Designing Knowledge Interface Systems: Past, Present, and Future

Shirley Gregor[1], Alexander Maedche[2], Stefan Morana[2], and Silvia Schacht[2]

[1]The Australian National University, Canberra, Australia ACT 0200
[2]Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany

shirley.gregor@anu.edu.org,{alexander.maedche,stefan.morana, silvia.schacht}@kit.edu

Abstract. *Knowledge interface systems (KIS) enable a dialogue between human and machines by utilizing an underlying knowledge-based system. The design and the effects of KIS have been a focus of researchers' interest for decades. Yet the existing knowledge of KIS is scattered, and researchers as well as practitioners face the danger of re-inventing KIS for a specific purpose or, worse, repeating mistakes of the past. This conceptual paper provides an overview of KIS capabilities and outcomes of their usage from the past to the present and proposes directions for future research. Our analysis shows that, in general, there is evolution of work on KIS over time, rather than revolution. This research will enable researchers to identify their contribution more clearly over and above what has been done before.*

Keywords: knowledge interface system, knowledge-based system, human-computer interaction, user interface

1 Introduction

Advances in technology mean an increase in the sophistication of interactions between human and machines. Greater intelligence in even simple tools such as email means that the tool can give targeted advice by pointing out missing steps in a process. Advances with 'big data' mean huge volumes of information are available to inform human decision making. Yet this information can be overwhelming without appropriate presentation and interpretation – a significant challenge to decision makers [1]. Thus, there is the need for an effective knowledge interface system (KIS) that enables a knowledge dialogue between human and machines. KIS have been developed and studied since the earliest days of knowledge-based systems (KBS) albeit under a variety of labels. They have been referred to as help or assistance facilities, explanations, recommendations, advice, nudges, data representations, dashboards, visualization, and guidance. The term KIS is compatible with the conceptualization of the "user interface" in early KBS such as decision support systems (DSS) (see [2]). Sprague and Watson [3] suggest that the user interface is the most important component of a KBS, because much of the power, flexibility and ease-of-use characteristics of KBS derive from this component. The ongoing importance of KIS is demonstrated by the example of advanced data visualization – the ability to present complex data in informative and aesthetically pleasing ways both quickly and clearly [4]. Businesses that make effective use of big data and visualization benefit, with research showing that data-driven businesses are six percent more profitable and five percent more productive than their competitors [5]. Pirolli [6], however, points out that we have limited understanding of how people navigate through the graphics in data visualization. Thus, there is a need for continuing research on KIS.

Despite the importance of KIS, the related research remains scattered and we believe the potential for integrating design-related knowledge across different forms of KIS has not been sufficiently realized. New forms of KIS are being developed without the benefit of lessons learned from the past or from the design of other members of the same system families. Furthermore, KIS appear in a primary role as a core element of the user interface and a secondary role in the form of an assistance function. Clarification of these two roles is necessary as otherwise researchers working with the secondary role may not realize that the design principles they employ may have commonalities with KIS in the primary role. This shortcoming should be of interest to members of the design science research (DSR) community engaged with new forms of KIS. Thus, the aims of the paper are to: (i) argue that KIS should be recognized as a special class of systems so that commonalities in design can be realized and leveraged, (ii) present some of the important lessons learned surrounding the design and use of KIS, and (iii) create an awareness for KIS design in the DSR community.

The paper has theoretical significance in that it represents an initial step in integrating design knowledge, past and present, for an important class of systems. The need for a cumulative tradition in theorizing in Information Systems has long been recognized [7]. Here we show how design knowledge and theory can be accumulated around a class of systems, identified by a common overarching purpose – in this case enabling knowledge interaction between a computer system and a human user. The establishment of an integrated body of knowledge means that researchers will be better able to demonstrate how they make a new contribution to knowledge. An integrated knowledge also means a better base for developers of KIS in research and practice.

The scope of the paper is restricted in that we are looking at human-computer interactions – not human-to-human communication as may occur in knowledge sharing communities. In addition, the focus of this paper is on the human's interaction with the knowledge and the design of this interaction, from a behavioral and technological perspective, and not the creation of the knowledge in the underlying KBS. Finally, it must be recognized that due to space limitations this paper identifies only a limited number of key themes relating to KIS. A full synthesis requires a longer treatment.

2 Knowledge Interface Systems

KIS are a form of human-computer interaction (HCI), a field that has a long history and well-developed and useful bodies of knowledge (e.g. see [8, 9]). KIS are a special case of HCI, however, in that they are concerned with the transmission of knowledge rather than simple data input and output. The knowledge on the machine side is generated by a KBS, such as a DSS, an expert system (XPS), a geographic information system, or a big data analytics application. In general, KBS capture, represent, and apply knowledge in different contexts [10]. KBS can involve a variety of intelligent capabilities, such as data mining, language processing, or sentiment analysis. KIS are distinguishable from the underlying KBS that generate knowledge – the KIS is a layer on top of the KBS. KIS can give varying forms of advice to the user to encourage different outcomes. A recommendation agent could give suggestions such as: "*Your recommendations are books by Austen, Elliot, and Hardy*". A more sophisticated KIS could include an explanation function that gives the reasons for the recommendations: for example, other customers who buy the same books as you also buy books of these authors. This additional explanation has been shown to increase trust in the recommendation agent and enrich user experiences [11].

Note that KIS are not used only with systems whose primary aim is decision support or knowledge transfer. The KIS can also join a secondary knowledge base to a general application system, where the user is engaged with a task and the KIS assists with the task accomplishment. An example could be the processing of emails and the KIS makes a suggestion about how the task could be better performed: e.g. "*Did you mean to include an attachment in your email*?" Thus we distinguish two roles for KIS: primary and secondary (assistance) (see [12]). In the secondary role, KIS assist users in the usage of many forms of application systems, such as ERP, CRM, or groupware. In both cases the characteristics of the users should be considered. Figure 1 illustrates these two roles and they are discussed further below.

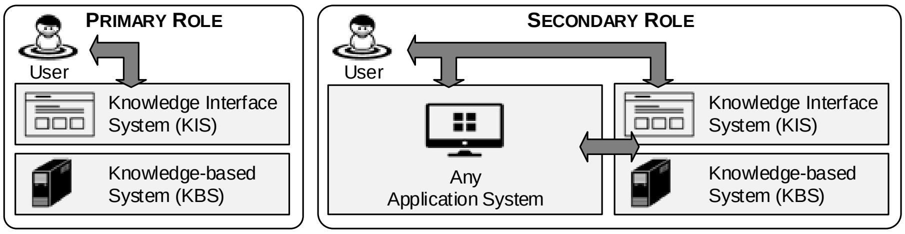

Fig. 1. Different Roles for Knowledge Interface Systems

3 Past, Present and Future: Revolution or Evolution of KIS?

It is of interest to see how past research on KIS compares with more recent research. Has there been a revolution in KIS or a steadier evolution? Is there some design knowledge or theory that has become well established in a cumulative tradition? What can we infer for the future?

For purposes of analysis, we compare how KIS were treated in the "past" (approx. before the year 2000) with research in the present (approx. since 2000). The choice of this point of time is somewhat arbitrary, but it represents something of a turning point in that new Web technologies and interfaces became increasingly available from this point. Further, we can locate textbooks and review articles that give an overview of knowledge concerning KIS at approximately that point (e.g. [2, 13, 14]).

Our aim is to overview some of the important knowledge that was built up around KIS in these periods, in terms of their design and the outcomes that resulted from their use. We use four dimensions for the comparison of KIS design knowledge: function (including content), presentation, provision mechanism, and context/user model. These dimensions are derived from previous work on explanation facilities [13] and intelligent assistance [14]. The dimensions are independent and each requires separate design decisions. For example, when considering an explanation capability, a core function could be a rule trace, presented in a textual format, user-invoked and adaptive to the user type (novice or expert). Similarly, in designing a visual analytic capability in a Business Intelligence and Analytics (BI&A) systems context, the designer can consider what functions to include (e.g. what parts of a data to display), how to display the data (e.g. 3D), what interactive mechanisms to allow (e.g. focus & context), and whether to track where the user's attention is mostly focused and then use these observations to adapt visualization algorithms (see [15]). Table 1 provides an overview of KIS capabilities and outcomes of their use for the "past" and the "present" along the four dimensions introduced above. Further observations on the systems in use in the two periods follows.

Table 1. Overview of KIS Research Past and Present

Design dimension of the KIS capability	KIS in past (before 2000)	KIS in present (since 2000)
Function	Basic explanations provided to improve **performance, learning, persuasion**, **trust, and acceptance** of advice [13]. Help functions used a repository of task knowledge to assist users in task performance [12].	Extensions to use with **recommendation agents** that build trust [11]; **affective KIS** to create emotions such as enjoyment [16, 17], for example, by **gamification,** or **persuasion** mechanisms [18, 19]; extraction of explanations from **neural networks** for legal compliance [20].
Presentation	Usage of various presentation formats such as **natural language (text-based)** and **multimedia (graphics, images, animations, and voice)** formats [13].	More extensive use of **graphics** (e.g. in process modelling) [21], **virtual reality** (e.g. in form of avatars) [22]; **visual analytics** [15, 23]; and **voice** as input and output (e.g. Siri) [24, 25].
Provision Mechanism	Provision of explanations either **automatically** or **manually** adapted to the **user context** [13].	Provision of explanations that are **intelligently** adapted to users and their usage context [26].
User Model	User model derived based on **user characteristics** (e.g. demographics) or **simple tracking/logging mechanisms** [2].	User model derived based on sensor data, e.g. use of **physiological and "emotional" monitoring** [27].

For analysis of the "past", we considered KIS primarily in three types of KBS that were prominent before 2000: XPS, DSS, and intelligent assistance (help) systems.

Expert systems (XPS) were first developed in the 1970s and can solve problems that ordinarily require human expertise [28]. Turban and Aronson [2] state that an XPS should contain a "user interface", a component for "*friendly, problem-oriented communication between the user and the computer… Sometimes it is supplemented by menus, electronic forms and graphics*". The XPS will usually also contain an "explanation subsystem", which can explain the reasoning behind a conclusion. Gregor and Benbasat [13] propose that the design of an explanation sub-system should be considered in terms of the (i) content type – type of explanation function, (ii) the explanations presentation format – text-based and multimedia, and (iii) the provision mechanism describing how the explanations are invoked – either by the user or the system.

Decision support systems (DSS) serve the central purpose of supporting and improving human decision making [2]. The DSS architecture should include a "user interface (dialogue) subsystem" that includes the capabilities for a natural language dialogue and interactions between the user and other DSS components, presentation of data in various formats including graphics, and help and diagnostic support [2].

Intelligent assistance systems facilitate both the accomplishment of a task by a user who does not know how to do it and aid users' learning processes so that their performance is improved in their primary task with the system [14]. Delisle and Moulin [14] consider that the KIS for an intelligent assistance system could include: (i) a user model, which keeps track of what the user is doing and what the user knows and does not know; (ii) a natural language interface; and also potentially (iii) an explanation facility. It can be seen from the above that there is overlap between the capabilities that each of the three types of KBS could possess. DSS and XPS can have help functions and intelligent assistance systems can include explanation facilities.

For the "present", we considered newer forms of KBS growing in importance since 2000 in addition to extensions to older KBS and use of new technologies: for example, KBS based on large amounts of structured and unstructured data such as BI&A as well as recommender systems.

Business intelligence and analytics (BI&A) and the related field of big data analytics cover data-related problems to solve contemporary business problems. Since the early 2000s, BI&A emerged as a class of KIS that aims to analyze huge amounts of data, implementing mechanisms such as web intelligence, web analytics, and user-generated content through Web 2.0-based social and crowd-sourcing system. Thus, BI&A evolved to enable analysis of not only structured, but also unstructured content [23]. A challenge of modern BI&A systems is the visualization of the data and thus, is also an issue that should be addressed by an appropriate design of the KIS.

Recommender systems aim at assisting users in their decision making based on the previously collected and aggregated data from other humans [29]. The underlying knowledge base is used to support users, but also created by investigating the users. Thus, research addressing KIS in the context of recommender systems focuses on the one hand on providing the actual recommendation to the user, and on the other hand, the discovery, aggregation, and collection of data for the knowledge base.

What can we conclude for the future based on the comparison between the past and the present? If the trends for KIS observed in recent times compared with earlier times continue, then we should expect the following: (i) new forms of KIS arising to match new forms of KBS, as observable with big data analytics; (ii) more functions included in KIS capabilities, such as emotion elicitation and gamification; (iii) growth in KIS for intelligence assistance in a secondary role following from what has occurred with recommendation agents in e-commerce and process guidance in enterprise systems; (iv) many opportunities for new and innovative KIS/KBS in a secondary role as an intelligent assistant; (v) new forms of provision mechanisms as interaction technologies develop; (vi) a maturing of user modelling and tracking techniques and more integration to mainstream usage; and (vii) hopefully, attention paid to design principles that have been shown to be sound over almost six decades, such as the efficacy of explanation functions in many different types of KIS.

There are many opportunities for designers. A designer can develop novel ideas by considering work done with KIS in sum and utilizing different options in combination: for functions, presentation, provision mechanism and user modelling.

4 Summary

This paper presents an overview of research addressing KIS from the past to the present. We perceive KIS as an important class of systems for users interacting with knowledge-based systems in particular, in addition to many application systems more generally. The existing body of knowledge contains much important design knowledge for KIS, but a common consideration of this knowledge is missing. Research on KIS design is scattered and researchers as well as practitioners face the danger of re-inventing KIS for a specific purpose or, worse, repeating the mistakes of previous researchers. An example of lack of consideration of existing KIS knowledge is the work on developing explanations for neural networks [20] which ignores prior work on explanations in different KBS. Pu and Chen [30] research explanation interfaces for recommender systems, but ignore important prior work on explanations (e.g. [13]) and other work on explanations in recommender systems (e.g. [11]).

To address this problem, our paper provides an overview of KIS design capabilities from the past to the present and proposes possible future research directions for KIS. Our analysis shows that in general there is an evolution of work on KIS over time, rather than a revolution. For example, the importance of justification explanations in KIS has continued to be demonstrated [11, 13]. Our work will enable researchers to identify their contribution more clearly over and above what has been done before. Importantly, we clarify the architecture of KIS in relation to KBS in general, and distinguish between the primary and secondary roles for KIS.

This paper presents an early stage of our research on KIS and has some limitations that should be taken into account. The overview of KIS research is selective and we do not claim exhaustiveness. Rather, we aim to raise interest in this interesting and important research field and give a baseline for future research and theorizing. Nevertheless, the analysis covers more than 40 years of research on KIS and indicates the benefits of treating KIS as an important class of systems. This work is a first step towards a comprehensive review of research in KIS that will serve as a base for theorizing around this important class of system. In subsequent work we will provide both more breadth and depth to conceptualization and analysis

References

1. Avenade: Global Survey: The Business Impact of Big Data, http://www.avanade.com/~/media/documents/research and insights/big data executive summary final seov.pdf (accessed January 21, 2016).
2. Turban, E., Aronson, J.: Decision Support and Intelligent Systems. Upper Saddle River, NJ: Prentice-Hall. (2001).
3. Sprague, R.H., Watson, H.J.: Decision Support for Management. Upper Saddle River, NJ: Prentice-Hall. (1996).
4. Lycett, M.: "Datafication": Making Sense of (Big) Data in a Complex World. European Journal of Information Systems. 22, 381–386 (2013).
5. McAfee, E., Brynjolfsson, A.: Big Data: The Management Revolution. Havard Business Review. 90, 60–68 (2012).
6. Pirolli, P.: Powers of 10: Modeling Complex Information-Seeking Systems at Multiple Scales. Computer (Long. Beach. Calif). 42, 33–40 (2009).
7. Keen, P.G.W.: MIS Research: Reference Disciplines and a Cumulative Tradition. In: ICIS 1980 Proceedings. paper 9 (1980).
8. Shneidermann, B., Plaisant, C.: Designing the User Interface: Strategies for Effective Human-Computer Interaction. Boston, MA: Addison-Wesley. (2005).
9. Carey, J., Galletta, D., Kim, J., Te'eni, D., Wildemuth, B., Zhang, P.: The Role of Human-Computer Interaction (HCI) in the Management Information Systems Curricula: A Call to Action. Communications of the AIS. 13, Article 23 (2004).
10. Dhaliwal, J.S., Benbasat, I.: The Use and Effects of Knowledge-based System Explanations: Theoretical Foundations and a Framework for Empirical Evaluation. Information Systems Research. 7, 342–362 (1996).
11. Wang, W., Benbasat, I.: Interactive Decision Aids for Consumer Decision Making in e-Commerce: The Influence of Perceived Strategy Restrictiveness. MIS Quarterly. 33, 293–320 (2009).
12. Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., Carey, T.: Human-computer Interaction. Harlow, England: Addison-Wesley (1994).
13. Gregor, S., Benbasat, I.: Explanations from intelligent systems: Theoretical foundations and implications for practice. MIS Quarterly. 23, 497–530 (1999).
14. Delisle, S., Moulin, B.: User Interfaces and Help Systems: From Helplessness to Intelligent Assistance. Artificial Intelligence Review. 18, 117–157 (2002).
15. Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., Melançon, G.: Visual Analytics: Definition, Process, and Challenges. In: Kerren, A., Stasko, J., Fekete, J.-D., and North, C. (eds.) Information Visualization SE - 7. pp. 154–175. Springer Berlin Heidelberg (2008).
16. Lin, A.C.H., Fernandez, W.D., Gregor, S.: Understanding web enjoyment

experiences and informal learning: A study in a museum context. Decision Support Systems. 53, 846–858 (2012).
17. Riaz, A.: Designing websites to elicit emotions and enhance comprehension of web-based information., unpublished PhD thesis, Australian National University (2015).
18. Schacht, S., Morana, S., Maedche, A.: The Project World - Gamification in Project Knowledge Management. In: Proceedings of the 2014 European Conference on Information Systems (ECIS 2014). Track 04, Paper 10 (2014).
19. Hamari, J., Koivisto, J., Pakkanen, T.: Do Persuasive Technologies Persuade? - A Review of Empirical Studies. In: Spagnolli, A., Chittaro, L., and Gamberini, L. (eds.) Persuasive Technology SE - 11. pp. 118–136. Springer International Publishing (2014).
20. Baesens, B., Setiono, R., Mues, C., Vanthienen, J.: Using Neural Network Rule Extraction and Decision Tables for Credit-Risk Evaluation. Management Science. 49, 312–329 (2003).
21. Morana, S., Schacht, S., Scherp, A., Maedche, A.: Designing a Process Guidance System to Support User's Business Process Compliance. In: ICIS 2014 proceedings. paper 6 (2014).
22. Chang Lee, K., Chung, N.: A web DSS approach to building an intelligent internet shopping mall by integrating virtual reality and avatar. Expert Systems with Applications. 28, 333–346 (2005).
23. Chen, H., Chiang, R.H.L., Storey, V.C.: Business Intelligence and Analytics: From Big Data to Big Impact. MIS Quarterly. 36, 1165–1188 (2012).
24. Assefi, M., Liu, G., Wittie, M.P., Izurieta, C.: An Experimental Evaluation of Apple Siri and Google Speech Recognition. In: Proccedings of the 2015 ISCA SEDE (2015).
25. Huang, X., Baker, J., Reddy, R.: A Historical Perspective of Speech Recognition. Communications of the ACM. 57, 94–103 (2014).
26. Ngai, E.W.T., Leung, T.K.P., Wong, Y.H., Lee, M.C.M., Chai, P.Y.F., Choi, Y.S.: Design and development of a context-aware decision support system for real-time accident handling in logistics. Decision Support Systems. 52, 816–827 (2012).
27. Liao, W., Zhang, W., Zhu, Z., Ji, Q., Gray, W.D.: Toward a decision-theoretic framework for affect recognition and user assistance. International Journal of Human-Computer Studies. 64, 847–873 (2006).
28. Russell, S., Norvig, P.: Artificial Intelligence: A Modern Approach. Upper Saddle River, NJ: Prentice-Hall (2003).
29. Resnick, P., Varian, H.R.: Recommender Systems. Communications of the ACM 40, 56–58 (1997).
30. Pu, P., Chen, L.: Trust-inspiring explanation interfaces for recommender systems. Knowledge-Based System. 20, 542–556 (2007).