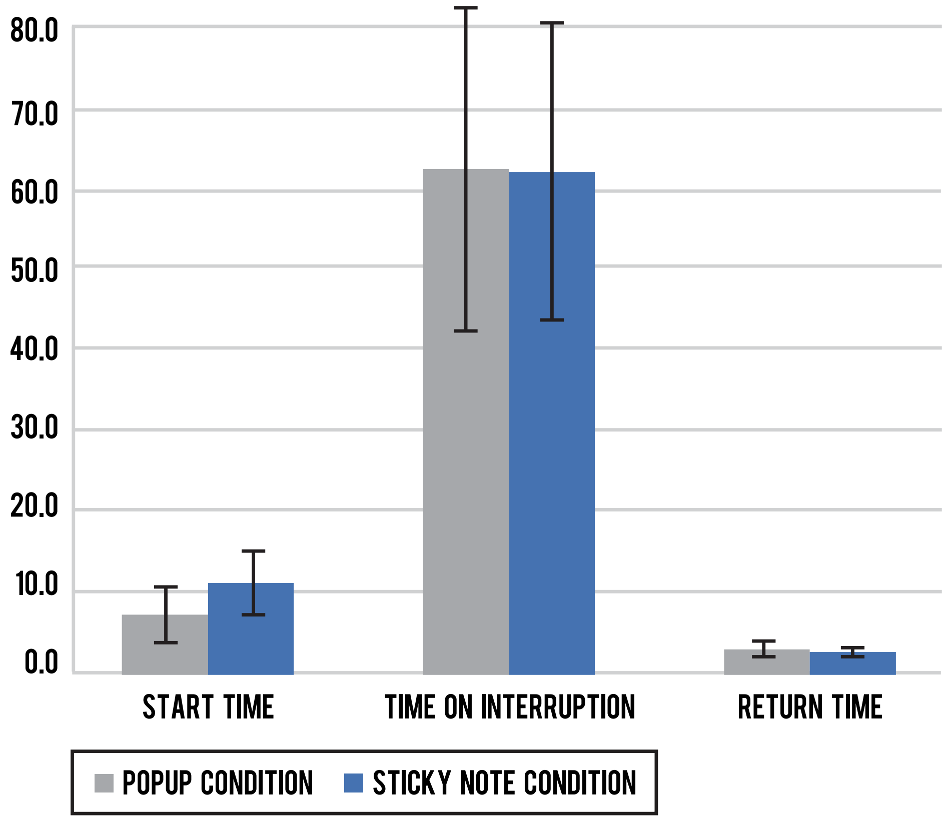

Figure 6.7: Average time measures (in seconds) for a single interruption under the pop-up and sticky note conditions: *start time*, *Time On Interruption (TOI)*, *return time*.

the subsequent pairwise t-tests revealed that there was only a significant difference between the uninterrupted control condition and the interrupted pop-up and sticky note conditions. Furthermore, the *primary task error rate* was lowest under the control condition (M = 2.94, SD = 2.84), but only slightly higher under the pop-up condition (M = 3.89, SD = 3.32) and in the sticky note condition (M = 3.00, SD = 2.89). Nevertheless, due to the high standard deviation, these results showed no main effect either.

Qualitative analysis of participants' switching behavior during the primary task showed a significant main effect for feedback modality, $F(1,17) = 5.09$, $p < .05$. Participants switched significantly more often between the transcript document and the media player window under the pop-up condition (M = 21.2, SD = 4.2) than the sticky note condition (M = 20.1, SD = 4.7) or control condition (M = 18.5, SD = 3.4), thus taking up smaller portions of information from the video before writing them down in the transcript document. Further analysis of the *awareness strategies* exhibited by participants in response to an interruption announcement showed that feed-

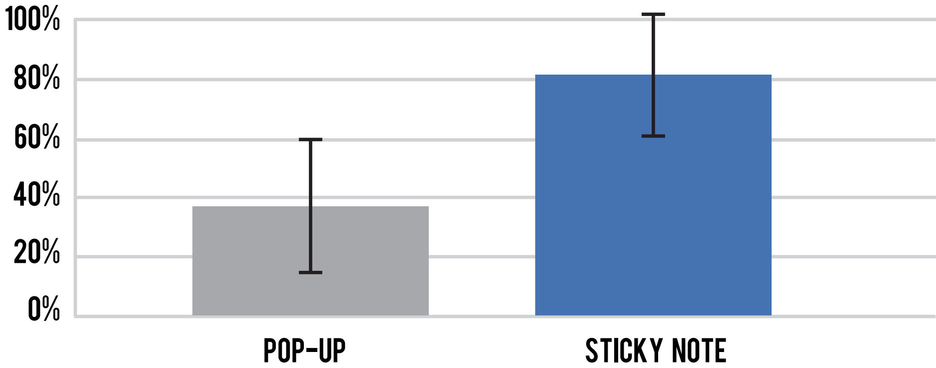

Figure 6.8: Average tendency of participants to postpone interrupting task processing (chunking behavior) under the pop-up and sticky note conditions.

back modality had a highly significant effect, since the tendency to postpone interrupting task processing was higher under the sticky note condition than the pop-up condition (see Figure 6.8). Processing of the interruption was postponed on average 81.48% (SD = 20.52%) of the time under the sticky note condition, as opposed to 37.04% (SD = 22.55%) under the pop-up condition, $F(1,17) = 21.10$, $p < .001$.

Interrupting Task Performance

In the interrupting arithmetic task, participants needed on average 62.20 seconds (SD = 20.01) under the pop-up condition and 61.81 (SD = 18.17) seconds under the sticky note condition to solve five arithmetic calculations presented during each interruption (*interrupting task performance*). The *interrupting task error rate* was slightly higher under the pop-up condition (M = 1.37, SD = 0.95) than the sticky note condition (M = 1.17, SD = 0.87). However, there was no main effect of the feedback modality on any interrupting task performance measures.

6.5 Discussion

Summarizing, we can state that our first hypothesis regarding the less disturbing effect of Move-it sticky notes as opposed to standard Microsoft Office Outlook reminders, was conclusively confirmed. The fact that the interruption-related task load ratings for interruption and workflow showed significantly better results under the sticky note condition as well as the highly significant results of the final questionnaire assessing the effects of interruption contribute to our expectations. According to that, participants felt less distracted from the primary task, felt less disrupted by the feedback, and felt less disturbed in their workflow under the sticky note condition than the pop-up condition. The higher disruptive effect for Microsoft Office Outlook reminders seems to be because the dialog box requesting the participants to perform the arithmetic training popped up in the middle of the screen and blocking user interaction with any other applications. As a consequence participants had to immediately deal with the request before they were able to continue on their primary task. Furthermore, the emotional state ratings are in line with participants' comments that the feedback from the moving sticky notes was mainly perceived in the periphery while performing the primary task, for example: *'I could observe the motion of the Post-it notes from the corner of my eye while I was concentrated on composing the transcript document'.* Thus, we conclude that our Move-it sticky notes successfully served as peripheral displays by drawing the participants' attention from the periphery without disturbing them while engaged in a primary activity. On the other hand, experience has shown that feedback being too subtle may not be noticed by people at all [30]. In the present experiment participants were aware of the fact that the sticky note attached to the side of the screen would begin to move when it was time to perform the arithmetic training. To find out if information awareness was still equally high in a real-world scenario, the conduction of a field study would be suitable. Most interestingly, eight participants commented that they noticed the sticky note feedback not only by the wiggling motion, but also by the subtle sound that was generated by the small piece of polyester film scrubbing along the backside of the Post-it note when actuated. Even though there were no statements about the noise being desirable or not, the large number of participants commenting on the auditory feedback suggests that this unexpected side-effect was clearly contributing to the noticeability of our Move-it sticky notes.

Similar to Salvucci and Bogunovich's [70] conclusion, we found that participants exhibited a strong tendency to postpone the processing of the interrupting task until they had reached a desirable stopping point in the primary task. According to that, results of the time measurements showed that the timespan between the announcement of an interruption and the start of the arithmetic training was significantly longer under the sticky note condition than the pop-up condition. People more often took their time to finish writing down the thought they were currently involved in (e.g., a word, a sentence) before dealing with the arithmetic training. This phenomenon might again be due to the Microsoft Office Outlook dialog boxes blocking any interaction on underlying applications and forcing the participants to immediately respond to the request. The most obvious way to deal with the feedback was to simply react to the alert and start with the arithmetic training. For example, one participant stated: *"When I was requested to perform the arithmetic training by the moving Post-it notes, I could ignore the feedback for the moment and finish my current line of thought. The Outlook reminders were particularly disturbing, because I had to respond to them immediately and was completely distracted from my current activity."*. Based on the fact that this *chunking behavior* was exhibited far more extensively under the sticky note condition, and keeping in mind the low disturbance ratings for the sticky note feedback, our findings indicate that, as the level of intrusion decreases, people are more likely to finish their current task before attending to the interruption. Thus, we conclude that our expectations were confirmed in this regard: participants seemed to be less stressed by the sticky note feedback and therefore perceived the interruptions to be less disruptive and annoying. Nevertheless, as pointed out by McFarlane [54], it has to be considered that users exhibiting extensive chunking behavior may indefinitely postpone or even forget to handle the interruption in some cases. For that reason, we integrated a reminder mechanism in our system, which caused the notification to be redisplayed when users did not respond within a predefined timespan (30 seconds in the present experiment). During the experiment, this phenomenon was observed with a total of three participants, who performed the arithmetic training only after receiving another reminding request.

Apart from that, our second hypothesis regarding the better task performance under the sticky note condition, was not supported. Even though participants found the Move-it sticky notes to be less disturbing than the Microsoft Office Outlook reminders, our measurements did not show any significant improvement in primary or interrupting task performance. Given the fact that, according to the task load ratings, participants perceived to have accomplished the task more successfully and with less effort under the sticky note condition, it is very interesting that performance measurements did not confirm these perceptions. Even though the sticky note feedback achieved slightly better results over all performance measures (*primary task performance*, *primary task error rate*, *interrupting task performance*, *interrupting task error rate*), the statistic evaluation showed no significant differences between the sticky note condition and the pop-up condition. This might be due to the fact, that both the primary and the interrupting task used in our experiment did not require constant attention from the participants such as a continuous gaming task like e.g., used in McFarlane's experiments on human interruption [54]. Thus, the disturbance caused by the interruption announcement did not have any observable effect on task performance. On the other hand, performance measurement results suggest that the overall task performance was at least equally good under the sticky note condition as under the pop-up condition and Move-it sticky note feedback is in this regard in no way inferior to common Microsoft Office Outlook reminders.

Chapter 7

Experiment 2: Watch-it Sticky Notes for Awareness

Supporting awareness of the presence of remote people is one of the typical application scenarios for Watch-it sticky notes. Thus, Watch-it notes are used as ambient displays remaining on the periphery of a user's attention and showing information of low to medium importance [52]. For example, a Watch-it sticky note supposed to provide a user with awareness of the status of particular instant messenger (IM) contacts serves as a subtle means of monitoring this changing, non-critical data while performing a continuous primary task. As soon as the online status of a contact changes, the Watch-it note will change its shape accordingly without forcing the user to switch the focus of attention. Based on this application scenario, the goal is to achieve the optimal tradeoff between maximal information awareness and minimal intrusion (see Figure 5.2) to support a user monitoring the availability of IM contacts in the periphery. According to Matthews et al. [53], this goal corresponds to the "make aware" notification level, defined as the demand to represent information of some importance and consume a user's divided attention, i.e., *supporting awareness* of some non-critical information. To evaluate the applicability of Watch-it sticky notes for awareness, we compared them with common Skype status updates, which are usually represented as pop-up windows appearing in the lower right corner of the screen.

7.1 Feedback Modalities

For interruption feedback we compared Watch-it feedback with common Skype pop-up notifications, which resulted in three feedback modalities.

- **No feedback (control condition):** Under this condition, participants are not interrupted at all while performing a continuous primary task. Attention is fully focused on the primary task and performance in this condition serves as a benchmark for the other feedback modalities.

- **Skype pop-up feedback (pop-up condition):** Under this condition, status updates are communicated by standard Skype status notifications, represented as a small pop-up windows appearing in the lower right corner of the screen. The participant's attention is divided between performing the primary task and the Skype update notification until the pop-up window disappears after a few seconds.
- **Watch-it sticky note feedback (sticky note condition):** Under this condition, status updates are communicated by shape-changing Watch-it sticky notes attached to the right side of the monitor. The participant's attention is divided between performing the primary task and sticky note feedback in the periphery.

7.2 Hypotheses

We expected that Watch-it feedback modality would demonstrate a less disruptive effect *(H1)* and information awareness *(H2)*, while achieving better task performance *(H3)* than standard Skype notifications. More specifically, we explored the following hypotheses to address critical questions like:

- How do the different feedback modalities affect task performance?
- How does the feedback modality influence people's perception of the task load? How disturbing do participants perceive the different feedback modalities?
- How long does it take people to notice the feedback? How often is feedback overlooked or misinterpreted?

H1: Awareness communication is less disturbing under the sticky note condition than the pop-up condition.

With Watch-it sticky notes, information about status of IM contacts is moved off the screen and placed in the periphery of the visual field. Due to the fact that none of the working area on the screen is occupied to communicate status updates, we expected feedback under the sticky note condition to be perceived less disturbing than the pop-up condition. Performance measures taken to validate this hypothesis were:

- Task workload perceived by the participants, defined as ratings in the modified NASA-TLX survey (see Section 6.3.5 for details).
- Distraction, disruption and disturbance perceived by the participants, defined as ratings in the final questionnaire.

H2: Awareness support is more efficient under the sticky note condition than the pop-up condition.

Research on feedback modalities for interruptions by Arroyo et al. suggests that responding to different perception channels is essential for effectiveness of interruption communication [3]. Conforming to that, we expected the feedback modality to influence perception of notifications and support awareness more or less effectively. Perceptual research provides evidence that motion signals are more effectively attracting a user's attention than optical signals, even when it appears in the periphery of the visual field [7, 24, 61]. The ability to perceive motion falls off much less towards the periphery of the visual field than for example ability to perceive color or shape. With this evidence, we expected awareness to be supported under the sticky note condition more efficiently than under the pop-up condition, though being processed in the periphery of attention. In other words, we expected status updates to be registered and acknowledged by participants faster and more reliable. Performance measures taken to validate this hypothesis were:

- Promptness of status acknowledgment, defined as the timespan between triggering a status update and acknowledgment by the participant (*awareness latency*).
- Number of correct status acknowledgments (*awareness achievement*).

H3: Task performance is better under the sticky note condition than the pop-up condition.

Very similar to the first experiment, we wanted to find out whether task performance was affected negatively when participants received status updates simultaneously to performing an attention-demanding primary task (see 6.2 for details). Again, we expected performance to degraduate less under the sticky note condition than the pop-up condition. Performance measure taken to validate this hypothesis was:

- Number of objects caught in the course of the primary gaming task (*primary task performance*).

7.3 Experimental Design

18 students (the same as in the first experiment) from the local university were recruited to perform a laboratory study. Participants were asked to perform an attention-demanding primary task of playing a "catch the falling objects" game. While participants were performing this primary task, status updates of IM contacts were triggered frequently and participants were asked to acknowledge each update as fast as possible. Summarizing, the study was a 3 (feedback modality) $\times$ 12 (interruptions), counter-balanced within-subjects design, which took about 7.5 minutes (2.5 minutes for each

condition). Primary task performance was measured in terms of number of falling objects caught during the game. Interrupting task performance was measured in terms of time needed to respond to the status updates, and the ratio of correct acknowledgments.

7.3.1 Experimental Tasks

The primary task consisted of playing a "catch the falling objects" game, where continuously generated objects were to be caught by controlling the horizontal movement of a virtual "bat" using the computer mouse (see Figure 7.1). Each round was 130 seconds in duration with twelve random status updates being triggered in regular intervals of 10 seconds.

This kind of task was chosen due to its attention-demanding characteristics, which impose a high cognitive load on the participants during the course of the game. For the main part, it was designed to be sensitive to interruptions, by selecting a relatively high density (generation interval = 750 ms) and speed (falling time = 2500–2800 ms) of the falling objects. As such, the gaming task was achievable with a success rate of 100% when participants payed full attention to it, but at the same time was sensitive to any distractions. While performing this primary task, participants were instructed to monitor the online status of three fictive Skype contacts and respond to each update as fast and accurate as possible by pressing an according key on the keyboard (e.g., "Press A if Andi's status changes").

Figure 7.1: Desktop screenshot of the primary gaming task, a basic "catch the falling objects" game.

Figure 7.2: The apparatus of the Watch-it experiment *(left)*, close-up of the Watch-it sticky notes used for user status update notifications *(right)*.

7.3.2 Apparatus

Apparatus was the same as in the first experiment (see Section 6.3.4 for details). For the sticky note feedback modality, three Watch-it notes showing the names of three IM contacts were placed (in alphabetical order) on the right side of the monitor as shown in Figure 7.2.

7.3.3 Procedure

At the beginning of the experiment, participants were welcomed and introduced to the purpose of the study. They were then given instructions on the task they had to perform and were instructed to do the task exercises as fast and accurate as possible. Subsequently, participants partook in a short practice round of game playing for one minute to become accustomed to the task. Each session then started with the control condition serving as a benchmark for the remaining two interrupted tasks. After performing the task under the control condition, participants were informed that they would also need to be aware of the remote presence of three fictional IM contacts under the conditions and acknowledge each status update by pressing the corresponding key on the keyboard (e.g., "Press A when Andi's status changes") as fast and accurate as possible. Participants were introduced to this awareness task by performing a short training round of acknowledging twelve status updates. In the training, participants were shown a window showing a list of the three IM contacts along with a status icon next to it. Status updates were represented by the icons next to the contact names changing accordingly. The keyboard assignment was announced at the beginning of the training and remained the same for the rest of the experiment. Thereafter, the primary gaming task and the awareness task were combined and participants performed them another two times under the pop-up and sticky note conditions.

To measure the effect of the interruptions on the user experience and emotional state, a modified version of the NASA-TLX survey was used. Similar to the previous experiment (see Section 6.3.5 for details), the physical demand scale was skipped and the following two items were added to get more specific information on the perceived impact of the continuous feedback:

- How disruptive was the alert for the workflow?
- How disruptive was the continuous feedback from the status updates?

Finally, after completing the task in all conditions, participants were given a follow-up questionnaire similar to the one described in the first experiment (see Section 6.3.5 for details).

7.4 Results

7.4.1 Emotional State Measurement Results

NASA-TLX Ratings

The overall ratings of the NASA-TLX survey are depicted in Figure 7.3. A two-way within-subjects ANOVA was conducted to evaluate the effect of feedback modalities on the perceived task load. For all tests an alpha level of 0.05 was used, the Greenhouse-Geisser correction was used when the assumption of sphericity was violated. The results are presented in Table 7.1. Post-hoc analyses were conducted on the significant main effects. These consisted of paired-samples t-tests with familywise error rate controlled across the test using Holm's sequential Bonferroni approach. Significant differences between the means of pairs of conditions are presented in Table 7.2.

NASA-TLX value	***F***	***p***
Mental Demand*	$F_{2,34} = 23.893$	0.000
Temporal Demand*	$F_{2,34} = 12.285$	0.001
Performance*	$F_{2,34} = 26.850$	0.000
Effort	$F_{2,34} = 29.717$	0.000
Frustration	$F_{2,34} = 30.442$	0.000
Workflow	$F_{1,17} = 7.460$	0.014
Interruption	$F_{1,17} = 11.184$	0.004

Table 7.1: Main effects for feedback modality on perceived task load (NASA-TLX). Starred (*) results indicate Greenhouse-Geisser corrected values.

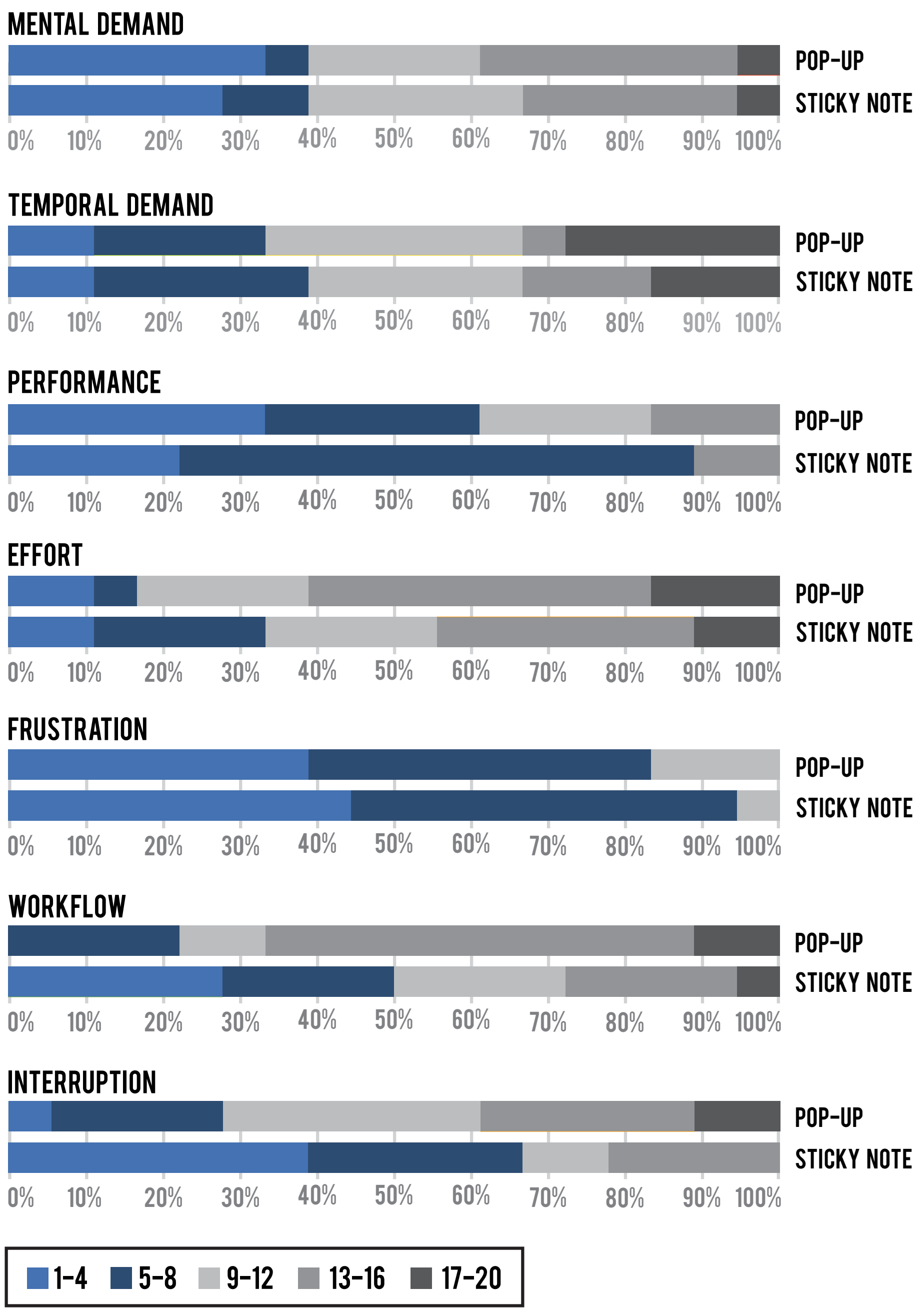

Figure 7.3: Ratings of the adapted NASA-TLX survey assessing seven workload-related factors (mental demand, temporal demand, performance, effort, frustration, workflow, interruption) for pop-up and sticky note feedback conditions.

NASA-TLX value	**Pair**	***F***	***p***
Mental Demand	Control – Pop-Up	$t(17) = -5.190$	0.000
	Control – Sticky Note	$t(17) = -4.960$	0.000
Temporal Demand	Control – Pop-Up	$t(17) = -3.861$	0.001
	Control – Sticky Note	$t(17) = -3.401$	0.003
Performance	Control – Pop-Up	$t(17) = 5.644$	0.000
	Control – Sticky Note	$t(17) = 6.891$	0.000
	Pop-Up – Sticky Note	$t(17) = -2.543$	0.021
Effort	Control – Pop-Up	$t(17) = -6.513$	0.000
	Control – Sticky Note	$t(17) = -5.359$	0.000
	Pop-Up – Sticky Note	$t(17) = 2.515$	0.022
Frustration	Control – Pop-Up	$t(17) = -6.093$	0.000
	Control – Sticky Note	$t(17) = -6.021$	0.000

Table 7.2: Significant mean differences along perceived task load (NASA-TLX) between pairs of feedback conditions.

The investigation of these results shows that participants perceived the workload for the experimental task significantly lower under the uninterrupted control condition than the interrupted pop-up and sticky note conditions, since there was a main effect across all scales. This indicates that the continuous gaming task in the present experiment was much more attention-demanding and consequently more sensitive to interruptions than the writing task in the first experiment. Apart from that, the experimental task was perceived to be accomplished more successfully (*performance*) and with less *effort* under the sticky note condition than the pop-up condition. Finally, there was a significant difference regarding the perceived impact of interruption. Thus, the contact status update notifications had less negative ratings on the *workflow* and *interruption* scales under the sticky note condition than the pop-up condition.

Final Questionnaire Ratings

The ratings of the final questionnaire are depicted in Figure 7.4. A two-way within-subjects ANOVA revealed a highly significant effect of the different feedback modalities on perceived effects of interruption on all three scales, as listed in Table 7.3. The results showed that *distraction*, *disruption*, and *disturbance* caused by the status update notifications were perceived to be significantly lower under the sticky note condition than the pop-up condition.

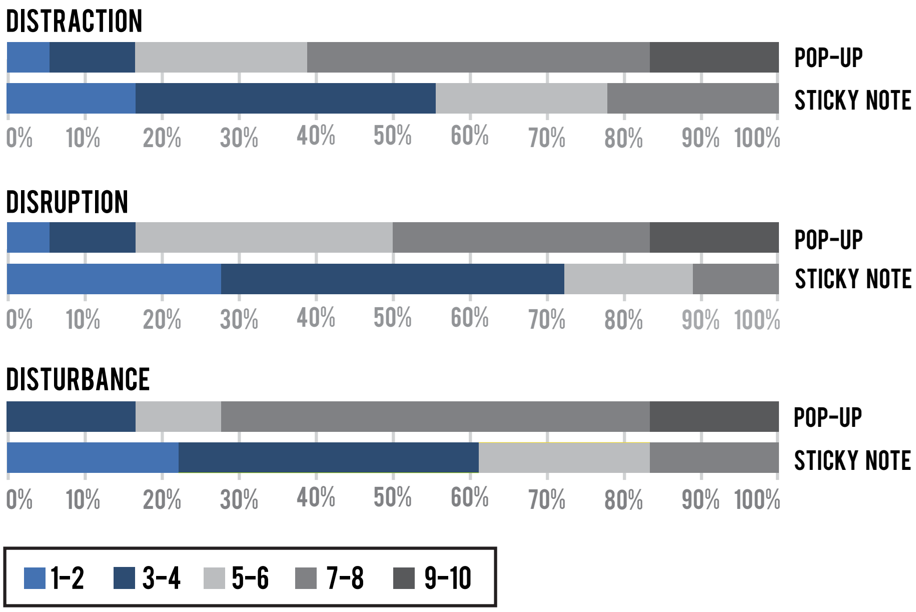

Figure 7.4: Ratings of the final questionnaire assessing the effects of interruption (distraction, disruption, disturbance) for pop-up and sticky note feedback conditions.

Effect of Interruption	***F***	***p***
Distraction	$F_{1,17} = 13.600$	0.002
Disruption	$F_{1,17} = 18.775$	0.000
Disruption	$F_{1,17} = 24.775$	0.000

Table 7.3: Main effects of the feedback modality on perceived effects of interruption (final questionnaire).

7.4.2 Performance Measurement Results

The analysis of the *primary task performance* revealed a major effect of the feedback modality on the success rate i.e., the number of objects caught during the continuous gaming task, $F(2,34) = 36.259$, $p < .001$. From the results represented in Figure 7.5 it is evident that the success rate was significantly higher under the sticky note condition than the pop-up condition. Furthermore, there was also a significant difference between the control, pop-up and sticky note conditions regarding the time that participants needed to acknowledge a status update after its occurrence (*awareness latency*), $F(2,34) = 123.465$, $p < 0.001$. Figure 7.6 illustrates the differences and makes clear that acknowledgment times clearly increased under the pop-up and sticky note conditions in comparison to the uninterrupted control condition, which

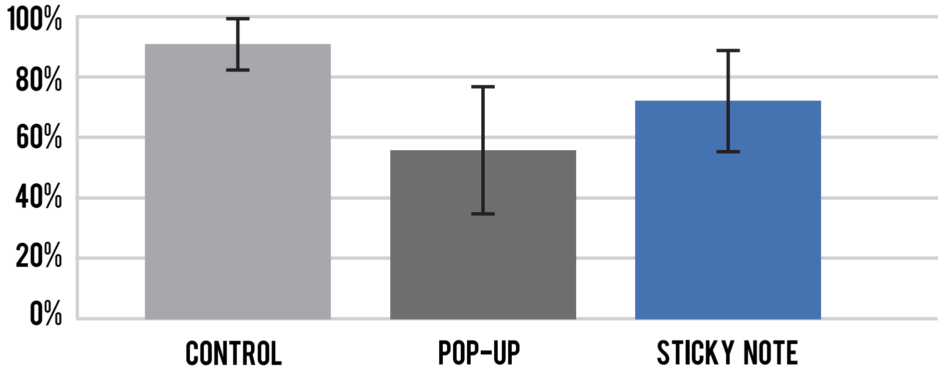

Figure 7.5: Average success rates on the continuous gaming task (*primary task performance*) under the control, pop-up and sticky note conditions.

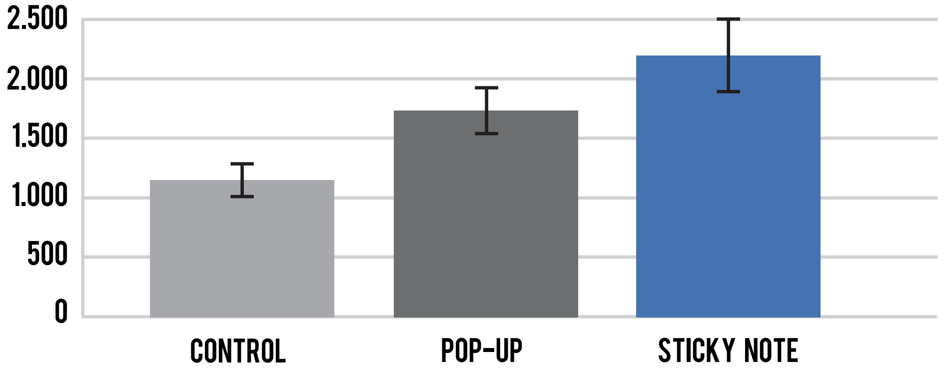

Figure 7.6: Average time (in milliseconds) participants needed to acknowledge a status update after its occurrence under the control, pop-up and sticky note conditions.

may be a result of the larger distance between the gaming window and the status updates in the corner of the display area resp. on the side of the screen. Nevertheless, contrary to our expectations, *awareness latency* was significantly higher under the sticky note condition than the pop-up condition. *Awareness achievement* on the other hand, did not show any significant effect. Acknowledgment rate was a hundred percent under the control and pop-up conditions and only slightly less under the sticky note condition (M = 98.61%, SD = 4.29%). Detailed results of the pairwise t-tests on significant performance measures are summarized in Table 7.4.

Measure	Pair	*F*	*p*
Primary Task Performance	Control – Pop-Up	$t(17) = 7.982$	0.000
	Control – Sticky Note	$t(17) = 5.013$	0.000
	Pop-Up – Sticky Note	$t(17) = -3.888$	0.001
Awareness Latency	Control – Pop-Up	$t(17) = -12.423$	0.000
	Control – Sticky Note	$t(17) = -13.910$	0.000
	Pop-Up – Sticky Note	$t(17) = 6.864$	0.000

Table 7.4: Significant mean differences along performance measures between pairs of feedback conditions.

7.5 Discussion

Summarizing, it turns out that our first hypothesis regarding the less disturbing effect of Move-it sticky notes in contrast to common Skype pop-up notifications was completely verified. In accordance to the findings of the first experiment, the task load ratings for *performance* and *effort* as well as the interruption-related ratings for *interruption* and *workflow* showed significantly better results under the sticky note condition than the pop-up condition. The final questionnaire ratings assessing the *distraction*, *disruption*, and *disturbance* caused by the status updates showed a significant main effect in favor of the sticky note feedback. However, considering that participants were all familiar with Skype or similar IM applications and used them on a daily basis, the high significance of these findings is rather surprising. For instance, one participant explained it like that: *"I am used to keeping an eye on the lower right corner of the screen watching out for Skype updates, the moving Post-it notes were rather unusual for me at the beginning"*.

The second hypothesis regarding the more efficient awareness support with Move-it sticky notes was not confirmed. There was no main effect for *awareness achievement*, and status updates were acknowledged by participants significantly slower (*awareness latency*) under the sticky condition than the pop-up condition. A possible explanation for this rather unexpected finding may be that the feedback under the sticky note condition allowed processing of the awareness information in the periphery without shifting the focus of attention from the primary task. As opposed to this, the pop-up windows disappeared after a fixed time of four seconds, consequently forcing the participants to shift their focus of attention soon after the appearance of the pop-ups in order to read, process, and acknowledge the status updates in time. Consequently, participants had more time under the sticky note condition to wait for an opportune moment to distract their focus of attention for a short moment from the primary task in order to press the according key on the keyboard – a highly interesting phenomenon, which has been observed with a total of twelve (i.e., 66%) participants. From the participants' comments we noticed a number of statements confirming these assumptions, like: *"Since every Post-it note was assigned a particular position and color, there was no need to read the name on it every time"*, or *"After a while I could easily determine from the corner of my eye which contact's status had just changed and didn't have to take my eyes off the game"*. The Skype notifications required the participants to read the name of the corresponding contact whenever a pop-up window appeared in the lower right corner of the display, while Watch-it sticky notes remained in a fixed position on the side of the screen and gave participants the opportunity to familiarize with the spatial arrangement and colors of the Post-it notes. Consequently, we conclude that the affordances of Move-it sticky notes, supporting flexible spatial arrangement and color-coding, were appreciated by the participants and made it easier for them to associate a particular Watch-it sticky note with a corresponding Skype contact.

Finally, the third hypothesis regarding the better task performance under the sticky note condition was confirmed entirely since participants caught significantly more falling objects under the sticky note condition than the pop-up condition. In contrast to the first experiment, the continuous gaming task in the present experiment was highly attention-demanding and glancing at the pop-up notifications resp. sticky notes in the periphery of the field of view had direct consequences on the control of the game. Thus, participants easily missed a falling object when they were distracted by the status update. Unlike standard Skype pop-ups, Move-it sticky notes gave participants the opportunity to memorize the associations between Post-it notes and messenger contacts. As mentioned above, status updates could therefore be perceived in the periphery of the field of view without shifting one's focus of attention from the primary gaming task.

Chapter 8

Conclusion and Future Work

We presented the Move-it system, an *active paper interface* that integrates the strengths of both the real and the digital world. By combining common Post-it notes with a technologically enhanced paperclip, we can give active feedback to the user through subtle motion cues and turn a passive piece of paper into an active medium. The intuitive interaction with real paper, digital data management, and the additional functionality of giving active physical feedback are the core features of the Move-it system. The combination of these research aspects is exactly what makes the novel approach of our unique intuitive interface and allows us to bridge the gap between the real and digital worlds. In our system, paper is not only seen as an input device but also as a tangible artifact suitable for temporary storage, communication, and reminding. Through three demo applications, we demonstrated the versatility of the Move-it system in specific everyday scenarios: Mind-it sticky notes for active reminding, Watch-it sticky notes for information awareness, and Find-it sticky notes for interactive bookmarking. To investigate the applicability of Move-it sticky notes as peripheral displays for human interruption, we carried out two experiments and found that our moving paper notes cause significantly less disruptive effects than common UI solutions such as dialog boxes or pop-up windows. The comments and the results of the experiments suggest that the affordances of Move-it sticky notes were found to be highly valuable and make the proposed system a promising solution for effective human interruption design.

Furthermore, the results of the experiments motivate us to improve the current system and to investigate new ways to improve user experience. For example, the motion generated by the interactive Move-it ioClip used in our current implementation is limited, since it does only support one defined shape to be "remembered". To generate more sophisticated motion patterns, it would be desirable for the paperclip to remember multiple and/or different shapes (e.g., curved) rather than switching between straightly expanded and contracted states only. For example, to depict the availability of an IM contact, the bending angle of a Watch-it sticky note could then be controlled by the software to distinguish between 90° (online), 45° (away/occupied), and 0° (offline). Keeping in mind the limitations of SMA technology discussed in Section 4.4, it seems also promising to eliminate the need for some external heating source and associated external power supply, currently limiting the portability of our system. One possible way to solve this problem would be the replacement of the currently used NiTi-based alloys by another type of SMA. Ferromagnetic shape memory alloys (FSMA) for example, change their shape in response to magnetic fields and are of particular interest for our system, as the magnetic response tends to be faster and more efficient than a temperature-induced response. Beyond that, the processing of the handwritten pen input could be extended by a more advanced text analysis to make text input more flexible (e.g., 5:00 pm vs. 17:00 h etc.). Instead, the pre-defined layout structures could be replaced by a natural language processing approach. This would obviate the need to distinguish between different types of Move-it sticky notes (i.e., Mind-it, Watch-it, Find-it) and lay the foundations for a generic solution supporting virtually any information source to be captured on a single Move-it sticky note. Another area, which has not yet been explored, is the establishment of a physical input channel. While Move-it sticky notes provide a physical output channel by giving feedback through deformation, it is also desirable to sense user input through physical manipulation e.g., dog-ears, tearing or crumpling. A Move-it sticky note could for example react to a dog-eared corner by opening the associated item in the PIM tool on the desktop computer, tearing or crumpling could invoke the deletion of the associated digital representation. With this extension, our interactive sticky notes could both *give* and *receive* active physical feedback. Finally, a field study could evaluate the applicability of Move-it sticky notes for human interruption in a real-world scenario like e.g., an office environment.

Appendix A

Attachments

Format: CD-ROM, Single Layer, ISO9660-Format

A.1 Master Thesis

Pfad: /

S0910629019.pdf	Master Thesis

A.2 Images

Pfad: /img

postit.eps	Location-sensitive Post-it notes, Figure 1.1
SME.eps	Shape Memory Effect, Figure 1.2
moveitNotes.eps	Move-it sticky notes, Figure 3.1
moveitNote1.eps	Mind-it sticky notes example, Figure 3.2
moveitNote2.eps	Watch-it sticky notes example, Figure 3.3
moveitNote3.eps	Find-it sticky notes example, Figure 3.4
moveitWorkflow.eps . .	Move-it workflow, Figure 4.1
anoto.eps	Anoto pen annotation, Figure 4.2
ioclipSensoryVEC.eps .	Move-it ioClip sensory, Figure 4.3
ioclipSensoryBMP.eps .	Move-it ioClips, Figure 4.4
ioclipBending.eps	Move-it ioClip actuation, Figure 4.5
moveitSetupBMP.eps .	Move-it system setup, Figure 4.6
moveitSetupVEC.eps . .	Move-it system structure, Figure 4.7
moveitSystem.eps . . .	Move-it system components, Figure 4.8
inputmanager.eps	Anoto pattern, Figure 4.9
strokemanager.eps . . .	Predefined input regions, Figure 4.10

itemmanager.eps	PIM synchronization, Figure 4.11
arduino.eps	Arduino microcontroller, Figure 4.12
interruptionLifecycle.eps	Human interruption lifecycle, Figure 5.1
interruptionMatrix.eps .	Human interruption tradeoffs, Figure 5.2
study01breakpoints.eps	Experiment1 task model, Figure 6.1
study01workflow.eps . .	Experiment1 task workflow, Figure 6.2
study01task.eps	Experiment1 tasks, Figure 6.3
study01apparatus.eps .	Experiment1 apparatus, Figure 6.4
study01TLX.eps	Experiment1 NASA-TLX ratings, Figure 6.5
study01final.eps	Experiment1 final ratings, Figure 6.6
study01TWT.eps	Experiment1 time measures, Figure 6.7
study01chunk.eps	Experiment1 chunking behavior, Figure 6.8
study02task.eps	Experiment2 tasks, Figure 7.1
study02apparatus.eps .	Experiment2 apparatus, Figure 7.2
study02TLX.eps	Experiment2 NASA-TLX ratings, Figure 7.3
study02final.eps	Experiment2 final ratings, Figure 7.4
study02success.eps . . .	Éxperiment2 success measures, Figure 7.5
study02time.eps	Éxperiment2 time measures, Figure 7.6
*.jpg	High resolution bitmap sources

A.3 Source Code

Pfad: /src/MoveIt

MoveIt.sln	Microsoft Visual Studio 2010 solution file
MindIt.xml	Mind-it sticky notes XML configuration
WatchIt.xml	Watch-it sticky notes XML configuration
FindIt.xml	Find-it sticky notes XML configuration
/MoveIt	Move-it Microsoft Visual Studio library
/MindIt	Mind-it Microsoft Visual Studio project
/WatchIt	Watch-it Microsoft Visual Studio project
/FindIt	Find-it Microsoft Visual Studio project

Pfad: /src/MoveItStudies

MoveItStudies.sln	Microsoft Visual Studio 2010 solution file
/MoveIt	Move-it Microsoft Visual Studio library
/study01	Experiment1 Microsoft Visual Studio project
/study02	Experiment2 Microsoft Visual Studio project

A.4 Study Data

Pfad: /doc

study01Disturbance.xlsx	Experiment1 emotional state measures
study01Performance.xlsx	Experiment1 performance measures
study02Disturbance.xlsx	Experiment2 emotional state measures
study02Performance.xlsx	Experiment2 performance measures

Pfad: /doc/questionnaires

TLX00.pdf	NASA-TLX survey, non-interrupted
TLX01.pdf	NASA-TLX survey, interrupted, Experiment1
TLX02.pdf	NASA-TLX survey, interrupted, Experiment2
final.pdf	Final questionnaire

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