Communications of the Association for Information Systems

Volume 27 | Number 1 Article 15

8-1-2010

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Abstract:

This article reflects on the discussions of the fifteen participants (co-authors) of a retreat on the "Foundations of NeuroIS" that took place in Gmunden (Austria) in September 2009. In particular, this article offers initial answers to a set of research questions which are important for the foundations of NeuroIS, an emerging subfield within the IS discipline. The key questions discussed during the retreat that are addressed in this article are: (1) What is NeuroIS, and how does it relate to sister disciplines, such as neuroscience, neuroeconomics, and neuromarketing? (2) Which neuroscience tools are relevant for IS research? (3) What can IS researchers learn from the neuroscience literature, and what do we already know about brain activity? (4) What are possible IS research topics that can be examined with neuroscience tools, and what are some promising research areas for NeuroIS? (5) How can NeuroIS be established as a new subfield in the IS literature, and what are the current challenges for NeuroIS? The article concludes by offering the participants' outlook on the future of NeuroIS.

**Keywords:** NeuroIS, cognitive neuroscience, brain, neurophysiological measurements, fMRI, EEG, TMS

Volume 27, Article 15, pp. 243-264, August 2010



Communications of the Association for Information Systems

## I. INTRODUCTION

In recent years, there has been an explosion in the application of neuroscience methods to study the functionality of the human brain. The field of cognitive neuroscience, which studies observable correlates of brain activity to identify the brain areas that underlie human functions and processes, has made significant advances during the last decade [Adolphs, 2003; Hüsing et al., 2006; Lieberman, 2007]. The increasing availability of neuroimaging tools that can capture brain activation, such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), as well as psychophysiological tools that can capture emotional and cognitive states, such as electrocardiography (EKG), facial electromyography (EMG), and skin conductance response (SCR), have been used to make significant theoretical advancements. These advancements are not only due to research conducted by scholars in biology and medicine. Rather, social scientists and social neuroscientists—mostly in economics, psychology, and marketing—started collaborations to examine a variety of social phenomena that allow for a deeper understanding of human behavior by studying the functionality of the brain [Glimcher et al., 2009].

Due to the recently increased availability of neuroscientific techniques and theories, recently Information Systems (IS) scholars have begun to investigate the potential of neuroscience for IS research. Dimoka et al. [2010], for example, outline a set of seven opportunities for how cognitive neuroscience can inform IS research: (1) localize the neural correlates of IS constructs to better understand their nature and dimensionality; (2) complement existing sources of IS data with neuroscientific data; (3) capture hidden (automatic) processes that are difficult to measure with existing measurement methods; (4) identify antecedents of IS constructs by exploring the specifics of how IT stimuli (e.g., the design of graphical user interfaces) are processed by the brain; (5) test the outcomes of IS constructs by showing how brain activation predicts behavior (e.g., decisions); (6) infer causality among IS constructs by examining the timing of brain activations due to a common stimulus; (7) challenge existing IS assumptions and enhance IS theories that do not correspond to the brain's functionality. Riedl [2009], to state another example, discusses a number of applications of neuroscience theories and methods in IS research. In particular, his conceptual framework outlines applications on four levels of analysis (individual, group, organization, and society). These levels of analysis emphasize that an individual's brain activity, although pertaining to the level of the individual, can nevertheless be influenced by and influence behavior at the other levels.

A few IS researchers have already conducted empirical studies using various neuroscientific methods. Moore et al. [2005] and Randolph et al. [2006] investigated opportunities for locked-in patients (people who are completely paralyzed and unable to speak, but cognitively intact) to communicate on the basis of brain-computer interfaces. Galletta et al. [2007] measured the stress of Internet users not only by a traditional questionnaire, but also by a "physiological measurement" that allowed for measuring stress "in a more objective manner." Dimoka and Davis [2008] studied the brain areas related to the Technology Acceptance Model (TAM) to identify the neural correlates of perceived usefulness and perceived ease of use for commercial websites. In another study, Dimoka [2010] provides neural evidence that trust and distrust in e-commerce are not the two ends of one continuum but rather two distinct constructs, thereby providing an answer to a question which could hardly be solved convincingly based on behavioral data and self-reported perceptions alone. Finally, Riedl et al. [2010] found brain activation differences between men and women when processing trustworthy and untrustworthy eBay offers. These results might indicate that IS-relevant gender differences on the behavioral level are correlated with differences in brain functionality.

The appeal of neuroscientific techniques is not confined to academia. For example, *Daimler-Chrysler* used fMRI to gain insights on how to improve their car design [Erk et al., 2001]. The video gaming industry, to state another example, has been using EEG-based headsets for a while to capture the brain's electrical states while playing games. These states are used to modify the gaming experience (see www.emotiv.com and www.neurosky.com). The world's largest software company, Microsoft, has also started a research program in the field of brain-computer interaction. A goal of this research is to complement traditional input devices (e.g., mouse) with additional non-muscular input-modality such as specific user thoughts [Tan and Lee, 2006]. This additional information channel could increase the productivity of computer users.

Considering both the recent efforts in research and practice to integrate neuroscience and IS research and the already existing research findings which demonstrate the potential of neuroscience for IS research, two North American scholars (Fred Davis and Angelika Dimoka) and one European IS scholar (René Riedl) organized a workshop recently to develop a research agenda for NeuroIS[1] that would bring together IS researchers with experience and/or interest in NeuroIS with academics from neuroscience. This format was considered to allow for a reflection of both the most recent developments in the IS discipline and the potential of the brain sciences for IS research. Gmunden, a small summer resort in Austria, was chosen as the scene for the meeting entitled "Gmunden Retreat on the Foundations of NeuroIS," which took place from September 22 to 24, 2009. The structure of the event was based on a number of discussion questions, which together form important contents toward a research agenda. In the following, we summarize and reflect on the discussions of the Gmunden Retreat that focused on the following questions:

1. What is NeuroIS, and how does it relate to sister disciplines, such as neuroscience, neuroeconomics, and neuromarketing?
2. Which neuroscience tools are relevant for IS research?
3. What can IS researchers learn from the neuroscience literature, and what do we already know about brain activity?
4. What are possible IS research topics that can be examined with neuroscience tools, and what are some promising research areas for NeuroIS?
5. How can NeuroIS be established as a new subfield in the IS literature, and what are the current challenges for NeuroIS?

Before we begin with our discussion, we would like to stress that a main objective of the present article is to outline the great potential of neuroscience to advance IS theorizing. As a consequence, in our opinion NeuroIS is not just a hype (see also Dimoka et al., 2009). Rather, we believe that neuroscience has the potential to considerably facilitate scientific progress in the IS discipline, because, as formulated by Dimoka et al. [2007, p. 13], "it is just hard to believe that a better understanding of brain functioning will not lead to better IS theories." Considering this statement and many other arguments which we will discuss in this article, we call for broad participation in the new field of NeuroIS.

## II. WHAT IS NEUROIS, AND HOW DOES IT RELATE TO SISTER DISCIPLINES, SUCH AS NEUROSCIENCE, NEUROECONOMICS, AND NEUROMARKETING?

The term *NeuroIS* (Neuro-Information-Systems) has been coined by Dimoka et al. [2007] to describe the "idea of applying cognitive neuroscience theories, methods, and tools in Information Systems (IS) research."

NeuroIS is a subfield in the IS literature that relies on neuroscience and neurophysiological theories and tools to better understand the development, use, and impact of information technologies (IT). NeuroIS seeks to contribute to (i) the development of new theories that make possible accurate predictions of IT-related behaviors, and (ii) the design of IT artifacts that positively affect economic and non-economic variables (e.g., productivity, satisfaction, adoption, well being).

IS research investigates the development, use, and impact of information technologies [Benbasat and Zmud, 2003]. Despite its unique focus, IS research draws upon multiple reference disciplines in the social sciences, such as psychology, economics, and sociology. Accordingly, neuroscience could also be another reference discipline that can help inform IS research [Dimoka et al., 2010; Riedl, 2009]. Therefore, research in neuropsychology (investigations on brain structure and functioning underlying human behavior), neuroeconomics (use of neuroscience to understand economic behavior), and neuromarketing (use of neuroscience to understand consumer behavior and marketing phenomena) can also help guide IS research, similar to how related social sciences have developed and used neuroscience theories and tools to inform their respective disciplines. The neuroscience literature provides a large number of useful insights related to IS research questions. Examples are neuroscientific theories in the domains of decision-making, learning, memory, reciprocity, and trust [Glimcher et al., 2009].

## III. WHICH NEUROSCIENCE TOOLS ARE RELEVANT FOR IS RESEARCH?

This section reviews neuroscience tools on the basis of already existing overviews. In particular, we draw on the following papers: Camerer et al. [2005], Kenning and Plassmann [2005], Lee and Chamberlain [2007], and Shiv et al. [2005]. During the retreat, the purpose was to discuss the broad spectrum of neuroscience tools available to NeuroIS rather than discussing each tool extensively.

[1] The organizers would like to thank Paul A. Pavlou, who provided his valuable support during the planning and execution of the event.

## Psychophysiological Measurements

Probably the oldest and simplest technique for measuring neurophysiological states is the measurement of psychophysiological indicators [Camerer et al., 2005]. Heart rate (often measured by EKG) can be used to detect cognitive attention, because the heart rate changes as cognitive attention is directed to a situation [Cacioppo et al., 1990; Fridlund and Izard, 1983; Lang, 1994]. Facial electromyography (EMG) can be used to measure the emotional response by attaching sensors to different parts of the face. Increased activity in the zygomatic muscle group (the smile muscle near the mouth) has been linked to positive emotion and increased activity in the corrugator muscle group (the frown muscle near the eye) has been linked to negative emotion [Cacioppo et al., 1990; Fridlund and Izard, 1983]. Skin conductance response (SCR)—essentially sweating—is an indicator of arousal; the more aroused an individual becomes, the more he or she sweats (e.g., in the palms), regardless of whether the arousal is positive or negative [Damasio, 1994]. Thus SCR is often combined with facial EMG to understand the direction and strength of emotion. Although these techniques do not directly measure brain activity, the captured indicators are closely related to the nervous system. Typically, psychophysiological responses to stimuli occur near instantaneously, while other neurological responses can require several seconds to occur. The participants of the retreat viewed these techniques highly appropriate for the investigation of a number of IS research questions, in particular in human-computer interaction and decision-making studies.

## Imaging of Brain Activation

Brain imaging techniques are the most popular neuroscientific tools at the moment [Camerer et al., 2005; Logothetis, 2008; Logothetis et al., 2001]. The logic of brain imaging is simple: It typically compares a person's brain activation under two conditions, a control condition and an experimental task condition. The differential activation indicates the brain areas that are involved with performing the task. In the following, we briefly describe five imaging methods, which capture brain activation and which we consider to be relevant for NeuroIS: electroencephalogram (EEG), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), magnetoencephalography (MEG), and near infrared spectroscopy (NIRS).

### Electroencephalogram (EEG)

This tool measures voltage fluctuations on the scalp which result from changes in membrane conductivity elicited by synaptic activity and intrinsic membrane processes. An electrode on the skin captures the summed post synaptic potentials generated by a large number of neurons. The main advantage of EEG is its high temporal resolution (i.e., milliseconds), and it is often used to follow the time course of neural activity. In contrast, spatial resolution is very limited. The so-called inverse problem [Helmholtz, 1853] which says that an infinite number of source configurations can generate identical surface potentials as measured by EEG, does not allow for an unambiguous identification of the neural generators (i.e., the location of the neural activity within the brain). Typically, localization of brain activity requires appropriate a priori assumptions about sources and parameters of volume conduction [Babiloni et al., 2005; Michel et al., 2004].

When applying EEG, one distinguishes between evoked potentials (EPs) and the spontaneous EEG. EPs are potential variations which occur synchronously to a certain stimulus. Averaging over a large sample minimizes non-phase locked components and only components which are phase-locked remain [Regan, 1989]. In contrast, spontaneous EEG is non-phase locked to a certain stimulus. Even though, it can also vary according to a stimulus. However, higher order techniques are necessary for analyzing the data and computing the relationship between the stimulus and EEG signals [Pfurtscheller and Lopes da Silva, 1999].

### Functional Magnetic Resonance Imaging (fMRI)

This tool tracks blood oxygenation in the brain and exploits the different magnetic properties of oxygenated and deoxygenated blood (the so-called BOLD contrast) [Kwong et al., 1992]. Simultaneous direct recording of neural processing and fMRI responses shows that the BOLD signal reflects the parameters of neural activity reasonably well [Logothetis, 2008; Logothetis et al., 2001]. In contrast to EEG, fMRI provides better spatial resolution (from one or two centimeters to a hundred micrometers), however, with a lower temporal resolution (a few seconds). As in EEG, in a typical fMRI study, multiple trials per person are averaged for the statistical analysis. It should be noted that the development of fMRI technology is ongoing and will continue to improve [Camerer et al., 2005].

It is of particular importance for the social sciences that it is possible to simultaneously scan the brain of two or more participants engaged in a social exchange (the so-called "hyperscanning method") [Montague et al., 2002]. This new technique is especially important for the analysis of social concepts, such as cooperation, trust, reciprocity, and related constructs. One study [King-Casas et al., 2005], for example, studied the brain activity of two persons while playing an economic game to study the brain activity related to each participant's inferences regarding trust and trustworthiness of the other participant. Obviously, because trust is a central construct in IS research [Gefen et al., 2008], new technologies such as hyperscanning have an exciting potential advancing scientific progress in the IS discipline.

### Positron Emission Tomography (PET)

Positrons are the antiparticles of electrons generated during the radioactive decay of specific radio-nuclides. As positrons are instantly destroyed upon generation (by encountering an electron), they dissipate into two high-energy gamma-quants that are emitted in diametrically opposed directions. These gamma-quants are detected by the PET scanner which calculates their point of origin from their respective path difference. Usually isotopes of elements are used that enter into metabolically relevant molecules, such as sugars or alcohols. After injection or inhalation of these radio-nuclids (e.g., modified glucose or neurotransmitters), their calculated spatial distribution allows inferring the blood flow or metabolic rate within the brain. Spatial resolution is relatively high (in the centimeter range), but temporal resolution is low (several minutes) [Kenning and Plassmann, 2005]. As PET scanners require the exposure of participants to radiation, the application to healthy test persons is usually restricted.

An example for a PET study with relevance for IS research is an experiment performed by Haier et al. [1992]. In this study, brain activity was measured twice in subjects playing the computer game Tetris, before and after practice. After four to eight weeks of daily practice on Tetris, brain activity decreased, despite a more than seven-fold increase in performance. This result suggests that learning can result in a more efficient use of the brain, reflected by a decrease in brain metabolism. This finding has direct implications for IS research, for example, when comparing the effects of different computer training designs.

### Magnetoencephalography (MEG)

This tool is sensitive to changes of the magnetic fields that are induced by electrical brain activity [Kenning and Plassmann, 2005]. The temporal and spatial resolution of MEG can be compared to that of EEG. This technique is, therefore, also suited to resolve the temporal sequence of the different cortical processing stages involved in decision-making and other human processes. In contrast to the EEG, however, MEG is able to depict activity in deeper brain structures [Bräutigam et al., 2001, 2004]. Nonetheless, the inverse problem also applies to MEG. Hence, source localization strongly depends on a priori assumptions. MEG has already been used, for example, to identify the neural correlates of shopping decisions [Ambler et al., 2004], which demonstrates its potential use to IS research (e.g., e-commerce).

### Near Infrared Spectroscopy (NIRS)

This is a tool of brain activity imaging by measuring changes in the haemoglobin oxygenation state of blood in cortical brain areas [Hoshi, 2003]. This tool exploits the property of blood to change its color depending on its level of oxygenation. Infrared light can penetrate the skull and enter a few centimetres into the gray matter of the cortex, where it is partly absorbed. From the measurement of the spectral content of the reflected infrared light, blood oxygenation can be inferred. A typical NIRS system consists of two types of optodes, emitters and detectors, that are placed on the skull. The emitters send infrared light through the skull that is partly absorbed and reflected back to the skull, where it is collected by infrared detectors. Depending on the oxygen content of the blood, the emitted infrared light will be absorbed differently. Similar to fMRI, NIRS does, therefore, measure the electrical activity of the brain indirectly by detecting local changes in blood flow and blood oxygenation that are closely related to neural activity. In addition, participants are not as restricted in their body movements as within an fMRI scanner. Therefore, NIRS is of particular value in studies with children who have difficulties lying down or sitting still. NIRS has, for example, been used in a number of studies monitoring changes of cerebral oxygenation in response to cognitive, visual, and motor tasks (for a brief summary see, Wriessnegger et al., 2008). Using a computer involves cognitive, visual, and motor elements. Hence, NIRS can be of interest to NeuroIS research.

## Brain Morphology

Neuroscientific tools are not confined to measuring brain activation. There are also techniques that investigate the brain's anatomy and allow comparisons, for example, between different subjects. The logic of brain morphology is to find a correlation between performance and parameters of brain anatomy. In the following, we briefly describe three methods, which capture brain anatomy and which we consider to be relevant in NeuroIS: mapping of brain lesions, voxel-based morphometry (VBM), and diffusion tensor imaging (DTI).

### Mapping of Brain Lesions

Accidents and diseases that damage localized brain regions also help understand brain functioning [Camerer et al., 2005]. When patients with known brain damage to an area responsible for a certain task tend to perform more poorly than healthy people, whereas they do well on other tasks, one may infer that this area is critically involved in the focal performance-impaired task. For example, the somatic marker hypothesis (SMH), a well-established neural theory of economic decision processes, was mainly developed based on evidence from brain damaged patients [Bechara and Damasio, 2005; Damasio, 1996].

It should be noted, however, that generalizing from single case studies has often been criticized. The large variance between individual brain anatomies makes it very difficult to generalize case results. Modern imaging techniques now allow going beyond single cases. In brain lesion mapping, a large number of patients with similar lesions are grouped according to whether they can perform a certain task or not. The lesion overlap in each group is then statistically compared to pinpoint more specifically the location of the brain area critical for a focal task. Evidence from these studies may be potentially very interesting to IS researchers, but requires close co-operations with hospitals to get access to brain damaged patients.

### Voxel-based Morphometry (VBM)

Voxel-based morphometry segments an individual's brain anatomy into grey and white matter images, which can be compared statistically at the group level. This tool has been used to compare the grey matter density in the brains of men and women, or of younger and older adults [Good et al., 2001]. For NeuroIS, it would be interesting to correlate grey matter density differences in brain areas important for decision making between two age groups or two groups showing consistently differential performance. Another interesting application is to track grey matter density changes induced by learning within or between individuals [Draganski et al., 2004; Maguire et al., 2003].

### Diffusion Tensor Imaging (DTI)

This tool is a specific imaging technique that allows tracking the direction of nerve fibres in the brain's white matter. The tool exploits the directional restriction of water molecules by the densely-packed myleinated (sheathed) neural axons in the white matter of the brain. In contrast, water molecules in cerebrospinal fluid or grey matter can move more freely and in all directions. The degree and the direction of the water molecule movement can be measured (fractional anisotropy) by an fMRI scanner [Bihan et al., 2001; Mori and Zhang, 2006]. This specific type of morphological imaging can reveal the fibre tract trajectories connecting one neural region with others [Camerer et al., 2005].

Specifically interesting are differences between different groups of subjects categorized according to their performance. Gold et al. [2007] applied DTI to investigate whether performance in visual word recognition correlates with different white matter architectures in specific brain areas. Also, speed of visual word recognition varies considerably between individuals. Gold et al. observed that these differences could in part be attributed to differences in brain anatomy. Speed of visual word recognition is an essential variable affecting linguistic competence and related behaviors (e.g., using computer programs). Moreover, recent studies have related DTI measures to personality traits [Cohen et al., 2009] and speed of reward-based learning [Cohen et al., 2008]. Because both personality and learning affect IT-related behavior, these studies could be starting points for NeuroIS investigations by means of DTI.

## Transcranial Magnetic Stimulation (TMS)

TMS is a method to stimulate the brain by sending electro-magnetic impulses through the skull. Electromagnetic pulses are sent through a coil held over a certain location of the head. They activate nerve cells which usually disrupts brain function in this area temporarily [Camerer et al., 2005; Lee and Chamberlain, 2007; Shiv et al., 2005]. The differences in cognitive and behavioral functioning that result from such disruptions allow inferring whether this region in fact is critical for a certain task. Theoretically, TMS allows for a more causal testing of brain function than correlative measures, such as fMRI and EEG do [Camerer et al., 2005]. However, there are also several disadvantages. First, the use of TMS is currently limited to the cortical areas close to the skull. Second, due to the interconnectedness of brain areas, the effects of TMS are not limited to the stimulated region, making causal interpretations difficult. Third, there is some evidence that TMS might have longer lasting effects on neural tissue [Jones, 2007].

## Combination of Neuroscience Tools

Every single neuroscience tool has its strength and weaknesses. Therefore, combining two (or more) methods may improve the validity of research findings. Like filling in a crossword puzzle, clues from one tool help fill in what is learned from other tools. For example, fMRI and EEG can be used in combination. Given fMRI compatible electrodes, EEG can be measured within an fMRI scanner. This combines the high temporal resolution of EEG with the high spatial resolution of fMRI. An advantage of this technique is that it allows identifying the neural generators of different components of an EEG signal. Moreover, NIRS and EEG can also be used together. Here, NIRS optodes are combined with an EEG measurement. This adds to the high temporal resolution of the EEG a greater security in spatial localization of sources close to the skull. In addition, participants are not as restricted in their body movements as within an fMRI scanner because NIRS is also comparatively robust with regard to body movement, as this tool relies on optical measurements. Finally, recent studies using TMS in combination with brain imaging techniques have found that TMS does affect the activation in several interconnected brain areas [Ruff et al., 2008]. This indicates that there is often no simple causal relationship between activation in one single brain area and behavioral performance. The complexity of causal relationship advocates the use of TMS with imaging methods.

## IV. WHAT CAN IS RESEARCHERS LEARN FROM THE NEUROSCIENCE LITERATURE, AND WHAT DO WE ALREADY KNOW ABOUT BRAIN ACTIVITY?

Given the extensive neuroscience literature that has been developed during the last decades, there are many insights that can be drawn from the existing body of knowledge to inform IS research. As noted earlier, there is a very rich neuroscience literature in the social sciences, such as psychology, economics, and marketing. Moreover, there is a broader cognitive neuroscience literature that also examines human behavior and has provided insights into the social sciences. Accordingly, one of the propositions posed by Dimoka et al. [2010] is to draw on the rich cognitive neuroscience literature to inform IS research, essentially using findings about the brain functionality to help inform IS theories.

Also, the cognitive neuroscience literature has created "maps" of brain activity by linking different mental processes into brain activations (termed *neural correlates*). Dimoka et al. [2010] reviewed the extensive cognitive neuroscience literature and classified processes into "decision-making," "cognitive," "emotional," and "social." Within each of these four categories, many specific processes have been mapped onto the brain by specifying their neural correlates from the literature (p. 5). Trust has been linked, for example, to striatum activation, whereas distrust has been associated, for example, with activation in the insular cortex [Dimoka, 2010; Riedl et al., 2010]. Similar mappings can be created for cognitive and emotional processes that could be valuable for IS research, such as cognitive effort or automaticity. However, the conclusion of the retreat was that each IS researcher should perform a more focused review of the cognitive neuroscience literature based on the particular process or construct of interest.

## V. WHAT ARE POSSIBLE IS RESEARCH TOPICS THAT CAN BE EXAMINED WITH NEUROSCIENCE TOOLS, AND WHAT ARE SOME PROMISING AREAS FOR NEUROIS?

As noted earlier, IS research can make use of both neuroscience tools (which have been described above), as well as theories and existing findings from the literature. While the usage of neuroscience tools requires access to research facilities (e.g., fMRI scanners), the application of neuroscience theories and findings is more straightforward. Therefore, benefiting from NeuroIS research does not necessarily imply conducting empirical neuroscience studies [Dimoka et al., 2010; Riedl, 2009].[2] Rather, it is equally important to apply the knowledge that has already accumulated in the neuroscience literature to inform IS research questions. Against this background, it could be fruitful, for example, to (1) motivate future behavioral studies, (2) design behavioral experiments, (3) substantiate the conclusions of behavioral investigations, and (4) even question existing assumptions and paradigms on the basis of neuroscience theories.

### The Example of Technology Acceptance Studies

In the following, we describe one example of how to use cognitive neuroscience theories in IS research. We do this by drawing on a prominent IS research stream, namely, technology acceptance studies (for a detailed theoretical discussion and fMRI evidence see Dimoka et al., 2007, 2010; Dimoka and Davis, 2008).

Technology acceptance research has made substantial progress spanning three decades, largely within the predominant paradigm surrounding the technology acceptance model (TAM) [Davis, 1989] and its extensions, such as TAM++ [Venkatesh et al., 2003]. Research within this tradition has theorized about behavior and behavioral intentions and its determinants such as various perceptions including usefulness, ease of use, subjective norm, behavioral control, and facilitating conditions. Despite the progress during the past decades, established academics (including Fred Davis, the TAM originator) have become increasingly more concerned that the rate of progress in TAM and TAM++ has stalled out, with additional studies providing at best only marginal incremental advances (i.e., explaining only a few percentages more of the variance of the dependent variable). Facing this situation IS research has started to evaluate the potential of neuroscience theories for technology acceptance research [Dimoka and Davis, 2008].

TAM has a very strong *rational* perspective about how people form their technology adoption decision (because the TAM and TAM++ literature largely draws upon the theory of *reasoned* action [Fishbein and Ajzen, 1975], and the theory of *planned* behavior [Ajzen, 1991]. However, several streams of research in neuroscience provide compelling

2 For a similar argumentation in marketing research see, for example, Huettel and Payne [2009].

evidence that the human brain uses two different processes in decision-making: controlled and automatic [for reviews see Camerer et al., 2005; Lieberman, 2007; and Deppe et al., 2005].

*Controlled processes* (also denoted as the C-system for the "c" in reflective) tend to be activated deliberately when a person is exposed to a certain situation, are serial (i.e., they use step-by-step computations), are usually associated with a subjective feeling of cognitive effort, and people can provide a sound introspective account of these processes being able to recall the arguments and steps resulting in the final decision. Therefore, these controlled processes imply a high level of rationality. Examples of using mostly controlled processes are solving a math problem or buying relatively expensive products such as a new car or condo. *Automatic processes* (also denoted as the X-system for the "x" in reflexive), in contrast, are the opposite of controlled processes on each of the four dimensions. That is, they are not accessible to consciousness, operate in parallel, are less effortful, and it is difficult for people to provide a good introspective account about them.

Automatic processes are considered to be the background mode of brain functioning [Camerer et al., 2005], due to their being active most of the time. Only when automatic processes become interrupted do controlled processes become active. Moments of interruptions are, for example, unexpected events, strong visceral states, or novel decision situations. As mentioned earlier, TAM and TAM++ are mainly built on the theory of reasoned action and the theory of planned behavior, thereby focussing on controlled rather than automatic processes. But since most of the human's brain activity is automatic rather than controlled [Camerer et al., 2005], future research could increasingly incorporate automatic processes into technology acceptance research to help overcome concern about the low rate of incremental progress in recent years [Benbasat and Barki, 2007].

IS researchers could use the theory of controlled and automatic brain processes to better understand the nature of adoption determinants, including internal mental constructs spanning the cognitive (absorption, fit, compatibility, workload, risk), affective (enjoyment, anxiety, flow, satisfaction), and social (influence, trust, image, identification, observational learning). A better understanding of these determinants (which would link the behavioral and neural level of analysis) could allow for a better design of IT artifacts and other interventions (e.g., computer user training), thereby positively affecting user productivity and well being.

The current neuroscience literature provides several insights into controlled and automatic processes in the human brain [Lieberman, 2007; Schneider and Chien, 2003]. In general, controlled processes are mainly performed in the frontal lobe (in particular the prefrontal cortex), whereas automatic processes are mainly executed in the parietal, temporal, and occipital lobes. The dorsolateral prefrontal cortex, for example, is a unique part in the frontal lobe. It is one of the more highly evolved regions of the human brain, and it is associated with higher functions, such as conscious behavioral control, executive functioning, cognitive performance, and problem-solving, thereby being one of the central regions involved in controlled processing. The amygdala, in contrast, which is located deep in the medial temporal lobe, plays a key role in automatic information processing, especially in situations of anger, arousal, distrust, negative emotions, and fear [for a short review of brain lobes and other important functions see Dimoka et al., 2007, pp. 18–19].

## Promising Research Areas for NeuroIS

In addition to technology acceptance research [Dimoka et al., 2007, 2010; Dimoka and Davis, 2008], several other IS research topics and questions are considered appropriate for investigation with neuroscience. First, a few existing publications addressing promising NeuroIS topics already do exist [Dimoka et al., 2007, 2010; Gefen et al., 2008; Riedl, 2009]. Second, during the retreat, the participants suggested further themes. However, we believe and hope that a number of further IS research topics and questions appropriate for investigation through neuroscience will emerge as increasingly more IS scholars start to get engaged into NeuroIS.

In the following, we discuss selected research areas for NeuroIS, thereby demonstrating the broad range of possible topics appropriate for investigation through neuroscience. The first three topics (uncertainty, risk, and ambiguity; trust and distrust; decision support systems) have already been discussed in the literature (see, for example, Dimoka et al., 2007, 2010). Hence, we only briefly outline the general ideas underlying these topics. Then, we outline three additional topics (brain-computer interaction; conceptual modelling; gender), thereby making explicit further promising directions for NeuroIS research.

### Uncertainty, Risk, and Ambiguity

Using the Internet may be perceived as uncertain, risky, and ambiguous [Gefen et al., 2003; Huston and Spencer, 2002; Pavlou et al., 2007]. As outlined in neuroeconomics [Camerer et al., 2005; Glimcher et al., 2009], neuromarketing [Plassmann et al., 2008], and NeuroIS [Dimoka et al., 2007, 2010], the neuroscience literature has already identified brain areas involved in processing uncertain (e.g., insula), risky (e.g., anterior cingulate cortex), and ambiguous (e.g., amygdala) stimuli. Drawing upon these neuroscience studies (which show that uncertainty, risk, and ambiguity are distinct constructs partly associated with different brain regions), IS researchers could evaluate the effects of IT stimuli on brain activation to investigate whether they reduce uncertainty, risk, or ambiguity [Dimoka et al., 2007, 2010]. For example, recommendation agents and avatars are well-known IT artifacts that may affect an online shopper's uncertainty and risk perceptions [Nowak and Rauh, 2006; Qui and Benbasat, 2005; Wang and Benbasat, 2005]. Consequently, the effects of manipulating important characteristics of these IT artifacts (e.g., facial expression, body gesture, or communication mode of an avatar) on brain activation could be investigated in a NeuroIS study.

### Trust and Distrust

Closely related to uncertainty, risk, and ambiguity is the topic of trust and distrust. Neuroscience has already shown that trust and distrust are usually processed in distinct brain areas, the former mainly in the striatum and the latter in the amygdala and insula [Baumgartner et al., 2008; Dimoka, 2010; King-Casas et al., 2005; Riedl et al., 2010; Winston et al., 2002]. Drawing upon this evidence, IS researchers could examine whether trust-building mechanisms can increase activation in the striatum and distrust-reducing mechanisms can reduce activation in the amygdala and insula.

Future studies could also identify the dimensionality of trust, the willingness to depend on another person, and trustworthiness beliefs about that person, by investigating whether it is possible to identify the brain areas associated with different dimensions of trustworthiness (ability, integrity, and benevolence) [Dimoka et al., 2007; Gefen et al., 2003]. Because different brain regions are associated with cognitive (prefrontal cortex) and emotional (limbic system) decisions, it could also be fruitful to study whether trust has both a cognitive and an emotional component by examining brain activations in response to trust-related decisions that involve both cognitive and emotional aspects. This could be a major advance in our understanding of trust because statistically most research to date has not been able to tease out the difference between trust and the trustworthiness beliefs [Gefen et al., 2003], although conceptually clearly they may not be the same [Mayer et al., 1995]. If biologically trust and the trustworthiness beliefs can be separated, as this seems to be the case [Dimoka, 2010], then this could open new interesting avenues for IS research (e.g., to explain gender differences in the neural correlates of online trust; Riedl et al., 2010).

### Decision Support Systems

The neuroscience literature provides a large number of insights into the brain processes underlying decision making (for a summary see the articles in Glimcher et al., 2009). These findings can be used by software engineers to develop decision support systems, thereby positively affecting decision quality, decision time, cognitive effort necessary to make a decision, and satisfaction with a decision [Payne et al., 1993]. The neuroscience literature on decision making and cooperation (see, for example, Glimcher et al., 2009) can also advance the group decision support systems (GDSS) literature [Dimoka et al., 2007; Riedl, 2009].

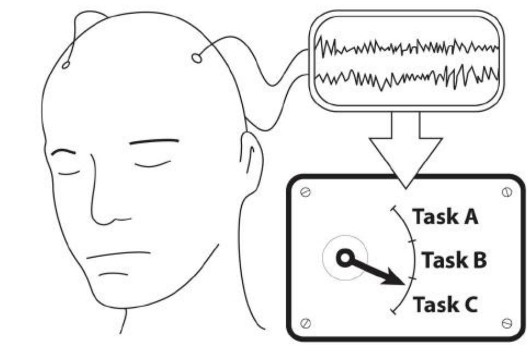
### Brain-computer Interaction

In 2007, a patent application of *Microsoft* entitled "Using electroencephalograph signals for task classification and activity recognition" became known in public [Tan and Lee, 2006]. A short time before this, Lee and Tan (2006) presented their research idea at a scientific symposium. The basic objective of these research efforts is to determine the mental task in which a computer user is engaged in at a particular point of time on the basis of EEG patterns only (see Figure 1). This idea was not new in 2006, because research in this field already started to emerge several decades before [Gevins, 1979a, 1979b; Vidal, 1973]. Moreover, similar research projects were reported in the more recent literature too [Fitzgibbon et al., 2004; Kübler and Birbaumer, 2008; Neuper et al., 2006]. However, the *vision* reported in the patent application is intriguing [Tan and Lee, 2006, p. 14]:[3]

> *[T]he method may be used to determine the cognitive workload levels, or workload types, e.g. verbal vs. spatial, of a plurality of user interfaces to compare the user interfaces' cognitive utility. It may also be possible to use the method to evaluate user interface cognitive utility and redesign user interfaces in real time to dynamically adapt user interfaces to users' states. Examples of such real time user interface adaptation include, but are not limited to, determining optimal information presentation, managing interruptions, adjusting the level of detail in displays, adapting user interface controls and layouts, adapting multimodal data presentation schemes, etc. For example, if a user is cognitively overloaded, i.e., has no more cognitive resources to deal with new information, the method may enable a system to recognize pending interruptions so that the system can buffer the interruptions until a user is less cognitively loaded. Alternatively, the method may enable a system to recognize that a user is verbally overloaded and present information in a spatial manner to use a user's spatial cognitive resources. The method may also be used to*

[3] Current research is far away from realizing the visions reported.

*present an enhanced, detailed awareness of pluralities of users enabling systems to dynamically distribute tasks among groups of users working on a common task.*




Source: Lee and Tan, 2006, p. 81.

**Figure 1: A Conceptual Illustration of a Brain-Computer Interface Using EEG Signals for Task Classification**

In essence, Microsoft's research and similar projects aim at the replacement of input devices (e.g., mouse, keyboard, joystick) through a computer user's thoughts. Current research shows, for example, that rudimentary navigation in virtual worlds is possible on the basis of a user's thoughts only [Friedman et al., 2007; Leeb et al., 2007; Scherer et al., 2008]. Moreover, in 1999, it was shown for the first time that completely paralyzed people who are unable to speak (but who were cognitively intact) could write letters on a computer screen on the basis of only their thoughts [Birbaumer et al., 1999]; it is interesting that research about this clinical issues was published in the 2005 and 2006 *Proceedings of the International Conference on Information Systems* (ICIS) [Moore et al., 2005; Randolph et al., 2006].

However, although the current research results in brain-computer interaction are promising, the examples discussed in the patent application of Microsoft are far away from the current state-of-the-art. Nevertheless, Riedl (2009) already outlined two possible long-term goals of this research in the business domain: (1) automatization of process steps in administrative work flows (e.g., enterprise systems recognize a user's thoughts and start with information processing without using an input device), and (2) increase of a system's usability (e.g., automatic redesign of an interface on the basis of a user's mental state).

### Conceptual Modelling

Conceptual modelling serves as an approach for representing selected phenomena in a certain domain for the purpose of IS design [Batini et al., 1992; Bodart et al., 2001; Wand et al., 1995; Wand et al., 1999]. The interest of IS researchers in conceptual modelling can be attributed to many factors. In essence, conceptual models further communication and discourse between IS developers and users, they enhance an understanding of a specific domain and provide input for IS design, and they enable requirements documentation for future reference [Kung and Solvberg, 1986; as cited in Wand and Weber, 2002]. As a result, conceptual models assist system analysts in detecting and correcting failures at an early stage and, therefore, play a major role in system engineering [Karimi, 1988; Kottemann and Konsynski, 1984; Lindland et al., 1994].

It has been argued that conceptual modelling is of critical importance [Moody 1998] because substantial cost savings are most likely achieved when problems are resolved early on rather than later in the IS development process. While the origins of conceptual modelling can be traced back to software engineering, there are several additional purposes of conceptual modelling, essentially referring to the different areas that are the object of modelling, among them data modelling [Batra and Marakas, 1995; Shoval and Shiran, 1997], knowledge modelling [Cuena and Molina, 2000; Mineau et al., 2000], business process modelling [Bandara et al., 2005; vom Brocke et al., 2010] or, in the broadest sense, enterprise modelling [Fox and Gruninger, 1998; Vernadat, 1996].

A fundamental question in conceptual modelling is the selection of an appropriate modelling language, which we define as any artificial language that can be used to express information, knowledge, or systems in a structure defined by a consistent set of rules. Such a language can be graphical, textual or tabular, and within these categories, there are a number of different language types in each case. In the past, the literature has already discussed the importance of cognitive psychology for the evaluation of modelling languages [Siau, 1999]. However, neuroscience has been suggested as a theoretical basis for the evaluation of modelling languages no more than a year ago by Riedl [2009]. Since the neuroscience literature offers a number of insights into cerebral mechanisms underlying the processing of objects, numerical data, and text [Logothetis, 2006; Nieder, 2006], which are important components of a language's notation, we believe that neuroscience theories and tools could be successfully used for the evaluation of modelling languages. It could be fruitful, for example, to evaluate the comprehensibility of various languages for different groups of stakeholders (e.g., software developers vs. users) not only by means of the traditional survey instruments, but also complementing them with neuroscience tools. Apart from the evaluation of modelling languages, a wide range of issues related to conceptual modelling might be informed by neuroscience, for instance, the process of conceptual modelling or the selection of modelling tools.

#### Gender

The IS literature reports a number of gender differences in IT-related behaviors. It was found, for example, that computer usage decisions of women are more strongly influenced by a system's perceived ease of use, whereas men's decisions are more strongly influenced by perceived usefulness [Venkatesh and Morris, 2000]. Moreover, there is empirical evidence that women and men differ in their perceptions of communication technologies, such as virtual communities and e-mail [Gefen and Ridings, 2005; Gefen and Straub, 1997]. The theoretical reasoning behind these phenomena was tied to sociolinguistics arguing that men and women communicate and understand communication and language differently. NeuroIS provides the possibility of augmenting this line of theory with biological factors. In the future, the explanation of gender differences in IT-related behavior could draw on neuroscience theories that found notable gender differences in brain anatomy and functioning [Bell et al., 2006; Cahill, 2006; Cosgrove et al., 2007; Haier et al., 2005]. A first NeuroIS experiment has already been conducted [Riedl et al., 2010]. This study investigated neural gender differences in online trust and it was found that trustworthy and untrustworthy eBay offers are processed differently in the male and female brain, thereby providing biological evidence that explains gender differences in trust behavior.

## VI. HOW CAN NEUROIS BE ESTABLISHED AS A NEW SUBFIELD, AND WHAT ARE THE CURRENT CHALLENGES FOR NEUROIS?

At the moment, the IS community is in the process of evaluating the prospects of neuroscience theories and tools for IS research and the possibility of NeuroIS as a new subfield within the IS discipline. However, if IS researchers want to adopt and use neuroscience theories and tools successfully, discussing the current challenges is necessary.

### Acquiring Knowledge About Neuroscience Theories and Tools

In the previous sections, we have provided initial insights into neuroscience theories and tools. However, for IS researchers to become "NeuroIS scholars," it is important to acquire more detailed knowledge of the cognitive neuroscience literature and neuroimaging tools. A promising starting point could be to read introductory and overview papers in related disciplines such as neuroeconomics (1–4 in the following list), neuromarketing (5–6), neuropsychology (7–8), and brain-computer interaction (9–10). We believe that the following papers can provide a first set of meaningful insights (title, journal, year of publication):

1. Neuroeconomics: The consilience of brain and decision [*Science*, 2004]
2. Neuroeconomics: How neuroscience can inform economics [*Journal of Economic Literature*, 2005]
3. Neuroeconomics: An overview from an economic perspective [*Brain Research Bulletin*, 2005]
4. Neuroeconomics: Cross-currents in research on decision-making [*Trends in Cognitive Sciences*, 2006]
5. Decision Neuroscience [*Marketing Letters*, 2005]
6. What is "neuromarketing"? A discussion and agenda for future research [*International Journal of Psychophysiology*, 2007]
7. Multilevel integrative analysis of human behavior: Social neuroscience and the complementing nature of social and biological approaches [*Psychological Bulletin*, 2000]
8. What are the brain mechanisms on which psychological processes are based? [*Perspectives on Psychological Science*, 2009]
9. Brain-computer communication: Unlocking the locked in [*Psychological Bulletin*, 2001]
10. Brain-computer interfaces for communication and control [*Clinical Neurophysiology*, 2002]

Moreover, also in the IS discipline, there are specific papers on NeuroIS, both conceptual [Dimoka et al., 2007; Dimoka et al., 2010; Riedl, 2009] and empirical [Dimoka, 2010; Dimoka and Davis, 2008; Riedl et al., 2010] that already exist. Further activities which may help to advance the field could be panel discussions [e.g., at the *ICIS* 2009; Dimoka et al., 2009b] and conference tutorials [Dimoka, 2009]. Of particular importance are (1) papers which extensively discuss both neuroscience tools and theories relevant for IS research; and (2) articles instituting quality standards for conducting NeuroIS studies, such as fMRI [Dimoka, 2010b]. In that sense, a "toolbox" for NeuroIS comprising knowledge on when to apply a certain tool and how to interpret results should be developed [Dimoka et al., 2010b].

Neuroscience knowledge (both about theories and tools) is often published in "pure" neuroscience journals. Therefore, it is important for IS scholars to know the mainstream neuroscience outlets. The following journals provide a first starting point to search for IS-relevant neuroscience knowledge (all journals are among the top forty outlets according to the *ISI Web of Knowledge Impact Factor 2008 Report*):

1. *Annual Review of Neuroscience*
2. *Behavioral and Brain Sciences*
3. *Biological Psychiatry*
4. *Brain*
5. *Cerebral Cortex*
6. *Current Opinion in Neurobiology*
7. *Human Brain Mapping*
8. *Journal of Cognitive Neuroscience*
9. *Journal of Neuroscience*
10. *Nature Neuroscience*
11. *Nature Reviews Neuroscience*
12. *NeuroImage*
13. *Neuron*
14. *Trends in Cognitive Sciences*
15. *Trends in Neurosciences*

### Making Editorial Boards Interested in NeuroIS

An issue closely related to knowledge acquisition concerns the expertise among reviewers and editorial boards. At the moment, relatively few IS researchers have a sound knowledge base in neuroscience tools and theories. Therefore, once NeuroIS papers are submitted to IS journals, it would be advisable for senior editors to recruit both NeuroIS and also neuroscience, neuroeconomics, or neuromarketing reviewers. This strategy is likely to result in substantiated research quality, because different views are applied to the paper.

### Sample Size

When compared to traditional survey and experimental research in the IS discipline, sample size is relatively small in neuroscience studies (a recent review including papers in the most prestigious journals such as *Neuron*, *Science*, and *Nature* found, for example, that the average sample size is eighteen subjects in neuroscience studies, Lieberman et al., 2009, p. 301). It is not uncommon for studies using psychophysiological measures to have slightly larger sample sizes, such as forty to fifty subjects. Important reasons for this relatively small sample size are that the recruitment of subjects is more difficult in neuroscience studies than in surveys or behavioral experiments and the costs per subject are also higher (see below). Obviously, this has implications for the experimental design of studies and subsequent statistical analysis.

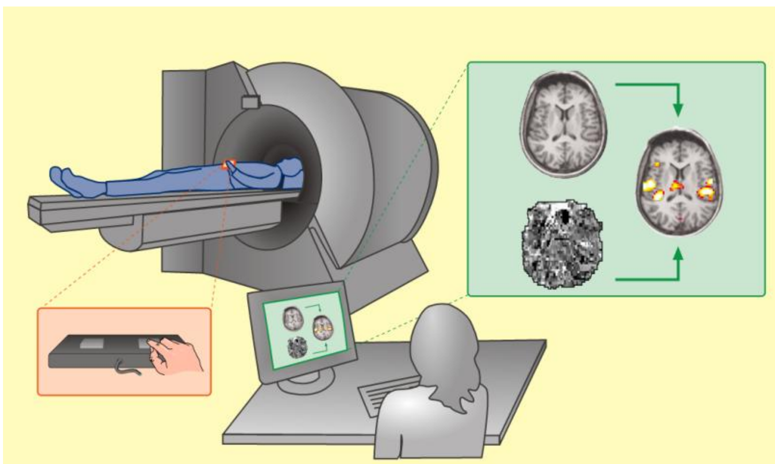
Statistical significance is influenced by two factors: sample size and the magnitude of the investigated effect. If sample size is relatively low, then researchers have to create stimulus material for the experimental and control task which allows for sharpening contrasts, and this might imply an extensive pre-testing phase before the actual neural experiment can be conducted [Riedl et al., 2010]. Another possibility to use participants more efficiently, especially in studies designed to investigate inter-individual differences that usually require larger sample sizes, is to identify two groups of participants that score extremely high or extremely low on a selected parameter of interest (e.g., trust or motor imagery skill) while holding other parameters constant [Guillot et al., 2008].

## Artificiality of the Experimental Situation

During an fMRI experiment, for example, participants are required to lie still on their back within the scanner while their head is restrained with pads to prevent head motion. Within the scanner participants can use simple devices to react to the stimuli presented by pressing a button (e.g., to state a chosen alternative in a decision task). Figure 2 shows a typical fMRI situation: participants lie in the scanner and are presented visual stimuli (either by looking through goggles or mirror systems), to which they can respond by pressing buttons. While processing the visual stimuli, researchers measure brain activation differences between the different areas in the brain. After the experiment, data can be analyzed in detail to gain insights into the relationship between brain activation patterns and subsequent behavior.

An fMRI scanner is also relatively noisy, posing a potential distraction and making auditory stimulus presentation difficult. Therefore, experimental situations in fMRI studies are artificial, because in real life, computer users usually sit in front of their computer in a familiar, comfortable, and quiet environment. Tools to measure psychophysiological responses are less intrusive, as participants usually sit in front of computers in a quiet environment, but still involve the use of sensors attached to the body.

The neuroscience literature sometimes reports on side effects of neuroscience methods. Abler et al. [2005], for example, found that local sensations on the scalp (due to the usage of repetitive transcranial magnetic stimulation, rTMS) and disturbance by the noise of the equipment may bias research results, requiring the use of suitable control or placebo conditions. However, although we should be cautious in generalizing from experimental situations to real-life situations, there is strong agreement among neuroscientists that fMRI and other neuroscience tools provide valuable insights into the neural basis of human behavior.



Source: Max Planck Institute for Human Cognitive and Brain Sciences.

**Figure 2. Typical Experimental Situation in an fMRI Study**

## Moral and Ethical Issues

In the past, in fields such as neuromarketing moral concerns have been discussed intensively [Farah, 2002; Wells, 2003]. The following citation nicely shows how opponents of neuroscience tools in marketing research present their argumentations (Editorial in *Nature Neuroscience*, entitled "Brain scam?" July 2004, p. 683):

> *Sellers have always spent a great deal of time, money and energy trying to find ways to influence buyers' decisions. Now, thanks in part to the increasing accessibility of functional magnetic resonance imaging (fMRI), marketing executives are hoping to use neuroscience to design better selling techniques. If the media hype is to be believed, then fMRI is being exploited by savvy consulting companies intent on finding 'the buy button in the brain', and is on the verge of creating advertising campaigns that we will be unable to resist.*

Moral concerns are likely to emerge in IS research as well, especially if one considers Microsoft's vision of adaptive user interfaces [Tan and Lee 2006]. Justin Mullins, a New Scientist journalist recently wrote in an article entitled "Microsoft mind reading":

> *Not content with running your computer, Microsoft now wants to read your mind too. The company says that it is hard to properly evaluate the way people interact with computers since questioning them at the*

*time is distracting and asking questions later may not produce reliable answers. "Human beings are often poor reporters of their own actions," the company says. Instead, Microsoft wants to read the data straight from the user's brain as he or she works away. They plan to do this using electro-encephalograms (EEGs) to record electrical signals within the brain ... Whether users will want Microsoft reading their brain waves is another matter altogether.*

In addition to these moral issues, ethical concerns have also been raised. One problem is the potentially harmful effect of TMS [Jones, 2007], or the radioactivity of the traces used in PET measurements. Another ethical concern is the high resolution anatomical image typically measured in fMRI studies, which bear the risk of detecting something of pathological relevance, such as a brain tumor, in otherwise healthy and, if not properly instructed, unsuspecting participants. These aspects emphasize that care must be employed in the use of neuroimaging tools in NeuroIS.

### Costs

It is possible that IS researchers are hesitant to explore the potential of NeuroIS due to the perception of high costs associated with using neuroscience tools. Hüsing et al. [2006] discussed the costs of various neuroscience tools. We summarize this discussion in Table 1, thereby making explicit notable differences between the tools.

**Table 1: Costs of Neuroscience Tools**

| Tool | Equipment acquisition | Additional costs per year | Per subject and hour |
|---|---|---|---|
| fMRI[1] | 1.4−2.7 million $ | $135,000−180,000 | $360−540 |
| MEG | 1.4−2.3 million $ | similar to fMRI | $270−450 |
| PET | 1.4−2.7 million $ | similar to fMRI | $450−900 |
| EEG[2] | $54,000−90,000 | low (unless the equipment needs repair) | $55 |
| NIRS[3] | $135,000−360,000 | low (unless the equipment needs repair) | $55 |
| TMS[4] | $54,000−135,000 | low (unless the equipment needs repair) | $55 |

**Notes:** [1] 1.5 Tesla, [2] 64 high-end channel system, [3] 16 sensors and LEDs, [4] high-end device.
Hüsing et al. (2006) state the costs in Swiss francs (conversion rate: CHF1 ~ $0.9).

In the present article, we already discussed a research program of Microsoft in the field of brain-computer interaction (BCI). It is interesting to note that Lee and Tan [2006, p. 82/83] stress that they used *low-cost EEG equipment* in their BCI experiments:

*The work we present in this paper is an initial step in exploring how BCI technology can be applied to HCI research. First, we demonstrate that effective exploration in this field can be accomplished using low-cost sensing equipment and without extensive medical expertise … using an off-the-shelf electroencephalograph (EEG) costing only USD$1500 ... Because much of the work in BCI has grown out of the rehabilitation engineering and neuroscience domains, a large portion of previous research has used high-end devices costing between USD$20,000−250,000 … we have found in our interactions that many HCI researchers are hesitant to explore the domain due to the perception of prohibitively high costs associated with owning and maintaining this equipment. Others may feel that the required domain expertise presents a major obstacle. In this paper, we demonstrate that effective BCI research can be accomplished without requiring such high-end and high-cost devices.*

Considering this statement and bearing in mind that psychophysiological measurements (e.g., heart rate, facial electromyography, skin conductance response) are typically much less expensive than the low-cost neuroscience tools (e.g., EEG), it is obvious that IS scholars have access to a large number of NeuroIS tools. Moreover, considering the typical sample size of fMRI experiments (~ 20 subjects) and the corresponding costs per subject and hour (~ $500), an fMRI experiment can be conducted for $10,000, an amount that is certainly not prohibitive.

## VII. SUMMARY AND CONCLUDING NOTE

In this article, we reflected on the discussions of the fifteen participants of a retreat on the "Foundations of NeuroIS" that took place in September 2009 in Austria. In essence, we offer initial answers to a set of research questions which are important for the successful development of NeuroIS, an emerging subfield within the IS discipline. In the present article, we addressed the following questions: (1) What is NeuroIS, and how does it relate to sister disciplines, such as neuroscience, neuroeconomics, and neuromarketing? (2) Which neuroscience tools are relevant for IS research? (3) What can IS researchers learn from the neuroscience literature, and what do we already know about brain activity? (4) What are possible IS research topics that can be examined with neuroscience tools, and what are some promising research areas for NeuroIS? (5) How can NeuroIS be established as a new subfield in the IS literature, and what are the current challenges for NeuroIS?

We conclude that the advent of neuroscience theories and tools allows IS research to integrate biological factors, in particular those related to the nervous system, into research on how humans develop and use IS. This, in turn, is likely to allow us to improve existing theories and develop new theories with higher levels of explained variance of important dependent variables (e.g., information processing, technology acceptance, user productivity), if compared to research based on traditional data sources. Therefore, we unequivocally consider neuroscience theories and tools as *complements*, not substitutes to existing IS theories and tools.

In essence, IS research seeks to describe, explain, and predict IT-related human behavior as well as to design IT artifacts. The question of how "nature" and "nurture" contribute to the manifestation of human behavior has always been one of the most fundamental issues in psychology. During the past decade, it has become a major question in economics. Hence, neuroeconomics has gained considerable momentum. However, scientific evidence [Cacioppo et al., 2000] shows that both biological influences of nature (e.g., aspects related to the brain) *and* environmental influences of nurture (e.g., culture or education) affect human behavior. Because the biological influences on human behavior, and especially those related to the brain, have only recently been made the subject of discussion in the IS literature [Dimoka et al., 2007; Kock, 2009; Riedl et al., 2010], we call for broad participation in investigating the neurobiological factors underlying IT-related human behavior.

## ACKNOWLEDGMENTS

Special thanks to the town of Gmunden, which provided financial support to organize the Gmunden Retreat 2009.

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*Editor's Note*: The following reference list contains hyperlinks to World Wide Web pages. Readers who have the ability to access the Web directly from their word processor or are reading the paper on the Web, can gain direct access to these linked references. Readers are warned, however, that:

1. These links existed as of the date of publication but are not guaranteed to be working thereafter.
2. The contents of Web pages may change over time. Where version information is provided in the References, different versions may not contain the information or the conclusions referenced.
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Communications of the Association for Information Systems

ISSN: 1529-3181