Advancing a NeuroIS Research Agenda with Four Areas of Societal Contributions[1]

Jan vom Brocke, Alan Hevner, Pierre Majorique Léger, Peter Walla, René Riedl

Abstract. *On the 10th anniversary of the NeuroIS field, we reflect on accomplishments but, more importantly, on the future of the field. This commentary presents our thoughts on a future NeuroIS research agenda with the potential for high impact societal contributions. Four key areas for future information systems (IS) research are: (1) IS design, (2) IS use, (3) emotion research, and (4) neuro-adaptive systems. We reflect on the challenges of each area and provide specific research questions that serve as important directions for advancing the NeuroIS field. The research agenda supports fellow researchers in planning, conducting, publishing, and reviewing high impact studies that leverage the potential of neuroscience knowledge and tools to further information systems research.*

Keywords

NeuroIS, Research Agenda, Emotion Sensing Technology, Design Science Research, Neuro-adaptive Systems

Introduction

At the 2007 ICIS (*International Conference on Information Systems*), Dimoka, Pavlou, & Davis (2007) coined the term "NeuroIS" and initiated—together with other scholars who presented research at the nexus of IS and neurobiology in the context of the 2007 ICIS conference—a new subfield by "applying cognitive neuroscience theories, methods, and tools

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in Information Systems (IS) research." (For a description of the genesis of NeuroIS, see Riedl & Léger (2016, pp. 73-74)). In NeuroIS studies, neurophysiological data are typically collected in combination with self-reported data to study existing systems' use and impact, as well as to inform the design of new systems; hence contributing to both behavioral and design-oriented IS research (Dimoka et al., 2012; Loos et al., 2010; Riedl, Banker, et al., 2010). In this new strategy of inquiry, researchers use data from the human body to measure the effects of human interactions with technology more directly; revealing the mechanisms underlying human behavior, particularly affective and other non-conscious processes (Dimoka, Pavlou, & Davis, 2011; Riedl & Léger, 2016; vom Brocke & Liang, 2014). The influence of non-conscious processes on human beliefs, attitudes, intentions, and behavior is well documented in the field of neuroscience where empirical research has shown the effectiveness of physiological measurement tools (e.g. Rugg et al., 1998). Even human self-awareness has been shown to consist of non-conscious aspects (Walla, Greiner, Duregger, Deecke, & Thurner, 2007) and, thus, it seems logical to apply neuroscience tools to investigate constructs relevant to IS research.

Early studies in NeuroIS demonstrate both behavioral science and design science research objectives. Dimoka (2010) investigates the concepts of trust and distrust in IS. The study shows that trust and distrust are associated with separate brain areas (trust with the *striatum* and distrust with the *amygdala* and the *insula*), challenging the previous understanding of trust and distrust as the two ends of one construct. Based on neuroscience evidence, today it is an established fact that trust and distrust are two separate constructs (Riedl & Javor, 2012). To improve IS design, vom Brocke, Riedl, & Léger (2013) identify three strategies with which to apply neuroscience in design science research (DSR) by adapting existing neuroscience *theory* to inform IS design (without using neuroscience tools), using neuroscience *tools* to evaluate IS design, and applying neuroscience *theory and tools* to develop neuro-adaptive IS (i.e. systems that automatically adapt in real time based on users' neurophysiological states to improve human-computer interactions). For a concrete example, see Astor, Adam, Jerčić, Schaaff, & Weinhardt (2013).

Over the past decade, the field of NeuroIS has developed rapidly and has made major achievements. Foundational papers, such as those of Riedl, Banker, et al. (2010) and Dimoka et al. (2012), provide important conceptual groundwork and help conceptualize NeuroIS as a discipline. Annual events attract eager researchers, such as the *NeuroIS Retreat*, which began in 2009 as an academic conference that focuses exclusively on NeuroIS (neurois.org). Special issues on NeuroIS have been published in leading journals in the field, including the *Journal of the Association for Information Systems* (*JAIS*) and the *Journal of Management Information Systems* (*JMIS*). Highly cited papers on how to conduct NeuroIS studies have been published: including articles on NeuroIS methods (Dimoka, 2012; Dumont, El Mouderrib, Théoret, Sénécal, & Léger, 2018; Fischer & Riedl, 2017; Gefen, Hasan, & Onaral, 2014; Hubert et al., 2017; Müller-Putz, Riedl, & Wriessnegger, 2015; Riedl, Davis, & Hevner, 2014; vom Brocke & Liang, 2014); new analysis techniques specifically designed for IS research (Courtemanche, Fredette, et al., 2018; Courtemanche, Léger, et al., 2018; Léger et al., 2014); and a plethora of studies on IS phenomena that apply neuroscience theory, methods, and tools (for a review see Riedl, Fischer, & Léger, 2017).

The 10th anniversary of the NeuroIS field offers us an opportunity to reflect on the field's status in order to identify directives for future research. We began the process by conducting a panel discussion with 40 audience members at the 2017 *NeuroIS Retreat*. The panel was entitled "NeuroIS 2007 – 2017: Hot Topics and the Future of NeuroIS" with the author team as panelists. Panelists were asked to present their views in three rounds of major achievements of the field so far, current themes and challenges to further development of the field, and directives and pathways for the future. In each round, they were asked to reflect on relevant topics, methodologies, and the discipline itself. The panelists focused on their areas of expertise and what they found most important to discuss; so not every panelist necessarily covered all three aspects per round. The panel took one hour and was followed by half an hour open discussion with the audience. Both panelists and the audience recognized the achievements of the field during the past decade, but also expressed that it is about time to start a new era of NeuroIS research. While the first decade naturally was about establishing the field and its foundations, the next decade should be more about contributing to solutions of contemporary problems relevant to society.

In the vein of Grand Challenge research (Becker, vom Brocke, Heddier, & Seidel, 2015; Kappelman, McLean, Luftman, & Johnson, 2013), the goal of this commentary is to distill the panel discussions in order to present selected NeuroIS research areas that show particularly high potential to make important contributions to society. In each of these areas, research questions can guide the community in selecting research topics that are adaptable to NeuroIS methods as well as to further grow and develop the NeuroIS community. Research on grand challenges and key questions of scientific disciplines has a long tradition and has been discussed in the Information Systems field (Brancheau, Janz, & Wetherbe, 1996; Dickson, Leitheiser, Wetherbe, & Nechis, 1984; Niederman, Brancheau, & Wetherbe, 1990). There are different approaches to identifying grand challenges, including conferences, summits, workshops, or, indeed, Delphi studies (Becker et al., 2015). In the field of engineering, for instance, Bhatia (2013) summarizes the results of the ‘‘Global Grand Challenges Summit’’ held at the *Institution of Engineering and Technology Conference* in London in 2013 on challenges for Engineering and International Development. In Medical Science, He, Baird, et al. (2013) summarizes the results of the discussion on grand challenges in interfacing engineering with life sciences and medicine, held during the first *IEEE Life Sciences Grand Challenges Conference* in 2012. Further, He, Coleman, et al. (2013) present the results of a discussion (three grand challenges on engineering and mapping the brain) at the *NSF Workshop on Mapping and Engineering the Brain* in 2013.

Thus, for NeuroIS, we build on the presentations and discussions from the panel on the 2017 *NeuroIS Retreat*. Further, we have conducted multiple rounds of further refinement and discussions among the team of authors, converging on four grand challenge areas for the next decade of NeuroIS research together with a set of operational research questions in each area. Then, we discuss how the four areas relate to one another. Finally, we show how the four grand research areas can guide research, education, industry outreach, and community building for the next generation of NeuroIS research.

Four Grand Research Areas for NeuroIS Research

Several conceptual articles propose topical research areas for NeuroIS. For example, Dimoka (2010) differentiates topics (based on Sidorova, Evangelopoulos, Valacich, & Ramakrishnan, 2008) on the individual, group, organizational, and market levels. Given the strategy of drawing on the measurement of the human nervous system, topics on the individual level, such as stress, are considered particularly suitable for NeuroIS. Researchers also argue that insights on the other levels can be gained from individual measurements and measurement devices. For example, fitness bracelets and smartwatches collect data in authentic environments (e.g. real-world offices), including data with which to measure groups in organizations and customers (e.g. Fischer & Riedl, 2016).

Riedl & Léger (2016) analyze topic areas in the empirical NeuroIS literature, concluding that "since the inception of NeuroIS in 2007, numerous IS topics have been proposed in research agendas and discussion papers that are suitable for investigation through a neuroscience approach. A number of these topics have been empirically investigated […,] providing support for the practical usefulness of the NeuroIS candidate topics suggested in early non-empirical articles" (p. 77). Major topics of NeuroIS, as outlined by Riedl & Léger (2016), include technology acceptance and use, online trust, human-computer interaction, electronic commerce, website design, and technostress.

In this commentary, we articulate the position that NeuroIS should increase its contributions to real-world phenomena. Drawing from calls for the IS community to contribute to addressing societal and economic challenges (Te'eni, Seidel, & vom Brocke, 2017; vom Brocke, Watson, Dwyer, Elliot, & Melville, 2013), we propose that NeuroIS should contribute more, and more directly, to solving such challenges in order to demonstrate its relevance. Specifically, NeuroIS research should demonstrate that through neuroscience knowledge and tools, new insights can be gained, which cannot be gained otherwise (vom Brocke & Liang, 2014). The panel identifies the following areas for NeuroIS to make high impact contributions: (1) IS design, (2) IS use, (3) emotion research, and (4) neuro-adaptive systems.

Information Systems Design

Human progress occurs when creative ideas are realized in design artifacts (products and services) and markets are formed to produce, trade, and use these artifacts in efficient and effective ways. While past thinking considered inspiration and invention as the (somewhat arbitrary) products of great minds, the growing field of neuroscience is advancing our understanding of how the human brain generates new ideas and instantiates them into reality and human use. At the same time, the information revolution has radically changed how we view and interact with the world. As a result, we have reached the point at which the fields of neuroscience and information technology (IT) can collaborate to identify and frame fundamental questions about the relationships among creativity, design, science, technology, innovation, and research, as well as human well-being. The goals of such studies should include the development of new neuroscience models of creativity, new paradigms for designing IT artifacts, novel approaches for education to optimize creative design thinking, and the development of creativity-enhancing IT tools for specific application domains.

Significant opportunities exist for new research directions in the synergy between NeuroIS and design. We contend that the IT artifact is under-researched and under-appreciated in NeuroIS (vom Brocke, Riedl, et al., 2013). The study of IT and IS in various socioeconomic contexts is predicated on deep knowledge about the artifacts in use. In their insightful essay, Orlikowski & Iacono (2001) argue that while the IT artifact is the core subject matter of IS research, it is too often taken for granted and treated as a passive black box for study. They challenge the IS community to engage more deeply and seriously with the "multiple, emergent, and dynamic properties" of the IT artifact. Similarly, we challenge the NeuroIS community to incorporate design science research (DSR) methods and thinking into their research goals and methods in new ways.

DSR aims to generate prescriptive knowledge about the design of IS artifacts, such as software instantiations, methods, models, and constructs (Hevner, March, Park, & Ram, 2004), and two types of contributions are identified: contributions to design artifacts and contributions to design theory (vom Brocke & Maedche, 2019). While contributions to design artifacts are made through conducting design processes in search of solutions to problems (Hevner et al., 2004), contributions to design theory are made through theorizing about such processes (Gregor & Jones, 2007). Both contributions relate to one another in many ways, in that, for instance, contributions to design artifacts are informed by design theories (as well as kernel theories), and design processes provide data to derive design knowledge in form of design theories (Gregor & Hevner, 2013). Recent thinking has proposed a model identifying six modes of producing and consuming design knowledge in DSR projects (Drechsler & Hevner, 2018; vom Brocke, Winter, Hevner, & Maedche, 2019).

Many critical cognitive and affective functions are involved in developing and operating such artifacts. Vom Brocke, Riedl, et al. (2013) were the first to present ideas on how to integrate NeuroIS with DSR. They identify three integration strategies to apply NeuroIS theories to inform the design of IS artifacts, NeuroIS methods and tools to support the evaluation of IS artifacts, and NeuroIS methods and tools to build neuro-adaptive IS artifacts. Riedl & Léger (2016) outline "ten contributions available from the application of neurobiological approaches to IS research and practice" (p. 12), five of which "have a design science (engineering) focus" (p. 19). They state five opportunities for contributions as follows (p. 20):

- The neuroscience literature can inform the design of IT artifacts, as well as IS investigations in general (e.g. by motivating behavioral experiments), and can do so without the application of neuroscience methods and tools.
- Brain activity or any other implicit physiological or behavioral phenomena can be used to inform IT artifact evaluation.
- Biological states and processes can be used in real time to design adaptive systems that may positively affect practical and relevant outcome variables, such as health, well-being, satisfaction, and productivity.
- Provision of real-time information on a user's own biological state (e.g. stress), based on a specific physiological indicator (e.g. skin conductance), constitutes an important foundation for a user to consciously control the physiological indicator. Such biofeedback systems may have positive effects on outcome variables, such as health or performance.
- Electrophysiological measures of brain function can be used to replace input devices (e.g. mouse or keyboard) in human-computer interaction, which may positively affect outcome variables, such as enjoyment (e.g. in the context of video games) or productivity (e.g. in the context of enterprise systems).

Although Riedl, Davis, Banker, & Kenning (2017) present an approach that elaborates on the first opportunity for research contributions, contemporary NeuroIS research has not substantially studied the other four opportunities. Here we expand on synergies between DSR and NeuroIS.

The DSR cycle comprises building and evaluating, both of which involve many cognitive and affective processes. Building entails three central processes (Hevner, Davis, Collins, & Gill, 2014). First, understand and represent the problem by capturing the problem space and managing complexity. Second, construct design candidates by creatively producing novel designs. Finally, select the best design candidate to build by the use of reasoning and judgment to narrow the range of candidate designs.

Evaluating also involves three central processes (Hevner et al., 2014). First, define the goodness criteria for a satisfactory solution to the problem (problem utility function and multi-criteria evaluation) (Gill & Hevner, 2013). Second, design or select evaluation methods to gather evidence of goodness (to include NeuroIS studies). Third, analyze the results to define DSR contributions and to evaluate user experience (UX) and satisfaction. At the same time, redefine the problem for the next DSR cycle.

Neuroscience research provides a rich knowledge base for understanding and applying the cognitive and the affective functions required in building and evaluating activities. For example, consider the following aspects as critical points in the DSR process:

- *Structuring the problem*. What cognitive and affective functions address the complexities of the problem space? How does the brain search the problem statement for potential solution patterns while finding effective representations of the problem structure?
- *Producing novelty*. How does the brain explore the potential solution space and create new ideas to produce innovative design candidates?
- *Managing refinement.* How does the brain control the assessment of candidate designs and search for the best designs to instantiate as artifacts for human use?
- *Achieving consensus*. How do the design team members collaborate with one another and with the design stakeholders throughout the design process? How are mental models of the problem space and the solution space shared among the design team members?

Future NeuroIS research should investigate how to advance our knowledge of IS design and evaluation activities by improving our understanding of the neurophysiology related to such activities. Doing so involves analyzing extant knowledge from neuroscience and studying how it can be applied to inform the activities related to IS artifact build and evaluation. Researchers will conduct additional empirical studies to complement existing knowledge, specifically accounting for IS design, such as by addressing their complexity and dynamics. Then, they will design artifacts to support the build and evaluation activities that take the related findings into account.

To conclude, we identify the following research questions, which serve as key challenges in order to make high impact societal contributions in DSR and NeuroIS:

How do humans understand complex problems, and what is the best way to manage the complexity? The ability to understand and plan solutions to complex problems has limitations, so we must advance from planning and prediction to controls and emergence (Hevner, 2017). Possible answers to these questions focus on rapid design cycles with key controls, such as scope boundaries and feedback loops.

What is a good artifact? In the problem definition phase, how do we define and measure a satisfactory solution? We require a more complete understanding of rich, multi-criteria utility functions (Gill & Hevner, 2013), so we can rank design candidates and make well-informed decisions about which designs to build and evaluate. Rich utility functions also provide guidance on the selection of evaluation methods with which to gather evidence (data) for analyses. Research from decision neuroscience, a field that has existed for approximately 15 years and has built a substantial knowledge base, can inform future NeuroIS research activities in this domain (e.g. Kalenscher, Ohrmann, & Güntürkün, 2006; Naqvi, Shiv, & Bechara, 2006; Sanfey, 2007; Trepel, Fox, & Poldrack, 2005). Startle-reflex modulation (e.g. Walla & Koller, 2015) provides a measure of raw affective processes outside consciousness. This approach can be used to form a better knowledge of human judgment and decision in IS design contexts.

How (and why) do designers approach design problems differently? Designers can follow diverse paths to address the same design problem *but cannot explain why*. Understanding the reasons for these differences in approach could help us attain a better fit between designers and the types of problems we give them, since different types of design problems might be better served by different design styles. Research on the neurophysiological correlates of creativity can inform future NeuroIS research activities in this domain. Because the integrative study of creativity and neuroscience started decades ago—see, for example, the Dietrich (2004) seminal review of the literature 15 years ago—NeuroIS scholars have a rich body of research from which to draw. (See also the Baas, Nijstad, & De Dreu, 2015 editorial on cognitive, emotional, and neural correlates of creativity and the other references cited in that paper.)

What *stopping rules* do designers use in the design process to move design candidates from the problem space to the solution space and to move artifacts from the internal environment to the application environment (Browne & Pitts, 2004)? Considerable time and effort are lost in useless brainstorming and evaluations of designs that are not feasible or are clearly sub-optimal. Browne & Walden (2011) report on a NeuroIS study on information search and stopping on the Web. Specifically, they use EEG measures to examine the changes in the cortical regions and cortical rhythms that occur when people stop their information search. They argue that stopping behavior is related to several constructs such as information overload or other cognitive processes (the user is not learning anything new, etc.), several of which have been studied in neuroscience. Thus, drawing upon this literature can be informative for IS design science researchers.

Since the make-up of a design team has a significant influence on the resulting design artifacts produced, how do issues such as trust/distrust, diversity, and personality traits (e.g. Big-5-Model, Goldberg, 1992) impact the collaborative performance of design teams? Understanding these collaboration challenges will help in forming and training effective teams. NeuroIS scholars should draw on the rich body of literature on the neural correlates of trust and distrust (for a review, see Riedl & Javor, 2012) and consider evidence from social neuroscience, which investigates the neural correlates underlying human social interaction (e.g. Adolphs, 2003; Adolphs, 2010; Cacioppo, Bernston, Sheridan, & McClintock, 2000; Lieberman, 2007). Objective design and product evaluation techniques can be used to complete subjective design judgments (e.g. Geiser & Walla, 2011; Grahl, Greiner, & Walla, 2012).

Information Systems Use

As Montag & Walla (2016) state in the abstract of their article about digital overuse, “It is not too late, but [it is] about time to realize how damaging IT overuse can be” (p. 1). Research on the effects of using digital communication devices and the Internet in general is important because empirical evidence points out negative consequences of IT use (e.g. Sariyska et al., 2014). From a neuroscience perspective, it seems clear that the biologically normal interpersonal communication that evolved over millions of years (e.g. Kock, 2009; Riedl, Mohr, Kenning, Davis, & Heekeren, 2014) could become heavily reduced, if not destroyed, in only one generation. Smartphones and other IT devices are fantastic inventions that enrich our lives, but similar to other developments that are meant to make life easier, save time, and increase well-being, IT products can also do the opposite, a phenomenon referred to as the paradox of progress (Brynjolfsson, 1993). Not only could our social lives be damaged (Montag, Blaszkiewicz, et al., 2015), but our productivity could be downsized (Montag & Walla, 2016).

In addition to technostress (e.g. Riedl, 2013; Riedl, Kindermann, Auinger, & Javor, 2012; Tams, Hill, Ortiz de Guinea, Thatcher, & Grover, 2014), a well-studied phenomenon in IS research (for a review, see Fischer & Riedl, 2017), Internet addiction has become an important topic for study (Camardese, Leone, Walstra, Janiri, & Guglielmo, 2015; Montag, Duke, & Reuter, 2015; Sha, Sariyska, Riedl, Lachmann, & Montag, 2019; Turel, Serenko, & Giles, 2011; Young, 1998). Although not yet officially recognized with a full set of diagnostic criteria, Internet gaming disorder appears in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders*. Moreover, Agogo & Hess (2018) present a review of negative affective responses to technology use, substantiating the significance of the IT (over)use topic in the IS discipline. According to Montag & Walla (2016), the cure is to "look into each other's eyes and begin to spend more quality time with our loved ones outside in nature instead of staring at digital devices" (p. 1).

A phenomenon related to stress and physiological activation is that information systems can impose time pressure through various urgency cues. This time pressure, as shown by Riedl and colleagues in a human-computer interaction context, may significantly affect activation of the autonomic nervous system, thereby influencing cognitive appraisal of a situation and subsequent behavior (Riedl, Kindermann, Auinger, & Javor, 2013). One example domain in which time pressure plays a dominant role is cybersecurity, in particular when users have to work against deadlines (Anderson, Vance, Kirwan, Eargle, & Jenkins, 2016).

Based on these examples, it is clear that NeuroIS has an opportunity to further investigate cognitive as well as affective effects of IS use. This can inform choice on when and how to use IS. For instance, there is a growing discussion on IS use in schools. Research has shown that overuse of IT has a negative impact on the quantity and quality of face-to-face communication (Drago, 2015). Nie & Erbring (2002) find that the more time people spend on the Internet, the more they lose contact with their social environment. In that regard, Uhls et al. (2014) study preteens who could not engage with screens for five days and how they then could better recognize facial expressions compared to a control group that had access to screens during the same period. Results indicate that increased opportunities for social interaction, combined with time away from screen-based media and digital communication tools, significantly improves preteens' understanding of nonverbal emotional cues. Walla & Lozovic (2019) conduct a NeuroIS pilot study based on a sample of digital natives and investigate the effects of reading from a mobile device, listening to an audio recording, and listening to an actual person who reads aloud. The results indicate that listening to an audio recording and listening to a real person is more pleasant than reading alone. However, listening to a person reading aloud results in the most negative subcortical raw affective physiological responses in digital natives.

Despite accumulating scientific evidence on the negative consequences of digital overuse, stakeholders still do not seem to plan anything that will maximize well-being and minimize health and economic problems. Regardless of the powerful IT lobby, eventually, this paradox of progress will capture the interest of industries and governments, and NeuroIS research can provide data and evidence to inform such discussions. This aspect of NeuroIS research assigns the IS community the important role of suggesting strategies to maintain human well-being by promoting biologically normal interpersonal communication. Because the IS discipline is legitimized by the positive effects of IT use (e.g. increased access to information, more communication possibilities, elevated performance and productivity), IS investigations into the negative effects of IT use and the ubiquity of digital devices are particularly important and credible.

Further, disciplines publish quality investigations in their top-rated outlets, not publications that have the potential to undermine the disciplines' legitimacy. And because IS scholars (unlike most of their peers in other disciplines, such as psychology or medicine) deal not only with empirical investigations of the effects of IT use, but also with designing and implementing systems, the IS community is in an ideal position to be the dominant research arm in the development of interventions—both technological (e.g. stress-sensitive adaptive enterprise systems; see Adam, Gimpel, Maedche, & Riedl, 2017) and non-technological (e.g. break designs for IT users in organizational settings; see Boucsein & Thum, 1997; Galluch, Grover, & Thatcher, 2015). Finally, since the IS discipline through its research fuels the use of IT in business and society, the study of IS use is not only an opportunity but also a responsibility of our field. NeuroIS research can help to make important societal contributions in this regard.

We identify the following research questions, which serve as grand challenges in order to make high impact societal contributions to IS Use (and IS Overuse) through NeuroIS:

How does the use of digital communication devices impact our task completion, performance, and/or productivity? They are meant to contribute to task completion and performance and save time, but is this really the outcome? There are definitely benefits related to IT usage (e.g. Brynjolfsson & Hitt, 2000; Keeney, 1999; Mata, Fuerst, & Barney, 1995; Melville, Kraemer, & Gurbaxani, 2004). However, accumulating empirical evidence suggests that due to several addictive functions digital communication devices make us spend more time on using them than initially planned. Recent evidence indicates that, in particular, technology-mediated interruptions may have severe negative consequences (e.g. work exhaustion) (Addas & Pinsonneault, 2015; Chen & Karahanna, 2018; Galluch, Grover, & Thatcher, 2015; Tams, Thatcher, & Grover, 2018). It follows that today we already know that digital communication devices may also have severe negative consequences (paradox of progress). Yet, the specific mediating mechanisms related to users' cognition and emotion are largely unknown and hence future NeuroIS research may significantly contribute to a better understanding of *why* and *how* these negative effects occur.

How does digital communication's inability to send the full range of non-verbal signals affect communication goals? Digital communication is rather limited in its inclusion of non-verbal signals, which are very important to deliver a message between communication partners. Over millions of years before language came into existence, only non-verbal signals were used to communicate and even today, our brain is wired to send and to receive non-language-related information. Unsurprisingly, this kind of information is mostly non-conscious. In the IS literature and beyond, under the label of *Media Naturalness Theory* (MNT), Kock (2004; 2005; 2009) develops a sound theoretical basis to study the consequences of media use with varying degrees of naturalness where face-to-face communication is the benchmark as it is the natural mode of communication that developed over millions of years. NeuroIS researchers can draw upon these grounding theories and investigate the neurophysiological processes underlying these effects (e.g. accomplishment of communication goals), thereby uncovering important mediating mechanisms. Two IS brain imaging studies already draw upon MNT (Riedl, Mohr, et al., 2014; Walden, Cogo, Lucus, Moradiabadi, & Safi, 2018). However, more research must follow.

How can digital communication devices be improved to achieve set communication goals? Knowing how detrimental the lack of various non-conscious, mostly non-verbal communication channels is in most situations, can we add features to our digital devices that are able to mimic non-verbal cues or even translate them directly through detecting them from the sender and the receiver?

Does the use of digital devices negatively affect the development of social abilities? Over millions of years evolution has made humans the social species it presently is. Following the "use it or lose it" principle, can we predict that intense and long-term use of digital communication devices will destroy the human ability to detect emotional cues in conspecifics?

Digital communication utilizes visual symbols to communicate feelings, the so-called emojis or emoticons. In face-to-face (analog) communication, emotions (e.g. actual facial expressions, speech prosody, body posture) communicate feelings (Walla, 2018). Can emojis replace real emotions and cause similar effects (as real emotions) on the receiver or are they not able to do so? Non-IS studies in this direction already exist (see, for example, a mini review by Aldunate & González-Ibáñez, 2017) and could be used as a basis for future NeuroIS research.

Emotion Research

Currently, not even the key players in emotion research agree on a basic set of emotions, which is not only disappointing but also academically frustrating. It is even stranger that the same scholars and all other active scientists start their papers by saying that no proper definition of emotion exists and no consensus has been reached on how to understand this topic. Because of this confusing situation, most authors do not dare to offer their own definitions of emotion; even if they do, the result is a complex view where *emotion* is usually used interchangeably with *feeling*. Surely, those terms deserve separate definitions. Since emotion-related phenomena (e.g. emotions in technology acceptance decisions or negative emotions that result from IT malfunction) are central to NeuroIS research, it is time to sort out these basic definitions in order to make progress and, in particular, to improve efficient communication of research results, new hypotheses, and constructs that matter to the community.

NeuroIS has an opportunity to clarify the concept of emotion, because in comparison to long established and conservative stand-alone fields, it is a young and open-minded multi-discipline (Information Systems and Neuroscience) area. It is open to new innovative concepts and, thus, it represents a better opportunity to change old and rigid constructs than, for instance, the emotion research community, which has struggled to come up with useful definitions for the terms emotion and feeling. Under the assumption that short and useful definitions are better than long and confusing definitions when communicating about emotion-related topics in the NeuroIS field, we propose to follow Walla (2018) on how to define emotion, affective processing, and feeling.

Walla (2018) provides a comprehensive understanding on how cognitive processing (e.g. language) is separate from affective processing that can lead to emotions. Cognitive functions, such as the use of language, are cortical, while affective processes are subcortical. He proposes a brain function model as a basis on which to understand that subcortical affective processing (i.e. neural activity) guides human behavior from deep inside the brain, while feelings are consciously felt bodily responses that occur because of supra-threshold affective processing. It is those feelings that are communicated to others via emotions, which take the measurable form of behavioral output. For example, the degree to which an individual accepts a specific IT device or system is largely reflected in one`s affective processing (neural activity) that might elicit feelings that cause emotions communicated by behaviors such as facial expressions. We note that in neuroscience and to some extent also in NeuroIS the term *behavior* is used more broadly than in mainstream IS research where behavior is related to actual usage behavior. According to this model (see Figure 1), an emotion is simply a motor output (i.e. muscle contraction) in response to prior neural activity that codes for valence—in other words, pleasantness or preference.

Explicit responses on NeuroIS-relevant topics can at best reflect feelings but not the underlying affective processes that cause them and that can finally be communicated via emotions. Verbally stated preferences are not necessarily reflective of affective processes that dominantly guide human behavior (e.g. usage of a specific IT device or system) via unconscious decision-making. Only objective measures can fully show the information processing that leads to behavioral adaptations. In IS research, for instance, Léger et al. (2014) investigate the role emotions play in using Enterprise Resource Planning Systems (ERP) systems. They show that both expert and novice users exhibit considerable electrodermal activity during their interaction with the ERP system, indicating that ERP use is an emotional process for both groups (note that increased electrodermal activity is typically a consequence of activity of the sympathetic part of the autonomic nervous system). However, the findings also indicate that experts' emotional responses lead to their sourcing information from the ERP, while novices' emotional responses lead to their sourcing information from other people.

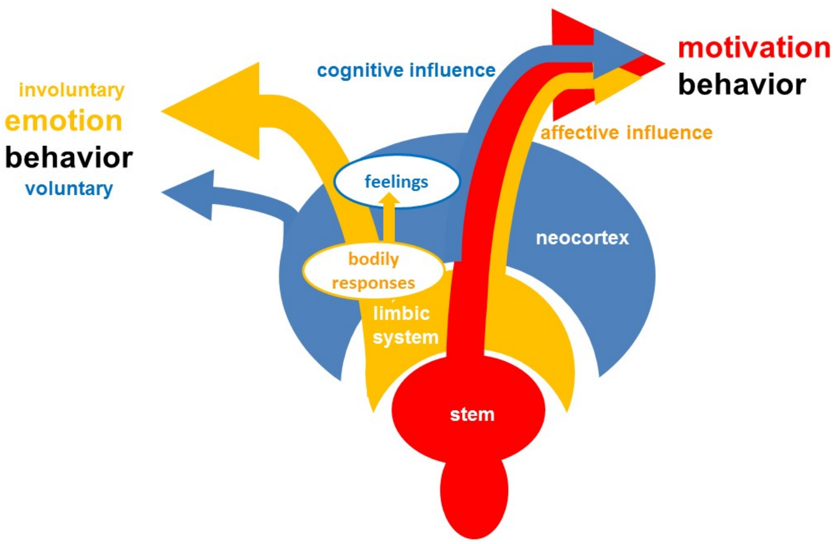

Figure 1: Neurobiological Brain Function Model Highlighting Differences between Cognitive and Affective Processing and the Different Nature of Feelings versus Emotions (Walla, 2018)

We identify the following research questions, which serve as grand challenges in order to make high impact contributions in Emotion Research through NeuroIS:

How do self-report measures differ from physiological responses? Assuming that people do not always do what they say (without lying); with respect to affective information processing, it appears helpful to combine self-reported with physiological data. Preference and technology acceptance as well as liking and positive attitude are all constructs that deeply engage affective processes in the brain. Language has only limited access to these primarily limbic processes and thus all experiments investigating such constructs should look for discrepancies between subjective self-reports and objective physiological data.

Is a subjective self-report or is an objective physiological response a better predictor of human behavior? Under the assumption that self-reports reflect conscious decision-making while specific physiological responses are also involved in the decision-making process, it is intriguing to find out which of the two is more predictive of future behavior.

Which IS constructs depend on affective information processing in the first place? The answer to this question will justify the need to follow rigorously a triangulation (multi-methods) approach with a focus on collecting self-report data together with as many different physiological data as possible.

Is the effect of product placement better evaluated with subjective or objective measures? For instance, evaluative conditioning has long been used to change products (e.g. IT devices) affectively in order to make them more appealing, but whether the effects of evaluative conditioning are better assessed with subjective or objective measures remains unanswered (Walla, Koller, Brenner, & Bosshard, 2017).

Is startle-reflex modulation a reliable replacement for relatively expensive brain-imaging technologies (e.g. fMRI) in quantifying raw affective-information processing? During the last few years startle reflex modulation, a relatively unknown method, has been shown to provide very useful insights into non-conscious affective responses that often deviate from conscious self-report (e.g. Koller & Walla, 2015; Kunaharan, Halpin, Sitharthan, Bosshard, & Walla, 2017).

Neuro-adaptive Systems

Neuro-adaptive systems are an outstanding example of what NeuroIS research is able to accomplish, which is to build systems that are sensitive to users' affective and cognitive states (vom Brocke, Riedl, et al., 2013). Neuro-adaptive systems are conceptualized as sensor-actor networks that are sensitive to human neurophysiological states. Simple systems have already entered the market, for example, in the form of bracelets that use body data, such as heart rate and skin response, to trigger or adjust applications on a smartphone (Whelan, McDuff, Gleasur, & vom Brocke, 2018).

Lux et al. (2018) review the literature for live biofeedback as a user interface design element. They draw from research in computer science, engineering and technology, information systems, medical science, and psychology to differentiate self-live biofeedback systems (that address the effects of live biofeedback on perception, behavior, and regulation of physiological activities within a person) from foreign-live biofeedback systems (that address social interactions between individuals).

Riedl & Léger (2016) identify affective computing as a major NeuroIS reference discipline with the goal of assigning to computers the human capabilities of observation, interpretation, and generation of emotional features. An example from the stress domain illustrates the potential of neuro-adaptive systems. Riedl & Léger (2016) write:

> "*IS design science research may benefit from neuroscience because engineering initiatives have already demonstrated that bio-signals indicating the cognitive and affective states of users (e.g., speech prosody, facial expressions, gestures, pupil dilation, skin conductance, or brain waves) may be automatically monitored by a system so that the system can dynamically adapt the GUI [graphical user interface] to the users' states .... For example, a system may use skin conductance levels to recognize that a user is stressed (increased skin conductance) and adjust the interface in real time—reducing the user's perceived level of stress by altering design elements (color, or the amount of information presented on the screen, for instance).*" (p. 17)

In research on the design, implementation, and evaluation of neuro-adaptive systems, NeuroIS scholars must not ignore the affective computing literature (e.g. Picard, 1997, 2003; Tao & Tan, 2005; Ward & Marsden, 2004). A particularly valuable source is *IEEE Transactions on Affective Computing*, a cross-disciplinary and international journal that is "aimed at disseminating results of research on the design of systems that can recognize, interpret, and simulate human emotions and related affective phenomena" (http://ieeexplore.ieee.org/). Since its inception in 2010, this outlet has been publishing both conceptual and empirical papers with high relevance to NeuroIS scholars. As an example, Calvo & D'Mello (2010) present an interdisciplinary review of models, methods, and applications on affect detection.

Generally, the goal of neuro-adaptive systems is to make human interaction with digital devices less stressful and more enjoyable, thereby increasing user performance and productivity in human-computer interaction tasks (Byrne & Parasuraman, 1996; Picard, 1997; Riedl, 2009). Neuro-adaptive systems will become a common phenomenon in the future. They can be implemented in most digital devices, such as in smart cars and houses, in order to adjust services to the emotional states of users. As such, neuro-adaptive systems will have an important societal impact, e.g. for inclusion of disadvantaged members of our society. Neuro-adaptive systems could also serve as personal digital assistants to support healthier lifestyles wherein systems will provide feedback information on the neuro-physiological state of the user and advise on needed activities such as resting or exercising. In addition, data taken from these neuro-adaptive systems, in an anonymous and aggregated form, will increasingly be used in evidence-based medicine in order to analyze behavioral patterns in relation to healthcare issues and diagnoses. It is expected that through such data analysis, the medical field will make one of the next big leaps in terms of early indication of unhealthy behavior and corrective advice; ultimately saving lives, reducing cost of health care, and enhancing the quality of live.

Despite the obvious research potential that neuro-adaptive systems hold for NeuroIS, their relevance to either academia or practice has rarely been described in the academic literature. To the best of our knowledge, the study by Astor et al. (2013), which develops and evaluates a neuro-adaptive system (specifically, a biofeedback system in a financial decision-making context) using an experimental approach, is the only example of a neuro-adaptive system published in an Association for Information Systems (AIS) basket-of-8 journal. However, we are starting to see IS researchers contributing to communities dedicated to the neuro-adaptation domain (Labonté-LeMoyne, Courtemanche, Fredette, Léger, & Sénécal, 2017) and we also observe corresponding papers in the recent editions of the NeuroIS Retreat proceedings (Demazure et al., 2019).

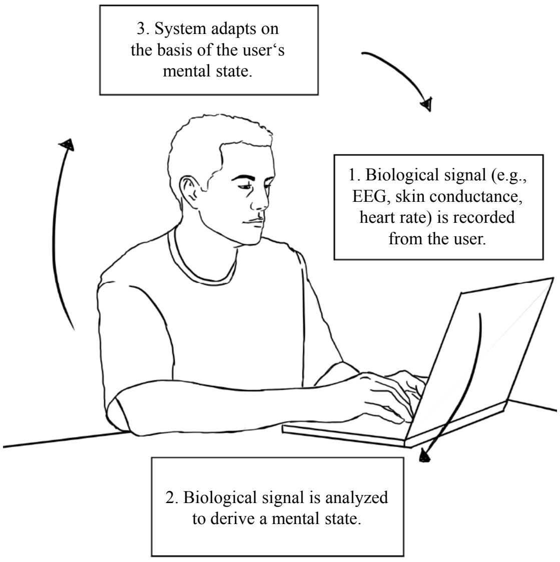

Figure 2: Conceptual Illustration of a Neuro-adaptive System (Riedl & Léger, 2016, p. 18)

Figure 2 shows a conceptual illustration of a neuro-adaptive system, based on a human-computer interaction situation (Riedl & Léger, 2016). We use this illustration as a foundation for the formulation of questions for future NeuroIS research in the area of neuro-adaptive systems and apply it to the context of technostress as a running example (for details, see the section entitled "Design Science and Engineering" in Riedl, 2013, pp. 43–45). The goal of the neuro-adaptive system in our example is to make human-computer interaction less stressful. It has been shown that various computer glitches (e.g. long and/or variable system response times) may cause considerable physiological stress reactions among users (see the evidence discussed in Riedl, 2013). The evidence indicates that experiencing a long system response time may result in the activation of various parameters related to the user's nervous system, such as changes in heart rate, skin conductance, pupil dilation, or even EEG waves. Therefore, a neuro-adaptive system must have the functionality to record one or more of a user's biological signals in real time (Figure 2).

In contrast to prior calls for research on neuro-adaptive systems (e.g. Loos et al., 2010; Riedl, Banker, et al., 2010; vom Brocke, Riedl, et al., 2013), here we indicate specific avenues for future research. We identify the following research questions, which serve as grand challenges in order to make high impact contributions to neuro-adaptive systems through NeuroIS:

Which physiological correlates (e.g. changes in heart rate, skin conductance, EEG waves) of IS constructs are relevant in human-computer interaction situations, such as stress, mental workload, flow, and joy? We note that a precondition for the relevance of a physiological signal is its measurability in real time. In other words, the latency between the onset of the signal that results from a user's stimulus perception must not be longer than a few seconds.

Which technologies and sensors most effectively measure the physiological signals in real time? Because of the high number of manufacturers, a well-structured analysis of products is needed from the NeuroIS community to help researchers make more deliberate decisions. Next, based on such biological signals, the system must use an algorithm to analyze the data and derive the user's mental state (Figure 2). In the example, the system must have the functionality to derive at least two of the user's stress states (high versus low stress). Because biological signals and constructs do not have a one-to-one relationship (e.g. Cacioppo & Tassinary, 1990), a user's stress state should ideally be derived from several biological signals (i.e. a many-to-one relationship, where two or more biological signals are associated with stress). Here, the fundamental questions include the following:

Which combination of physiological signals best characterizes a user's level of stress in human-computer interaction tasks? Depending on the construct at hand, NeuroIS scholars must answer this question for each construct in a study. For example, a scholar who is interested in flow during a human-computer interaction must answer this question for flow.

How are the physiological signals integrated to develop a diagnostic index for technostress? This question concerns algorithm development. Riedl, Davis, et al. (2014, p. xviii) define diagnosticity as a measure's property that "describes how precisely it captures a target construct as opposed to other constructs." We believe that single-signal neuro-adaptive stress systems are less accurate (if accurate at all) than systems that use a stress index based on a combination of biological signals.

As indicated in Figure 2, based on the derived mental state (in this case, technostress), the system adapts in real time with the goal of reducing a current stress level. Whether the system does so effectively must be assessed based on a new cycle of biological-signal measurements. Therefore, a neuro-adaptive system is a closed-loop type. Additional questions for future research include the following:

If two algorithms can be used to derive a mental state, how can we show that one approach is better than the other? One possibility would be to use a self-reported measure of perceived technostress as a benchmark. However, because self-reported (techno)stress and physiological stress do not necessarily correspond (Riedl, 2013), the value of this form of benchmarking test is limited. Thus, predictive validity tests must also be used. Here, an algorithm's superiority is determined based on its potential to predict a meaningful outcome variable in the study context. In the case of technostress, performance is an example of a meaningful outcome variable (Tams et al., 2014).

How frequently should a system assess a user's mental state and adjust the user interface? Imagine that a system adjusts its interface every 30 seconds (e.g. via adjustments in color or in the amount of information presented on the screen). Against this background, another fundamental question for future research arises. How frequently should a stress-sensitive neuro-adaptive system adjust so that it does not become another source of stress?

Discussion

In this commentary, we have identified four grand areas for NeuroIS research to make important societal contributions. An important insight drawn from our panel and this discussion is that NeuroIS can and should make research contributions to multiple fields; IS, neuroscience, application domains (e.g. healthcare), and to a new emerging field of its own. From its inauguration onwards, NeuroIS has intended to contribute to IS research through the application of neuroscience methods and theory (Dimoka et al., 2012; Riedl, Banker, et al., 2010). Vom Brocke & Liang (2014), for instance, prominently state that "both point of departure (as well as the point of arrival) of any NeuroIS study must be in the field of IS research." The results from our expert panel confirm this orientation, in that two out of the four grand research areas are important application areas of IS research, namely IS design via DSR and IS use.

Interestingly, however, our panel also reveals the importance and opportunity for NeuroIS to contribute to the understanding of the concept of "emotion", which is a contribution to the field of neuroscience. Already today, NeuroIS has proven to advance neuroscience methods and tools. For example, Léger et al. (2014) develop novel ways of applying the eye-fixation-related potential (EFRP) during an authentic IS interaction. Compared with the traditional event-related approach (Luck, 2014), this technique makes it possible to measure accurately the cognitive activity associated with the user's attention to a screen. The EFRP approach opens the door to studying automatic and unconscious repeated behaviors in human-computer interaction, such as email checking or social media behavior, which can also be used beyond the application area of IS (for example, many psychologists have become interested in these topics in the past decade).

As another example of NeuroIS contributions to neuroscience, Courtemanche, Léger, et al. (2018) propose a novel way to visualize the source of emotional and cognitive constructs on an interface. They show that traditional eye tracking enables the visualization of an eye-fixation heat map showing the density of a group of subjects' fixation during a particular time window (Nielsen & Pernice, 2010). These works address the research question, "Where in the interface do people look the most?" (Wooding, 2002). The new technique called UX Heatmap (Courtemanche, Léger, et al., 2018) measures the user's gaze to triangulate psychophysiological constructs onto the interface, enabling the representation of the neurophysiological signals' distribution on the interface and answering an important question for interface designers: "Where in the interface do people react emotionally and/or cognitively?" In sum, compared with the traditional approaches, combinations of eye tracking and facial recognition make it possible to measure accurately the cognitive and the affective activities that are associated with a user's visual attention to a screen. This patent-pending technique is used not only by major international organizations for their UX research, but also by research neuroscientists.

We foresee that novel approaches and IT devices developed in NeuroIS studies will contribute to the development of new neuroscience methods and tools. For example, HEC Montréal's Tech3Lab (https://tech3lab.hec.ca/en/) is currently leveraging an in-memory analytical appliance to handle large neuroscience data and exploit the opportunities that arise from using the multi-project datasets while maintaining the richness of unaggregated data. Further, NeuroIS researchers possess the ability to contribute to the neuroscience domain by introducing new advances in IT and data science. For example, Fredette, Labonté-LeMoyne, Léger, Courtemanche, & Sénécal (2015) propose new statistical models that are constructed for the analysis of EEG data in IS research (Müller-Putz et al., 2015), where the number of EEG trials is often limited to preserve the experiment's ecological validity. New advances from the field of artificial intelligence also contribute to accelerating NeuroIS research, especially in the development of neuro-adaptive systems (Karran et al., 2018).

The panel believes that neuro-adaptive systems (e.g. emotion-sensing IS, Whelan et al., 2018) will play a prominent role in the definition of a separate field of NeuroIS research. Such systems establish a new class of information systems and a new emerging field of its own. Research on neuro-adaptive IS (area 4) seem to integrate all other research streams, with emotion research (area 3) providing a theoretical and methodological base for innovative digital IS design (area 1) which will contribute to improved IS use behavior (area 2). We find that research on neuro-adaptive systems is particularly promising for NeuroIS, because they are exciting innovative artifacts that showcase both principles and affordances of NeuroIS contributions.

The case of neuro-adaptive systems also alludes to the importance of reference disciplines and application domains beyond IS and neuroscience. As an example, NeuroIS researchers still have much to learn from the tools and the practices of neuroscience in the life sciences. Several studies reveal that NeuroIS research can learn from the research and practice in life sciences to improve how it operates and conducts research. For example, trade magazines, including *Lab Manager* (http://www.labmanager.com/) and *The Scientist* (https://www.the-scientist.com/), have published stimulating articles on topics that are relevant to NeuroIS research, such as managing laboratory personnel, acquiring tools and instruments, and managing laboratory data.

Implications

The four areas for future NeuroIS research presented in this commentary have important implications for further developing the field. To conclude, we briefly discuss significant implications for research, education, industry engagement, and community building.

Guiding Research: The four grand areas for NeuroIS research have an immediate impact for researchers to guide their studies and to direct them towards areas with great potential to make important societal contributions. We invite fellow researchers to conduct empirical and DSR studies on the related research questions, but also meta-analyses and reviews, to further our conceptual understanding of the areas and to refine and extend the agenda presented in this commentary.

Guiding Education: The increasing amount of scientific evidence provided by neuroscience in the IS field necessitates the inclusion of basic neuroscientific knowledge in the core training of IS researchers. Therefore, we call for graduate programs in IS (MBA, MS, PhD) to introduce a seminar on NeuroIS. Riedl & Léger (2015) have developed a reference syllabus for such a seminar, published by the AIS on the EDUglopedia.org platform (https://eduglopedia.org/). Because the NeuroIS field is still in its formation phase, reference syllabi should be updated regularly. The four grand research areas can provide interesting insights into relevant courses and modules for such programs.

Guiding Industry Engagement: While NeuroIS has developed in academia over the last decade, its industrial outreach has been limited. However, we contend and have evidence (see, for example, the Tech3Lab's collaborations in Montréal) that industry is strongly interested in the research results from our community, especially in an IS design context. Since all four grand areas for future NeuroIS research are of high relevance for society and economy, these areas will also be highly suitable to engage with industry. Apart from funding and data collection, industry engagement will also increase dissemination and recognition of NeuroIS research and it will continuously stimulate alignment of NeuroIS research with industry and society needs. The initiative of the Deloitte Neuroscience Institute is an example of practitioners providing neuroscience-based advice on the design of digital products and services. NeuroIS researchers have also started to publish NeuroIS-related articles in practitioners' magazines, for example, about emotion-sensing devices' potential for decision-making (see Whelan et al., 2018 in *MIT Sloan Management Review*).

Guiding Community Building: The NeuroIS community has developed greatly during the past decade, through venues such as the *NeuroIS Retreat* (www.neurois.org) as well as special issues in the main journals of our community. In addition, a text book exists (Riedl & Léger, 2016) and case book is currently being compiled by the community (Randolph, vom Brocke, Davis, Riedl, & Léger, in press). We encourage all readers to become a member of the NeuroIS Society founded in 2018 (http://www.neurois.org/board-and-founding-members and http://www.neurois.org/membership/). The growth of a vibrant NeuroIS community will strengthen the reach and impacts of the field. We propose that the four grand research areas will provide more structure to NeuroIS. At the annual conference, for instance, papers could be grouped into specific sessions along the four presented areas, and hence progress in the respective areas would be discussed more explicitly. Also, the structure could be used to plan joint activities between IS and non-IS scholars, thereby fostering progress in the area to make possible break through achievements.

Conclusion

While the first decade of NeuroIS has been focused on building foundations, the next decade should have more of a focus on demonstrating societal value through highly impactful NeuroIS research. To support this process, we have identified four research areas, which show particular potential for NeuroIS to make such important societal contributions. For each of these areas, as a starting point, we have provided a set of operational research questions. A summary of all research areas and questions is provided in the appendix. Apart from contributions to IS, which up to now has been the predominant focus, contributions to neuroscience as well as contributions of a unique NeuroIS type (e.g. neuro-adaptive systems) will be made. Research contributions of high societal value will further the recognition of IS as a field that makes important contributions. This new agenda for NeuroIS research has important implications, specifically to guide research, education, industry outreach and community building for the next generation of NeuroIS research.

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Appendix

Research Area	**Research Questions**
Area 1: Information Systems Design	• How do humans understand complex problems, and what is the best way to manage the complexity? • What is a good artifact? In the problem definition phase, how do we define and measure a satisfactory solution? • How (and why) do designers approach design problems differently? • What *stopping rules* do designers use in the design process to move design candidates from the problem space to the solution space and to move artifacts from the internal environment to the application environment? • Since the make-up of a design team has a significant influence on the resulting design artifacts produced, how do issues such as trust/distrust, diversity, and personality traits impact the collaborative performance of design teams?
Area 2: Information Systems Use	• How does the usage of digital communication devices impact our task completion, performance, and/or productivity? • How does digital communication's inability to send the full range of non-verbal signals affect communication goals? • How can digital communication devices be improved to achieve set communication goals? • Does the use of digital devices negatively impact the development of social abilities? • Can emojis replace real emotions and cause similar effects (as real emotions) on the receiver or are they not able to do so?

Area 3: Emotion Research	• How do self-report measures differ from physiological responses? • Is subjective self-report or is an objective physiological response better predicting human behavior? • Which IS constructs depend on affective information processing in the first place? • Is the effect of product placement better evaluated with subjective or objective measures? • Is startle-reflex modulation a reliable replacement for relatively expensive brain-imaging technologies (e.g., fMRI) in quantifying raw affective-information processing?
Area 4: Neuro-adaptive Systems	• Which physiological correlates (e.g., changes in heart rate, skin conductance, EEG waves) of IS constructs have been investigated that are relevant in human-computer interaction situations, such as stress, mental workload, flow, and joy? • Which technologies and sensors most effectively measure the physiological signals in real time? • Which combination of physiological signals best characterizes a user's level of stress in human-computer interaction tasks? • How are the physiological signals integrated to develop a diagnostic index for technostress? • If two algorithms are used to derive a mental state, how can we show that one approach is better than the other? • How frequently should a system assess a user's mental state and adjust the user interface? • How frequently should a stress-sensitive neuro-adaptive system adjust so that it does not become another source of stress?