Thinking with Our Hands –

Theoretical Foundations of Multimodal Interfaces in Concept-Forming

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Abstract. Multimodal interfaces have been researched and positively evaluated in the context of improvement of task performance and skill communication. In this study we are discussing the possibilities to extend the notion and benefits of multimodal interfaces in support of cognitive tasks such as concept-forming, information organization and memory. Anecdotal evidence that this extension might be appropriate and promising is discussed and potential areas that could be supported in this way are described. Our study aims to bring together theoretical foundations coming from grounded cognition and connect them to practical study results in order to establish further research and evaluation directions.

Keywords: Multimodal interfaces, pseudo-haptic, information seeking, search interfaces, grounded cognition

1. Introduction

It has become commonplace to say that in our current days computers have invaded almost every aspect of our lives. Originally conceived as dedicated information processing systems, computers were intended to help us comb through the constantly growing amounts of information. This task was generally conceived of as an abstract task of sorting through numbers and texts, and manipulating them. The conceptual tools used to carry out this task are derived from the metaphor of documents and writing and involve predominantly our visual sense to solve problems and carry out domain specific tasks such as reading and editing texts, evaluating the – mostly textual – display of search results etc. Our tactile senses are reduced to handle the keyboard and the mouse. These physical activities do not directly contribute to the task of information processing. Moving the mouse does not help us understand a text better, it is simply a way of e.g. scrolling through the text in order to read it and process it through visually perceived information.

As forms of computing have entered many other aspects of our day-to-day activities also the tasks and forms of interaction have changed. In particular haptic interaction has received a lot of attention since the introduction of touch screens. By now we can say that mouse and keyboard are rivaled by touch-sensitive devices for human computer interaction. The absence of any haptic features on touch screens and the resulting lack of precision of interaction with those devices has triggered avid research in how haptic feedback can be integrated (Onishi, Sakajiri, Miurat, & Ono, 2013; Yang, Zhang, Hou, & Lemaire-Semail, 2011). In most of these studies, though, the haptic clues are used to replicate the functional principles of the mouse and keyboard-style interactions. They aim to make the operation of touch-screen devices easier and more precise – and success has been shown. These studies also show that our perception is fundamentally multimodal, it uses information from multiple senses to construct a representation of our environment. In order to increase performance in the operation of computing interfaces the information from multiple sensory modalities, mostly visual, auditive and haptic, is used to promote information processing on all of these levels. This allows a more effective integrated approach than the sole reliance on the visual sense could deliver (Oviatt & Cohen, 2000). Using multiple sensory modalities we can potentially increase our ability to process information and to act in our environment. While most studies in human computer interaction focus directly on the support of computing tasks such as interface operation, data input etc., we are interested if the notion of multimodality can also be used to support tasks such as information organization, memory, and concept forming. The domain within which we are investigating this question are tools for library searches. Our goal with this study is to discuss the theoretical foundations of multimodal interfaces as applied to tasks of concept forming, such as the evaluation of search hits. As earlier studies employing multimodal interfaces provided anecdotal evidence of a correlation of effects of multimodality and concept-forming, this study is intended to further investigate this problem field with a review of relevant theoretical concepts. We aim to establish the nature and direction of future research endeavors. In this study we are looking at the theoretical foundations of multimodality and concept forming in cognitive science and connect them to the results of practical studies.

1.1 Multimodality

As a first step it is necessary to clarify what the term multimodality is intended to refer to within the context of our study. The interest in sensory modalities in support of the information exchange between humans and computers has received a lot of attention and various studies have been made within the field of human computer interaction. Nevertheless in many concepts of multimodality the understanding of what modalities are varies. In most approaches pertaining to human computer interaction the modalities which together form the model of multimodality are the human senses with which we receive information from our environment, i.e. our five senses of vision, hearing, touch, smell, and taste (see e.g. Bolt 1980). As Bernsen argues in (Bernsen 2008), within those sensory categories, which we could describe as the 'media' through which the information exchange is materialized, we have to distinguish several subcategories, which we could call semiotic modalities, such as textual versus iconic. This distinction is necessary since we exchange several different 'kinds' of information within one and the same 'medium' or sensory category. Images and text, both part of the visual sensory category, are very different in the way they are en- and decoded as carriers of meaningful information. The same applies to spoken language and abstract auditory cues. The study of how we decipher these subcategories has less been a concern of human computer interaction rather than social semiotics (Kress 2010). Given these examples the distinction of subcategories is necessary and helpful to support a more in depth analysis of all elements at work in an exchange of information. This subcategorization has its problematic aspects, though. The gesture of pointing at an object would be considered an action in the haptic domain for the person pointing. For the person decoding this message it would be in the visual domain. This consideration points to the importance of establishing the point of reference for the analysis of an information exchange correctly – but it also points to the close relationship between the different modalities and senses. In this study we are interested in those close relationships, how the perceptual data of one modality influence those of another and the effects of these influences on concept forming.

1.2 Concept-Forming Process

Another aspect in need of clarification is our use of the term concept-forming. As explained above with the example of (Bolt 1980), a dominant aim of studies in human computer interaction was to look to multimodality to improve user performance in the operation of task oriented interfaces, such as the interface of a word processor, or of highly skill oriented tasks such as teleoperation applications (e.g. Pittman, LaViola, & Joseph, 2014). Our interest here is not on skill improvement, though, but aims to establish if multimodal interfaces have the potential to support processes of knowledge creation. We refer to activities such as the cognitive evaluation of information units like search hits of a library search, the formation of memory in the task of memorizing information units like authors, book titles or article contents and the establishment and evaluation of relationships between units of information. Adopting the notion of the concept as knowledge about a particular context from cognitive science (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003), we use the term concept-forming to refer to the process of constructing context-specific knowledge about a question at hand. We are looking more specifically at the process of conceptual work on a research question, which is tackled through the evaluation of various information units, such as database and library searches or measurement data. As Barsalou et al. argue in (2003) knowledge sedimented in concepts guides our perception and the way how we establish relationships between the data we perceive; in a similar way knowledge also guides us in the reconstruction of memories and in the encoding and decoding of linguistic expressions. This means the concept-forming process is deeply ingrained in acts of perception and memory.

Proponents of grounded cognition state that the formation of our concepts about the world is dependent on perceptual modalities. Lakoff and Johnson describe the formation of concepts as based on various layers of metaphors grounded in physical sensory experience (Lakoff & Johnson, 1980). The more abstract a concept is the more layers of metaphors are used to connect the concept to the sensory physical experience, which means that in a more or less direct way sensory experience provides the grounding for our knowledge. In (Barsalou 2008) Barsalou supports the argument that the internal representations of concepts are dependent on modalities. Various studies indicate that stimuli pertaining to different modalities can support concept-forming and Barsalou points to studies of property verification, in which the participants have to verify properties pertaining to specific modalities (e.g. visual or auditory) of concepts. In these studies the verification of the auditory property "loud" for "blender" is faster when prior to that other verifications in the auditory domain were done, whereas it is slower when prior verifications were done in a different modality. Similar results have been found in relation to the haptic modality (Barsalou et al., 2003).

In this sense it seems motivated to extend the notion of multimodality to processes of concept forming and to investigate how multimodal interfaces can support these processes. Our interest in this study is therefore to examine if multimodal sensory clues can be used to support our cognitive processing of information. And in particular our question is whether we can we use haptic clues to increase cognitive efficiency. Our turn towards haptics is motivated by the recent advances and the proliferation of haptic interface technologies. We seek to formulate new directions for research and to evaluate if the potential use of multimodal interfaces including haptic sensation is a promising basis for new designs of library search interfaces.

2. Haptics in Information Seeking

Most of the current implementations of novel haptic interfaces going beyond the experience with keyboard and mouse use touch screens or some forms of gestural control. Touch screen interfaces such as described in (Yang et al., 2011) remain relatively stable, they mostly use buttons or related interface elements. The task to produce haptic feedback for virtual buttons is rather clearly defined and requires just one kind of mechanism to simulate many kinds of buttons. The mechanism can be implemented as a physical structure custom tailored to the intended functions like the simulation of button edges to increase the ease and precision of use of on-screen keyboards (Pakkanen, Raisamo, Raisamo, Salminen, & Surakka, 2010). For our question of how multimodal haptics interfaces can support concept-forming processes we will have to think about haptics and haptic sensation in a broader sense. We have to look for solutions that can cover a wide range of tasks and application domains. What kinds of interface options might be appropriate for this task will be discussed further down in our study. It seems clear, though, already on a first approach that library search, search hit evaluation and concept-forming, would not significantly benefitfrom a more precise operation of interface widgets. If we want to extend the involvement of multiple senses, and namely the haptic sense, towards general cognitive processing tasks, we would have to accommodate a wider and more flexible range of haptic stimuli. We found that library search offers us a compelling example case to discuss this problem field with a concrete example at hand. Even though library search today is mostly done through online search engines we still have an inherently physical connection to the library. We still conceive of the information carrier as paper, gathered in journals and books, which are stored in a physical location, on shelves, which again are located in a dedicated building. This means we dispose of a set of familiar object associations along with the notion of a spatial structure of the library building. These associations provide a connection point to work with when we conceive of possible haptic sensations in support of memorizing information items, relationships between those items, and the task of establishing orientation and navigation among many information items.

Many libraries have by now adopted so called next generation catalogues, which offer a lot more information than the classic list of search hits with author, title, date etc. They give access to the full content of books, video clips and journal titles, and they allow to access book covers, reviews, images and other information elements (Yang & Hofmann, 2010). Next Generation catalogues have mostly replaced older versions of library catalogue systems. Part of what makes those new catalogues popular are tagging systems allowing the user to tag their results with user defined tags (Ballard & Blaine, 2011). This means that an advanced library search system has to deliver not only access to the bibliographic information about the holdings but also ways to navigate, sort and refine the search hits and to build relationships and concepts based on them. As more information is contained in the query results and the discoverability of titles is increased, the effort to structure the search hits becomes more consuming and requires more powerful support structures. Possible support structures beyond the textual realm can address aspects such as navigation, i.e. orientation and way-finding through various search representations, physical markers such as cover images etc. to locate, recognize and evaluate titles within a defined information need and probably many others. If we analyze the experience of dealing with real books in a 'brick and mortar' library, clues such as location and physical appearance of a book play important roles in the task of finding the appropriate knowledge items. Context of shelf location provides connections of a kind that is often not easily represented by tag or keyword relationships. This points to the role of physical factors in the library search experience, which are served by the use of real objects with certain physical, haptic qualities.

Drawing on these properties associated with the library as a physical entity to support interaction and information seeking in computer-based search interfaces seems promising. Studies analyzing for example signage systems in a library indicate that properties going beyond the textual indexing provided by the catalogue have measurable influence on the circulation of books in physical libraries (Stempler 2013). Conceiving of an information retrieval system as a designed construct – for example a library building – informed by certain values, it becomes important to reflect those values in order to positively influence user acceptance and attitudes towards the system. The system design is another non-textual aspect expressed in its appearance and the values expressed by its design that has an impact on the efficiency of concept forming processes (Pavlovsky n.d.). As the physical presence of the described properties has an impact on information seeking processes and concept forming it stands to be expected that similar approaches can be used to support concept-forming in the virtual realm.

2.1 Anecdotal Evidence

From earlier studies we have obtained indicators for the role haptic experience plays in our concept forming processes. Of particular interest is the anecdotal evidence we received in response to a project about a planned urban restructuring project in Downtown Los Angeles. The project was a visualization of the planned construction of a subway interchange hub and its integration into the existing city structure of the neighborhood. The project used a touch sensitive model of the neighborhood built out of multiplex wood. The model was completely white and served as a projection surface for various visualizations of the dynamics, and the historic and social structure of the area. User interactions were tracked through a depth camera (Microsoft Kinect) which allowed users to tangibly explore the area by pointing to certain places or physically touching buildings or other parts of it (Chen & Kratky, 2013). The same visualizations were presented to another group of users without the tangible interface only as a series of images and videos. In casual interviews with members of both groups we found that those who used the tangible interface had a better concept and recollection of the city situation and of how the planned intervention was going to interact with the existing city structures than the group of people who had only seen the visualizations. It seems that the model supported the spatial orientation as well as the ability to remember aspects of the construction and how they fit into the bigger picture of the neighborhood.

A second study examined the use of a handheld touch-screen device (Apple iPod) as an interface to explore virtual representations of physical objects (Kratky 2012). The project was designed as a test scenario for a natural history museum, intended to gauge user responses to a novel form of exploring objects from the collection through a tangible interface. In this project we did not produce a custom-made tangible experience like in the previous example but used the form factors of the off-the-shelf device. With the device museum visitors could explore extremely high-quality three dimensional representations of jelly-fish, which were presented along with the real objects behind glass. The jelly-fish were too fragile to be exhibited in a fashion that was open enough to explore them from all sides, so the iPod app was supposed to complete the experience of seeing the real object, unreachable behind glass, and exploring it on the screen. The screen display had added explanations of parts of the jelly-fish and allowed to zoom in and out and turn the objects. Again through casual interviews with users of the app and non-app-users we found that the app-users had a significantly better understanding of the shape of the different creatures than the visitors who only looked at the objects behind glass from the front.

Both examples point to the role haptics play in the process of concept-forming, but comparing the two examples also tells us that not only the real physical experience has an impact on memory and concept-forming but also the virtual experience. In the second example users were only able to interact with a screen-based representation, swiping their fingers over a touch screen while holding an object with realistically very different dimensions and features than the object they were examining in their hands – but nevertheless they were able to form a significantly better concept of the objects than those who only saw the real objects. App-users also reported that they had a feeling like holding the object in their hands.

2.2 Pseudo-Haptics

The focus of haptic interface implementations is generally the production of perceivable physical stimuli through vibration, electro motors and other means of generating actual forces. Several studies have shown, though, that effects similar to the increased task performance with multimodal haptic interfaces can be achieved simply through the simulation of the additional haptic information in other sensory modalities. As the second of our previous examples also suggested, the combination of visuals with certain haptic information can lead to a situation where the user believes to experience phenomena, which are actually not existent. For example in an experiment in which the participants had to use a track-ball-like interface device to control the visual representation of a spring the users felt different degrees of compliance of the spring as the result of a change in the rate in which the track-ball transmits their input and a change in the movement of the spring image. Even though the users did not have to change the force they exerted on the input device, they felt they had to put in more force and perceived the result as a ‘pseudo force feedback’ (Lecuyer, Coquillart, Kheddar, Richard, & Coiffet, 2000). The visual and the haptic information are processed together and deliver a compound sensation, that can even be perceived in a different sensory modality thatn those by which it is produced. Lécuyer goes on to describe that the visual information obtained by lip reading actually is processed by the auditory regions of the cortex. As Lécuyer outlines in (Lécuyer 2009) the pseudo haptic sensation is created through visual feedback synchronized with a certain sensory-motor action of the user. Both informations are processed in conjunction and lead to a percept that borders on sensory illusion. Similar phenomena to the visuo-haptic coupling have been observed with auditive and haptic combinations (Lai, Niinimäki, Tahiroglu, Kildal, & Ahmaniemi, 2011). Pseudo-haptic effects have been proven to be effective in the execution of shape identification as well as operation and interaction tasks (Ban, Narumi, Tanikawa, & Hirose, 2012). Even though again pseudo-haptic settings are used predominantly for skill-based tasks it seems appropriate to assume that they can also be used in support of concept-forming tasks. The wide range of visual, auditory and haptic couplings suggests that it could be used to address a wide bandwidth of different haptic phenomena and tasks. This presents a possible solution to the demand for a broad spectrum of haptic sensations as discussed earlier.

3. Supporting Cognitive Efficiency

In contrast to most other haptics and pseudo-haptics studies we are interested in the effect of pseudo-haptic effects on concept-forming processes. While task completion studies have found measurable differences in haptics supported multimodal interfaces (Leung, MacLean, Bertelsen, & Saubhasik, 2007), so far no empirical data about concept-forming processes are available. We can describe the desired effect as an increase in the cognitive efficiency of users in information retrieval and evaluation actions. Cognitive efficiency is a concept used in several disciplines such a neuroscience, psychology, education and others to describe the ratio between "increases in the rate, amount, or conceptual clarity of knowledge, versus costs, such as cognitive effort, needed to attain knowledge" (Hoffman 2012). The variable of cognitive efficiency can be used to track and evaluate the speed and quality of concept formation in information seeking. In our current society a high cognitive efficiency in the processing of search hits or in the evaluation of often abundant information offerings is an important factor. As Hoffman discusses in (2012) cognitive efficiency is considered to be consisting of three main areas: neurological efficiency, the location and degree of brain activity, instructional efficiency, the effectiveness of instructional methods, and of learning efficiency, a characteristic of the individual learner. It is in particular the instructional efficiency that can be addressed through information retrieval interface solutions. The goal would be to reduce the mental effort involved into the deciphering of the presentation of search results, appropriate structuring of the necessary working memory and a presentation design that actually takes the neurological efficiency of the learner into account. On both levels efficiency can be gained by distributing the cognitive load across the available sensory modalities. As van Gog et al. write, integrated or multiple modality formats foster learning if they distribute the cognitive load in appropriate ways across the modalities (Gog, Kester, Nievelstein, Giesbers, & Paas, 2009). Gog et al. go on to suggest three methods of measuring cognitive efficiency. One measure relies on concurrent and retrospective verbal reporting, which asks users to report their thoughts and decision-making processes during interaction with the interface. Another possible measure may be obtained by eye tracking during the interaction process. This measure can identify fixation lengths that may be associated with situations of high cognitive load, as well as speed and structure of eye movement, which can reveal erratic saccades versus smooth directed exploration. A third measure can be obtained through concept maps, asking the participants to visualize schemata of concepts and their relationships formed during the interaction.

3.1 Possible Cognitive Effects of Multimodal Representations

In the following we will discuss the main areas of information seeking processes that can potentially benefit from multimodal haptic representations in the attempt to increase cognitive efficiency. The results from pseudo-haptics research imply that through a combination of visual representation in conjunction with sensory-motor action can result in reliable and stable pseudo-haptic effects. As high-level requirements of an information seeking system we can identify actions of discovery of information items, the evaluation and recognition of relevant items, the navigation of groups of information items, and the establishment of relationships between information items. It is probable that several of these actions can be supported through effects of multimodal pseudo-haptic interfaces. Actions involving object recognition and navigation can benefit from a visuo-haptic grounding of the representation of information items. For example it can be imagined to represent information items with physical properties allowing for efficient identification and recognition of items. In a similar way orientation and the navigation of groups of information items can be supported. Through viso-haptic and maybe audio-haptic cues the orientation can be supported involving experiential spatial cues. Concrete implementation of these properties will have to be carefully considered and prepared with tests. This development will have to build on top of the results of earlier investigations in spatial representation of search hits and other interface designs that have already been evaluated (Van Hoek & Mayr, 2013).

Another crucial aspect of concept-forming in response to query results is the ability to remember results in order to determine relationships to earlier query results. Memory is crucial to most of the tasks involved in the information seeking process. Not only the establishment of conceptual relationships and the evaluation of information items relies on memory, but also orientation among groups of items and recognition of items. Similar to the arguments of grounded cognition, also memory can be conceived of as grounded. Glenberg describes memory in (Glenberg 1997) as conceptualized patterns of possible bodily interactions, resulting in the notion that the meaning of an object resides in what a person can do with the object, event or sentence. Such a concept of memory as a complex of embodied concepts implies that through appropriate multimodal haptic cues the formation and these memory conceptualization can be supported. If the processing of information items does not have to rely on abstract textual descriptors only – as it is the case in most information seeking systems currently – other cues such as object appearance information can contribute to a successful and efficient memory construction and recall. Again the precise implementation will have to be tested and carefully developed, but we can derive potential directions from these reflections.

3.2 Mapping of Pseudo-Haptic Variables

In this section we will discuss some potential approaches and areas of inquiry for the implementation of multimodal pseudo-haptic information retrieval systems. In order to ground our reflection in a concrete scenario we will assume an interface giving access to the holdings of a library. The holdings are assumed to be consisting of books, journals, images, sounds, and objects of varied nature. The holdings are assumed to be mostly digitized, accessible digitally through a computer-based interface. In terms of pseudo-haptic couplings we are focusing on visuo-haptic and audio-haptic displays, assuming a combination of screen-based visuals and haptics implemented as touch (touch-screen) and gestural control (both as gestures on the touch screen as well as gestures in space acquired through a tracking device) as well as auditory cues.

In the example case of library search we can build on the association of information units as tangible objects such as books with defined appearance properties and the fact that these objects exist inside the spatial structure of the library as a way of delivering grounding for object recognition and orientation. An important part of the information seeking process is the ability to intuitively direct queries to the information retrieval system that will result in responses close to the information need. While normally done through keyword search, this action could be supported by e.g. spatial coding of areas of interest – as it is traditionally done in the library. Starting the formulation of a search in a certain spatially grounded section could alleviate the difficulty of having to know and distinguish various specialized databases from each other to understand where to best direct the query. A seamless spatial navigation in the query formulation process can mitigate errors in the initial database selection.

To modify queries, open or narrow their scope, it is imaginable to use gestures of encorporation or focus as a way to broaden or narrow. These gestures can be combined with deictic gestures to identify the direction in which the action of inclusion or exclusion of information items is aimed. Rather than a refinement of search properties through keyword adjustment, a gestural translation of the process could reduce the cognitive burden of the search refinement considerably.

A similar approach can be imagined for the structuring and analysis of search results. The possibility to virtually arrange groups of information items to express relationships in the process of formation could be helpful in order to support the formation process as well as to support the ability to repeatedly access items and find them again.

In order to support memory forming it is imaginable to elaborate the representation of information items such that they can be shown with their physical qualifiers. These qualifiers could be their external appearance, parts or full content, as well as crucial properties such as dynamics (in the case of time-based media or other objects that have a time-based dynamic like tools or kinetic objects). If these properties are part of the item representation the users can immediately form a comprehensive understanding of the information item and its relevance for their information need, without having to page the item and after direct examination decide on its relevance.

4. Conclusions and Further Research

Looking at the available literature it appears that an extension of the notion of multimodal representations to interfaces in information seeking is promising. It seems possible to garner benefits from multimodal pseudo-haptic settings for the process of concept-forming in similar ways as benefits have been shown in skill communication and performance. The approaches outlined above are theoretical conclusions derived from the discussion of our study. In order to evaluate their applicability further studies will be required. It seems possible to investigate the proposed interventions as simplified lab tests before implementing them in a larger scale as a library search interface. Conclusive verification, though, would necessitate a larger comprehensive implementation that allows to study interrelationships of the different properties. This study should involve actual users and extend over a longer timeframe in order to observe user responses and effects on their work and scholarship.

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