INFORMATION MAPPING

Knowledge-based support for user interface design

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1. Introduction

The design of a user interface can be considered an *information mapping* task. The task consists in mapping (a) information from the task domain of the artefact being designed as well as other relevant constraints on the design process, onto (b) a set of input/output modalities which, when fully specified, will constitute the user interface of the artefact. Interface designers thus essentially solve information mapping problems whether or not they think of themselves in those terms. This raises the question if it might be possible to provide knowledge-based support of the information mapping process. Over the last 2-3 years we have been developing an approach to this question, called *modality theory.* This position paper presents the research agenda of modality theory (Sect. 2), briefly introduces modality theory and the information mapping methodology (Sect. 3), describes recent results on knowledge-based support of the information mapping process (Sect. 4) and concludes by pointing out some core questions for future work (Sect. 5).

2. The Research Agenda of Modality Theory

Literally thousands of different combinations of input and/or output (information) *representational modalities* are currently becoming available to designers of interfaces for human-computer interaction, from unimodal spoken language input to complete multimodal virtual reality interactive systems. Each single modality or multimodal combination has its own specific capabilities of representing or conveying information and it is obviously important to be able to select the right combination of modalities for a given application. The question is how this might be done in a principled manner so as to optimise the usability of the interface, given the specific purpose of the artefact to be designed. Answering this question involves addressing the research agenda of modality theory whose development forms part of the ESPRIT Basic Research project AMODEUS [Barnard 1993]. The agenda is as follows [Bernsen 1993a]:

(1) to establish sound foundations, both conceptually and in terms of an operational taxonomy, for describing and analysing any particular type of unimodal or multimodal output representation relevant to human-computer interaction;
(2) to create a conceptual framework for describing and analysing interactive computer interfaces so as to cover both input and output of information;
(3) to apply the results of steps (1) and (2) above to the analysis of the problems of information mapping between work or task domains and human-computer interfaces in information systems design.

The main problem raised by agenda item (1) is how to build a theoretical foundation for addressing the information representing capabilities of thousands of different, potentially useful combinations of output modalities. The only viable approach seems to be through the generation and analysis of a limited set of elementary or *unimodal* modalities from which any particular *multimodal* representation or modality combination can be built. The taxonomy of generic unimodal output modalities which resulted from adopting this approach is presented in [Bernsen 1994a,c]. We are beginning to address input modalities (agenda item (2)) in terms of the concept of an interactor. Agenda item (3) is to develop an operational 'bridging' representation between the science base of modality theory and design practice [Barnard 1991]. We call this bridging representation the *information mapping methodology* or IMAP.

3. The Information Mapping Methodology and Modality Theory

The IMAP methodology is assumed to proceed in five steps or two main phases [Bernsen and Bertels 1993, Verjans and Bernsen 1994]. In the *first phase,* the aim is to obtain the information which is needed to select a reasonable and possibly optimal mapping onto some interface input/output representation. The nature and variety of the information relevant to this end should not be underestimated. Relevant information includes information on task domain, intended users, task environment, task performance on representative tasks, user preferences, standards, resource constraints etc., but of course with a special focus on the information to be exchanged between user and system during task performance. This information or these interface requirement specifications should be represented explicitly and succinctly in some way. We ourselves use the Design Space Development (DSD) notation for representing design space structure [Bernsen 1993b, 1993c, Bernsen and Ramsay 1994a, 1994b]. In the *second phase* of IMAP, the rules of modality theory are applied to the results of phase one in order to map the collected information onto a suitable set of input/output modalities. From the point of view of IMAP, modality theory consists in a large set of rules, such as, e.g., the following:

> Visualise specific information in 1D, 2D or 3D spatial, temporal development being important to the visualisation <->
> Consider using dynamic analogue graphics.

Visualise specific information such that freedom of visual inspection is less important than development, movement or change <->
Consider using dynamic analogue graphics.

The expression '<->' is read, from left to right, as the 'if-then' of production rules. From right to left, rules are read 'modality x (e.g., dynamic analogue graphics) is [good/bad] at representing [left-hand side of rule]'. Core terms occurring in the rules such as 'specific' (or 'specificity'), 'dynamic analogue graphics' or 'freedom of visual inspection', are technical terms of modality theory. Technical terms belong to one of two categories, modalities and supporting theoretical terms. Modality theory includes 70 different unimodal modalities or modes of representation in the media of graphics, acoustics and haptics. Modalities are analysed at up to 4 different levels of abstraction [Bernsen 1994a,c]. The supporting theoretical terms are the terms, such as 'information channel', 'specificity' or 'freedom of visual inspection' which are needed in order to analyse individual modalities. A core result of analysing individual modalities are the rules of modality theory.

An application of modality theory for the purpose of information mapping can be thought of as the application of rules such as those illustrated above. Rules 'fire' when triggered by appropriate information about the artefact which is being designed. The result of information mapping will be sets of possible input/output modalities and modality combinations which are capable of representing the information needed for the representative tasks. The next section describes how this works in practice.

4. The CERD Case Study

IMAP has been explored in a number of case studies. Early design of a spoken language dialogue system and the design of a toy 'water bath' monitoring and control system were analysed in [Bernsen and Bertels 1993]. In [Verjans and Bernsen 1994] IMAP was applied to PaTerm, an interactive tool for adding lexical databases to the machine translation system PaTrans. Our understanding of the strengths and limitations of IMAP has been further advanced through a recent study of CERD, a flight sequencing tool for use by air traffic control officers [Bernsen and Verjans 1995]. The PaTerm and CERD studies represent applications of IMAP to full-scale realistic design processes.

Our analysis of CERD was able to depart from a comprehensive DSD representation of the CERD design process, which had been done by Ramsay and Bernsen with no particular regard to the requirements of IMAP [Ramsay and Bernsen 1994, Ramsay 1994]. This representation turned out to be quite suitable for the purpose of IMAP as it provided a comprehensive representation of the design commitments which constrained the design of the CERD interface. The DSD thus allowed us to quickly proceed to the second phase of IMAP, i.e. the actual information mapping using the already existing rules of modality theory as well as new ones constructed for the purpose of handling the CERD problem.

The information mapping was done according to the following basic principle. Information mapping is inference. The basic principle, then, is that information mapping is only allowed when based either on general principles of logic or on rules of modality theory. In other words, inference based on designer's craft skill is not allowed. In this way, it can be made clear to what extent modality theory, being the science base of IMAP, actually does contribute to user interface design.

Briefly, the CERD functionality is to do with data on a large number of flights waiting to be allowed to land; with a small number of more or less complex operations which the air traffic control officer (ATCO) may execute on the flight queue, such as swapping or resequencing of flights; and with e-mail communication between the ATCO and the National Airspace System (NAS) which authorises the ATCO's operations. To do the information mapping, one selects the pieces of DSD information one at a time and asks whether this particular piece of information either (i) directly implies a certain interface property or (ii) triggers a modality theory rule which in its turn produces constraints on the properties of the user interface being designed. A certain piece of information may also do both (i) and (ii) or neither of them. The result of this process is called an *abstract interface sketch.* The sketch includes the interface objects and their properties in so far as these can be determined from application of modality theory. In the case of the CERD, which requires a static graphic interface including a number of different static graphic representational modalities, this abstract interface sketch can actually be drawn (see [Bernsen and Verjans 1995]). In any case, the interface objects can be linguistically described as a basis for their subsequent implementation [ibid.]. The reason why the interface sketch is necessarily abstract is that the rules of modality theory are not relevant to the fine details of interface design nor to the results of a very detailed user task analysis which can only take place once there is an approximate interface sketch to work on. The abstract interface sketch is such an approximate sketch.

The following example illustrates the IMAP treatment of actions on incoming flights.

(a) What to represent
There are 4 different types of action to be performed on the represented incoming flights using the CERD rest (or main) menu: assign, reposition, resequence and swap.

(b) IMAP Rules
10. Allow alternative types of action to be performed on the same represented data <->
Create interactors which clearly indicate the alternative types of action.

(c) Information representation
Create 4 static (Rule 7) graphic (Rule 2) interactors (Rule 10) which clearly indicate alternative types of action: an assign interactor, a reposition interactor, a resequence interactor and a swap interactor. Label the interactors ‘Assign’, ‘Reposition’, ‘Resequence’ and ‘Swap’, respectively (Rule 9). Interaction is through pointing gesture or touch (Rule 6).

Step (a) represents a piece of information drawn from the DSD representation of CERD. Step (b) shows the firing of a modality theory rule (Rule 10). Step (c) describes the derived interface properties. Their derivation requires the use of rules which have fired earlier during IMAP and which are referred to in brackets. The numbering of rules is done for ease of reference during the IMAP process. Some of the information represented in (c), such as there being 4 interactors, results from straight inference from (a) without the need for modality theory rules.

The IMAP analysis of the CERD required a total of 19 rules, many of which were re-used several times, and the result was an abstract interface sketch which could be used for detailed analysis of some of the more complex among the ATCO's operations, such as that of simultaneously resequencing a large number of flights. Arguably, this interface sketch comes close to representing all of the output objects and interactors needed for the CERD. The detailed representation of objects through choice of information channels and layout, however, is beyond IMAP which stops when the objects represented in the abstract interface sketch have been grouped according to functionality (see [Bernsen and Verjans 1995]).

5. Conclusion and Future Work

The CERD IMAP analysis has been very helpful in clarifying basic and interrelated issues such as (a) the level of interface design detail supported by modality theory; (b) the fact that IMAP should be used during early interface design; (c) the nature of the abstract interface sketch; (d) the role of the abstract interface sketch in supporting more detailed task analysis; and (e) how to maintain a 'purist' IMAP analysis based solely on rules and logic. One of the big outstanding questions is whether it will be possible to achieve consistency and some kind of completeness of the rules generated by modality theory. Another question is whether and how to eventually mechanise IMAP. We have so far created two generations of our (multimedia) modality theory workbench and theory demonstrator which is being used to explore and demonstrate modality theory [Bernsen, Lu and May 1994, Lu and Bernsen 1995]. Use of this system for interface design support, however, still requires a good deal of natural intelligence. We are addressing these questions through continued work on analysing modalities and through further case studies in which IMAP is being applied to realistic interface design processes.

References

[Barnard 1991] Barnard, P.: Bridging between basic theories and the artefacts of human-computer interaction. In J.M. Carroll (Ed.): *Designing Interaction. Psychology at the Human-Computer Interface.* Cambridge: Cambridge University Press.

[Barnard 1993] Barnard, P.J.: Modelling users, systems and design spaces (Esprit Basic Research project 3066-AMODEUS). *Proceedings of HCI 93*, Orlando, Florida.

[Bernsen 1993a] Bernsen, N.O.: A research agenda for modality theory. In Cox, R., Petre, M., Brna, P. and Lee, J. (Eds.): *Proceedings of the Workshop on Graphical Representations, Reasoning and Communication.* World Conference on Artificial Intelligence in Education, Edinburgh, August, 43-46.

[Bernsen 1993b] Bernsen, N.O.: The structure of the design space. In Byerley, P.F., Barnard, P.J. and May, J. (Eds.): *Computers, Communication and Usability: Design Issues, Research and Methods for Integrated Services.* Amsterdam, North-Holland, 221-244.

[Bernsen 1993c] Bernsen, N.O.: Structuring design spaces. *InterCHI '93 Adjunct Proceedings,* 211-212.

[Bernsen 1994a] Bernsen, N.O.: Foundations of multimodal representations: A taxonomy of representational modalities. *Interacting with Computers* Vol. 6, No. 4, 347-71.

[Bernsen 1994c] Bernsen, N.O.: A revised generation of the taxonomy of output modalities. *Esprit Basic Research project AMODEUS Working Paper* RP5-TM-WP11, 1994.

[Bernsen and Bertels 1993] Bernsen, N.O. and Bertels, A.: A methodology for mapping information from task domains to interactive modalities. *Esprit Basic Research project GRACE Deliverable 10.1.3.*

[Bernsen, Lu and May 1994] Bernsen, N.O., Lu, S. and May, M.: Towards a design support tool for multimodal interface design. The taxonomy workbench and theory demonstrator. *Esprit Basic Research project AMODEUS-2 Working Paper* RP5-TM-WP5, 1994.

[Bernsen and Ramsay 1994a] Bernsen, N.O. and Ramsay, J.: An executive summary of the DSD framework illustrated by two worked exemplars. In Buckingham Shum, S., Jørgensen, A., Hammond, N. and Aboulafia, A. (Eds.): AMODEUS-2 HCI modelling and design approaches: Executive summaries and worked examples. *Esprit Basic Research project AMODEUS-2 Working Paper* RP4-TA-WP16.

[Bernsen and Ramsay 1994b] Bernsen, N.O. and Ramsay, J.: Design structure, process and reasoning. The advancement of a tool for the development of design spaces. *Esprit Basic Research project AMODEUS-2 Working Paper* RP3-ID-WP28.

[Bernsen and Verjans 1995] Bernsen, N.O. and Verjans, S.: Designing interfaces by information mapping. A case study of the CERD design (journal submission).

[Lu and Bernsen 1995] Lu, S. and Bernsen, N.O.: The taxonomy workbench. A multimedia database system for analysing representational modalities (conference submission).

[Ramsay 1994] Ramsay, J.: The representation of PAC modelling of the CERD using the Design Space Development Framework. *Esprit Basic Research project AMODEUS-2 Internal Report* RP3-ID-IR12.

[Ramsay and Bernsen 1994] Ramsay, J. and Bernsen, N.O.: DSD report on the CERD exemplar. In Buckingham Shum, S. (Ed.): Preliminary modelling of the CERD flight sequencing tool. *Esprit Basic Research project AMODEUS-2 Working Paper* RP4-TA-WP23.

[Verjans and Bernsen 1994] Verjans, S. and Bernsen, N.O.: PaTerm: A case study in information mapping. *Esprit Basic Research project AMODEUS-2 Working Paper* RP5-TM-WP6.

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