The AMODEUS Project ESPRIT Basic Research Action 7040

FINAL REPORT (also incorporating Exploitation of Results Report)

Assaying Means of Design Expression for Users & Systems

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1. Executive Summary

1.1 Abstract

This project has been concerned with the development of interdisciplinary approaches to studying interactions between users and systems as well as routes for transferring basic research in Human-Computer Interaction (HCI) to interface designers. The programme of work included (a) developing cognitive models of users; (b) developing formal representations of system architectures; (c) developing practical means of integrating over user and system concerns; (d) developing modality theory and (d) developing techniques for transferring basic knowledge to designers and for empirically evaluating their efficacy. The work of the project been conducted around analyses of three examplar systems concerned with air traffic control, education, and audio-visual communications. The project has documented these developments in a large number of published papers.

1.2 Review of main aims

Although each divides into several specific objectives, the Action has three broad aims:

- (A) To establish a set of related integration frameworks for expressing different aspects of the design of user-system interaction.
- (B) To extend the scope of basic modelling techniques to provide analytic leverage on the problems of user-system interaction with sophisticated interactive technologies;

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(C) To assess how integration frameworks, modelling techniques and the substantive principles they convey may successfully be transferred to and used by the design community.

1.3 Review of Approaches

As a truly interdisciplinary enterprise, the work of the project naturally draws upon a significant range of representational and empirical methods. These include descriptive taxonomies in system, user and design domains as well as an analysis of the gulfs between research tools and design practise; empirical observation and contrastive experiments for studying users and designers; formal methods for representing abstract system models and techniques for representing and contrasting software architectures; production system techniques and cognitive task analysis techniques for modelling user cognition; formal and semi-formal techniques for representing interactions, design space analysis, design processes and domain-based requirements. Various techniques are under consideration for transferring knowledge to, and for the training of, interface designers.

Although this represents terrific methodological diversity, by their very nature some of the representational techniques are intended to integrate over other sources. A unique feature of the AMODEUS consortium is the commitment of all groups to applying their methods to the analysis of the same problems in practical interface design. In the course of the projects four systems acted as "common Exemplars for various purposes: (a) an intensely supportive learning environment (ISLE); (b) an advanced media space design problem from a mainstream Esprit project (EUROCODE); (c) A safety critical air traffic control interface (the CERD) for which the design process relied heavily on formal methods; and (d) a multimodal interface to an air travel information system (MATIS). The products of such conjoint analyses formed the basis for integrating and transferring basic science into design contexts.

1.4 Progress and Results

Although there have been some minor deviations from the detailed initial plans, the overall work of the group has proceeded smoothly and enabled the overall objectives to be achieved within the three-year time course. The project has produced in excess of two hundred working papers. More than half (112) of these have already been published and we would ultimately expect around 150 or more published papers to appear as a direct result of AMODEUS-2. In addition, there are several software demonstrators, of an academic nature, covering the dynamic illustration of cognitive and modality

theory; tools for integrating design concepts, tools modelling information flow in, and knowledge requirements of, user cognition. There are also tools for developing and testing key software concepts, and demonstrator software to advise upon the matching of methods to design problems. The project has also developed new ideas for transferring research results to the design community including pioneering use of electronic document archives accessed over the Internet.

At the end of the project, all fifteen deliverables had been produced on schedule. These contain scientific papers reporting on full work carried out under the various research themes. Key results are listed below and elaborated, by research theme, in subsequent sections of this final report. Reference to the other deliverables is obviously required for full description of the technical results.

Key results are:

Objective (A) Integration and Design Expressions

- For both a media space exemplar and an air traffic control exemplar, large design spaces have been developed incorporating various modelling analyses.
- New formal techniques for modelling interactions between users and systems have been introduced.
- A software demonstrator of integrated representations has been developed.
- A hypertext tool for navigating design spaces is under development.
- A range of tutorial material covering integration methods has been produced.

Objective (B) Modelling for sophisticated interactive technologies

- A system reference model has been developed, refined and disseminated. This includes an
 advanced theory of presentations and software engineering concepts to support the design of
 multimodal interactions.
- User modelling techniques have been developed for advanced graphical interfaces including dynamic, multimodal and gestural issues.
- Modality theory (a systematic framework for the analysis of input/output modalities of
 information representation) has been developed together with a methodology for applying
 the theory in practical interface design.
- A range of documentation, tutorial material or handbooks, have been produced for each of the above areas.

Objective (C) Transferring and Use

- A conceptual framework was developed for identifying opportunities and obstacles in communicating modelling approaches to designers.
- Summaries and worked examples of *all* the modelling approaches were assembled and made available outside the project. Full tutorial material is now available for a restricted range of modelling concepts.
- Several modelling, encapsulation and transfer exercises have been carried out in collaboration with design teams or educational institutions
- A demonstrator decision aid for designers has been developed.

Workpart Summaries

2.1 System Modelling (RP1)

2.1.1 Objectives

This project package was intended to contribute to all three project aims: (1) by seeking to extend the scope of modelling techniques to graphics and to various input-output modalities, such as speech, pointing, and so forth; (2) to contextualise these modelling techniques within the framework of the other AMODEUS 2 models, particularly those relating to cognition; (3) to make system concepts precise and to relate them to the proposed integrative frameworks (SITUE, Design Rationale, Interaction Framework); and to use modelling notations and frameworks that are relevant to the requirements of industrial and commercial use. In large part, all three of these aims were achieved. In the context of (1) substantial progress has been made towards a model of presentations [Duke 94b] that can be used to capture important properties of the perception of presentations. In addition the notion of interactor has been used to specify and analyse multi modal systems, in particular the MATIS speech, mouse and keyboard entry system [Duke 95a]. A methodology to model the software architecture of interactive systems starting from the task specification has been developed [Paterno' 94b]. In the context of (2) properties (see, for example, [Coutaz 95]) have been constructed in interaction with user modellers, and progress has been made to represent the principles in an agent neutral way through interaction framework [Harrison 95]. Syndectic modelling [Duke 95c] has made use of the interactor as a basis for modelling both system and cognition in the context of multi-modal systems. In the context of (3), an exemplar based on EuroPARC's audio-visual office environment has been used to demonstrate the validity of system modelling in the context of one integrative framework, namely OOC.

The system modelling work contributed to three of the specific objectives (section 1.3.2 of the Technical Annex). Models and notations were developed that supported the implementation of systems with an emphasis on the satisfaction of cognitively significant criteria (for example, [Duke 94a; Paterno' 94b]). We produced a natural language reference model that can be used irrespective of the chosen engineering technique. This formed the basis of the reference model deliverable at the end of year 2, and forms chapters 1, 2, 5 and 7 of a book being prepared for publication in the Springer practitioner series (this is also the final System Modelling deliverable). We also extended the agent language, which is strongly based on Z and CSP, and the LOTOS based specification of interactors. (This work was aimed at objective 4 of the Technical Annex: the development of agent languages and system reference models that can support the refinement of design constructs into implementations in a principled way.). The York interactor model (see, for instance, [Duke 93]) extends the agent language by adding presentations, and by introducing the idea of an interactor as a structuring notion that is independent of style of specification. We have explored a selection of specification styles and these are reflected in the range of publications by Duke and Harrison. LOTOS style interactors have been simplified [Paterno' 92], related to task representations and been used with Action Based Computation Tree Logic as a basis for property checking and analysing undesirable behaviours (see [Paterno' 94a; 94b]). The PAC Model has been consolidated and extended to support both multimodal interaction and synchronous types of groupware supporting man-to-man communication [Salber 94; Salber 95]. We have also considered the complementary roles that these techniques might play within the design and implementation process [Duke 94c].

System models were extended to encompass multi-modal interfacing techniques (objective 5). As already mentioned in the previous paragraphs, we developed a mathematical model for the concept of an interactor or interaction object (see [Duke 93; 94b; 95a; 95d]). The formal treatment of interactive graphics, in abstract, has only been a subsidiary issue in the course of the project (mainly because the choice of exemplars did not demand a more sophisticated model). However Duce and Duke have independently been working on models of graphics [Duce 94].

The interactor notation and reference model were both developed with the purpose of connecting theory to design practice. The reference model is intended to meaningful to industrial designers and implementors as a guide to understanding how to model and implement usable interactive systems. We related these ideas to existing software engineering notations by ensuring that the interactor model structured existing notations and models, thereby making it possible to reuse refinement calculi and proof theories (see [Duke 95b; Paterno' 94a]). We believe that the current deliverable achieves this objective; a belief that is confirmed by the fact that Springer have agreed to publish it as part of their Practitioner Series. We have presented the material at tutorials and seminars at conferences (e.g., Eurographics'95 and Interact'95) and industry the latter particularly in France and Italy. This provides a contribution to objective 7.

2.1.2 Achievements

Another way of summarising the achievements of the system modelling package over the three years of the Amodeus 2 project is to describe them in the context of the chapters of the final deliverable. This document encapsulates all the strands of work contained in this package. The project has led to a deeper understanding of the relationship between the different activities at Grenoble, Pisa and York. It has enabled a more "process" orientated view of the use of these various notations and principles. It has led to an understanding of how system representations might be used in linking with user modelling techniques. Specific achievements in relation to integration (for example, interaction framework and syndectic modelling) are left to the discussion of the Integration package. New work, apart from the integration activity, has been made possible as a result of this activity, especially the investigations of verification techniques in the context of the two interactor models. The material presented in the deliverable has been used as a basis for various dissemination exercises including an explanation of the work carried out on a particular exemplar (a component of an air traffic control system) to a systems developer (Praxis).

We call the final deliverable the Amodeus system reference model although its scope has extended since the Amodeus 2 Technical Annex was first written. It is primarily intended for software designers. Its foundational concepts can also be used by cognitive modellers for classifying interactive systems, for understanding the properties of a particular system, or for identifying issues of interest for usability assessment. Concepts, throughout the document, are described in terms of two of the common exemplars - MATIS (an airline information system) and CERD (a component of an air traffic control system). It is intended to help systems engineers conceptualise, design and implement multi-modal interactive systems.

Chapter 2 of the document is concerned with the *concepts and properties* that define the *problem space* that is the scope and dimensions of designing interactive systems. It provides designers with a common set of vocabulary and issues to characterize a particular design or to reason about alternative designs. Here the basic components of system modelling are introduced which for the basis for the notations for task analysis as well as interactor and architecture modelling. It describes concepts associated with multi-modal systems. It describes a collection of principles of interactive behaviour that may be taken into account when designing interactive systems. This chapter reflects the summary and reconciliation of different perspectives in establishing a common terminology and base understanding that can be used in the various modelling techniques. It also involves a discussion of some ways in which user and system modelling may be brought together.

Chapter 3 shows how interactor-based system modelling supports the properties and concepts presented in Chapter 2. The three interactor-based modelling techniques developed in the Amodeus project address different issues and cover different needs within the development process. This chapter contrasts an informal but structured object oriented approach (PAC), with formal specification techniques. The York model uses a hybrid specification technique involving state, action and presentation whereas the CNUCE model is event based using a process algebra as its starting point. The chapter deals with the roles that these approaches have and discusses, particularly in the context of the formal models, how properties or requirements of interactive systems may be folded into these system models. Examples are given for all the techniques. In the context of the York model some simple requirements are shown to be true of the specification using simple proofs based on the axioms of interactors. The chapter also contains a description of how a task description may be mapped into an interactor architecture in the context of the LOTOS interactor model and demonstrates heuristics for general procedures for moving from tasks to interactors. The York notion of interactor has been used, explicitly, to connect system concepts with cognitive concepts in understanding human and system processing for small scenarios. In the LOTOS model a cycle of interaction is understood in which user events as well as system events can be recognised.

Chapter 4 describes tools and techniques based on the Amodeus interactor modelling approaches to formally *validate or verify system properties* of interactive systems. These tools support predictive assessment of a particular design solution as well as experimental evaluation of running prototypes. A key issue here has been deciding what is particularly distinctive about interactive system specification and properties. It contrasts preliminary work on theorem proving techniques with more developed model checking techniques based on LOTOS and ACTL. This chapter covers work that extends the original Amodeus 2 goals and will lead to methods that will make the system modelling techniques more adoptable by industry. It is important in the validation of these techniques that modellers can check and demonstrate properties of their specifications. This work builds on a wider interest in verification and validation and addresses the distinctive properties of interactive systems. It is concerned with what is important and distinctive about proving properties of interactive systems; it is concerned with how relative views can be extracted from specifications so that properties can be checked using

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finite models. It is also concerned with how the properties can be established and how the baseline events are defined. At this stage properties are close to trivial. However, a useful foundation has been established for future research which is ahead of other related research at Georgia Tech, Atlanta and Waterloo.

Chapter 5 is concerned with *software mechanisms*. The intent is to provide software implementers with a generic class of software solution that support properties and features identified in Chapter 1 and that can be embedded into interactor-based architectures such as the one described in the document (PAC-Amodeus). At this stage of the development of the work, the software mechanisms are concerned with temporal aspects of mixed mode input. Here problems arise because the cost of processing commands using different modalities may lead to a temporal sequence of commands that does not correspond to the actual order input. This is but one example of a potentially large set of important implementation techniques that relate our model of multi modal systems to efficient and user supportive implementations.

Chapter 6 exemplifies the interactor-based modelling technique with two case studies: MATIS and CERD. It also illustrates links with the other modelling approaches of the Amodeus project such as user modelling and design rationale. Here substantial components of the two case studies are expressed in terms of the two formal modelling approaches to illustrate techniques in a more extended form. The CERD work has been presented to Praxis with some success (see report of RP4). There is a well founded belief that interactor notation is close to industrial application. The MATIS work has formed the basis of a benchmark that is to be used as a challenge to the growing community of researchers concerned with the use of formal specification techniques in the development of interactive systems and should stimulate valuable further research.

Chapter 7 is the *system glossary* of the reference model. It contains the complete list of concepts, properties, and issues identified by the Amodeus project as well as other properties introduced ealier in the literature but relevant to our modelling techniques.

(http://www-lgi.imag.fr/Les.Groupes/IHM/AMODEUSGlossary.html).

This glossary has developed and evolved over the project.

2.1.3 Where from here?

A further way in which we might measure our achievement is by considering the literature in the area covered by System Modelling. In 1989, Coutaz (Grenoble) and Dix, Harrison, Runciman and Thimbleby (all then at York) were almost alone in their interest in linking formal or structured system models with cognitive modelling. The map has now changed. Many publications have been produced in this field. For example, the CNUCE group, as well as Tampere, Toulouse, Waterloo, Georgia Tech, Huddersfield, Middlesex, Bari, Grenada, Chicago, Glasgow are particularly interested in formal System Modelling and have produced papers that build on our work.

There are many directions now in which to go. More work is required mapping tasks to system models. Better models of resources, such as presentation and time, are required. Some of this work is being sponsored by BAe at York, some by EDF in France. Some forms part of new research proposals. More work is needed to understand the verification of specifications against user requirements, both the technology of checking the specifications and understanding more intimately the extent to which cognitive models may be used in this process and how other contextual issues may be taken into account. We also look forward to industrial evidence that these techniques help.

2.1.4 Key Papers

We summarise the key papers delivered by the system modelling research package:

[Coutaz 93]

Coutaz, J., Nigay, L. & Salber, D. *The MSM Framework: A Design Space for Multi-Sensory-Motor Systems.* In EWHCI'93: Selected Papers. L. Bass, J. Gornostaev, & C. Unger (eds). Volume 753 of Lecture Notes in Computer Science. Springer-Verlag, 1993. [Coutaz 94]

J. Coutaz: Evaluation Techniques: exploring the Intersection between HCI and Software Engineering, Workshop on "Software Engineering and Human Computer-Interaction", International Conference on Software Engineering, ICSE'94, Sorrento, May, 1994.

[Coutaz 95]

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J. Coutaz, L. Nigay, D. Salber, A. E. Blandford, J. May and R. M. Young. *Four Easy Pieces for Assessing the Usability of Multimodal Interaction*. INTERACT'95, IFIP Fifth International Conference on Human Computer Interaction, 25-29 June 1995, Lillehammer, Norway, 1995.

[Duce 94]

Duce, D.A., Duke, D.J., ten Hagen, P.J.W. & Reynolds, G.J. (1994) PREMO - An Initial Approach to a Formal Definition, *Computer Graphics Forum, vol 13, 3,* pp. 393-406. [Duke 93]

D.J. Duke and M.D. Harrison. *Abstract Interaction Objects*. Computer Graphics Forum. 12 (3). Conference Issue: Proc. Eurographics'93. 1993.

[Duke 94a]

D.J. Duke & M.D. Harrison. From Formal Models to Formal Methods. In R.N. Taylor and J. Coutaz, editors, Formal Methods and Human-Computer Interaction Volume 896 of Lecture Notes in Computer Science, pages 159-173. Springer Verlag, 1995.

[Duke 94b]

D.J. Duke & M.D. Harrison. *A Theory of Presentations.* FME'94: Industrial Benefit of Formal Methods. M. Naftalin, T. Denvir & M. Bertran. Lect. Notes in Comp. Sci. Vol. 873. pp.271-290. Springer Verlag. 1994.

[Duke 94c]

D.J. Duke, G. Faconti, M.D. Harrison and F. Paterno', Unifying Views of Interactors, In Proceedings of Advanced Visual Interface '94 International Workshop, Bari, (ACM Press), 1994.

[Duke 95a]

D.J. Duke & M.D. Harrison. Interaction and Task Requirements. In DSV-IS'95: Eurographics Workshop on Design, Specification and Verification of Interactive Systems. Springer Verlag, 1995. To appear.

[Duke 95b]

D. Duke & M.D. Harrison *Mapping User Requirements to Implementations*. Software Engineering Journal. Vol 10 No. 1 pp 3-13. 1995.

[Duke 95c]

Duke, D.J. Reasoning about gestural interaction. Computer Graphics Forum 14(3). 1995. [Duke 95d]

D. Duke & M.D. Harrison *An Event Model of Human-System Interaction*. Software Engineering Journal. Vol 10 No. 1 pp13-20. 1995.

[Harrison 95]

Harrison, M.D., Blandford, A.E. & Barnard, P. J. *The Requirements Engineering of User Freedom.* In Paterno,. F., (Ed.) The Design, Specification and Verification of Interactive Systems, Proceedings of the Eurographics Workshop, Carrara, Italy, 8-10 July, Springer 1995 to appear.

[Nigay 93]

Nigay, L. & Coutaz, J. A design space for multimodal interfaces: concurrent processing and data fusion. INTERCHI'93 Proceedings, Amsterdam, S. Ashlung, K. Mullet, A. Henderson, E. Hollnagel, T. White Eds., ACM New York Publ., May, 1993, pp. 172-178. [Nigay 94]

Nigay, L.Conception et modélisation logicielles des systèmes interactifs : application aux interfaces multimodales. Thèse de doctorat Informatique, Laboratoire de Génie Informatique (IMAG), Université Joseph Fourier, 28 janvier 1994, 315 pages.

[Nigay 95]

Nigay, L. & Coutaz. A Generic Platform for Addressing the Multimodal Challenge, CHI'95, ACM New York, Denver, May 1995, pp. 98-105.

[Paterno' 92]

Paterno', F. and Faconti, G. On the Use of LOTOS to Describe Graphical Interaction. In A. Monk, D. Diaper, and M.D. Harrison, editors, People and Computers VII: HCI'92 Conference, pages 155-174. Cambridge University Press.

[Paterno'93a]

F.Paterno'. "Definition of User Interface Properties Using Action-Based Temporal Logic". Proceedings of the Fifth International Conference on Software Engineering and Knowledge Engineering, pp.314-319, ISBN 0-9641699-0-8, S.Francisco, June 1993.

[Paterno' 93b]

F.Paterno', A.Leonardi. "A Semantics-based Approach to the Design and Implementation of Interaction Objects", Computer Graphcs Forum 13 (3), pp.195-204, Blackwell Publisher.

[Paterno' 94a]

F. Paterno', A. Leonardi, S. Pangoli. A Tool Supported Approach to the Refinement of Interactive Systems. In the Proc. of *Eurographics Workshop Design*, *Specification*, *Verification of Interactive Systems*, F. Paterno' Ed., 1994, pp. 85-96.

[Paterno' 94b]

F. Paterno' & M. Mezzanotte. Analysing Matis by Interactors and ACTL. Amodeus-2 Technical Report, Number SM/WP36, 1994.

[Paterno' 94c]

F.Paterno'. "A Theory of User-Interaction Objects", Journal of Visual Languages and Computing, Academic Press, Vol.5, N.3.

[Salber 94]

Salber, D. & Coutaz, J. Fenêtres sur groupe : des mediaspaces pour collaborer et communiquer. 3ème Journées Internationales sur L'interface des Mondes Réels et Virtuels, EC2 Publ., Montpellier, 7-11 février, 1994, pp. 309-318.

[Salber 95]

Salber, D. De l'Interaction Homme-Machine individuelle aux systèmes multiutilisateurs, l'exemple de la Communication Homme-Homme Médiatisé. Thès e Doctorat Informatique, Laboratoire de Génie Informatique (IMAG), Université Joseph Fourier, Grenoble, France, to appear 8 Sept. 1995, 250 pages.

2.2 User Modelling (RP2)

2.2.1 Aims and Objectives

User modelling is intended to enhance the quality of interface design — both the process and the outcome — by drawing designers' attention at an early stage of design both to what is good about the usability aspects of a proposed interface and to what may be problematic. In this way, user modelling can help designers to prioritise what they still need to put effort into, and provide the conceptual framework required to devise solutions to problems.

The specific objective of this Research Package was to develop user models of sufficient scope to deal with user behaviour in perceptually rich interactional settings (Project Objective 6). By this means it contributed to overall project Aim B, which was to extend the scope of basic modelling techniques to provide analytic leverage on the problems of user-system interaction with sophisticated interactional technologies. User modelling activity was also directed towards the integrational work (aim A) by furnishing analyses and discussion of the common material, and in the development of novel approaches that brought together system and user modellers. It also addressed transfer issues (aim C) by encapsulating key concepts and procedures, and assisting in exercises where these were taught to HCI students and designers.

2.2.2 Overview

Complementary approaches to user modelling were pursued to address concerns at different levels of analysis. Programmable User Modelling (PUM) was the most concrete approach. It consisted of an Artificial Intelligence style of explicit simulation model, which derives its predictive power primarily from an analysis of the knowledge needed by users to perform tasks with the proposed interface. The next approach, Cognitive Task Analysis (CTA) consisted of an application-oriented approximation to an underlying model of the dynamics and constraints of human cognitive processing, which infers characteristics of the users' performance from characteristics of the interface and task. A third, and more abstract approach, made use of the COSITUE framework to analyse the full space of usability concerns. It was initially planned to use this approach to locate user modelling within the surrounding context of system, interface, task, and experience, and to form the basis of inter-relating theoretical approaches to analysing user knowledge at different levels of detail.

These three user modelling approaches began the project in different stages of development. COSITUE was the most novel of the three. With a categorical approach to recording the development of design commitments, its effort was shared between User Modelling and the Design and Integration research package (RP3). In continuing its initial development (as part of Task 2 in the first year of the project: *Develop the SITUE framework in relation to user modelling*) it became clear that the temporal nature of its user modelling, showing how user-based commitments and requirements evolved in the course of a design, had closer affinities with representations of design context than with the cognitive modelling and simulation approaches of PUM and CTA. Rather than constrain the approach, it was decided to allow it to extend its scope and to consolidate its effort within RP3, as Design Space Development (DSD). The resources originally allocated to its role in RP2 were accordingly reassigned to RP3, and its work is reported in Section 2.3 The work and achievements of the PUM and CTA approaches are presented below.

The first year was largely devoted to the consolidation of theoretical work that had begun in Amodeus-1, and in setting the stage for its extension to modelling the multimodal and highly-interactive scenarios that were to be the focus of work in the second and third years (Task 1: *Extend simulation and approximate modelling techniques*). The PUM approach was limited to 3 months resources in this year, and concentrated on the development of STILE, which translated Instruction Language descriptions into runnable Soar code. The CTA approach began to explore the cognitive implications of requiring users to blend multiple streams of information, and to produce communicative behaviour in multiple modalities (i.e., speaking, gesturing and typing).

In the second year, most attention was focused on the analysis of three common exemplars, EuroCODE, CERD and MATIS (Task 4: *Apply user modelling techniques to common exemplars*). The EuroCODE exemplar was a prototype Audio-Visual (AV) connections system. The design context was highly exploratory, with the designers testing out new ideas and drawing on a range of existing design solutions for inspiration. This, together with the fact that the design being analysed was a fairly early prototype, including several aspects which were under-defined and some which were inconsistent, resulted in analyses which were fairly informal. The nature of the exercise, where we were basically asked to "comment on this design" and "contribute to the design space", resulted in modellers

proposing partial re-designs of aspects of the system. As well as presenting our analysis in modelling terms, we also expressed as much as possible in terms of Questions, Options and Criteria, so that it could be incorporated within a large common design space by members of the RP3 research package (Task 3: *Develop relationships with other approaches*).

The final year of the project saw the user modelling approaches consolidating their work in two ways. Most effort was given in support of the Transfer and Assay research package, in encapsulating the techniques and teaching HCI students and designers how to apply the techniques in practice (Task 5: *Consolidate the user modelling techniques*). Together with the System Modellers and the Integration and Design research package, additional effort was put towards the integration of the user modelling techniques with methods of design representation (Task 6: *Synthesise with other approaches*).

2.2.3 Theoretical Developments And Consolidation

Programmable User Modelling

At the start of Amodeus 2, the focus of the work on PUM was on developing running models, implemented in the Soar (Laird, Congdon, Altmann and Swedlow, 1990) problem-space architecture. In the first year, work concentrated on the implementation (in Lisp) of the STILE translator, which translates domain knowledge expressed in the Instruction Language (IL) into Soar code (Blandford & Young, 1993; UM/WP6 in Deliverable 2). This work helped to bring into focus several aspects of PUM which were ambiguous or restrictive. Theoretical work in the second year identified a range of such problems and considered routes by which they might be addressed. One of the theoretical developments in the final year was to make a clear separation between the device description and the user model. A paper resulting from this work (Blandford & Young, 1995) focused on models of interactive problem solving that account for the general problem solving techniques people exploit in performing tasks with computers, the device-specific knowledge they need, and the sources of that knowledge. We have extended our approach that originally focused exclusively on the user's knowledge and problem solving capabilities to allow us to specify separately the behaviour of the computer system. This allows us to recognise design features that depend on the user keeping track of nondisplayed aspects of the device state, as well as those the user can see. This aspect of the work still focused on the development of running models. However, in parallel, the analysis of the common exemplars was done using the Instruction Language in a relatively informal way, without generating running models.

The informal use of the IL on the common exemplar material was built upon in several ways in the final year of the project. Firstly, we reflected on the experience of applying the PUM technique to substantial design problems, and drew out some general lessons about how the approach scales up. We demonstrated how PUM can be applied with less formality to practical design problems, and showed how many of the insights come through the process of applying PUM, rather than through the product (i.e. the IL description). The cost of applying the technique need not be excessive (as it would be if a full IL specification and running model were generated at all stages of design), but the results can yield useful design insights. In this context, the running model serves the role of 'notional target' for the modellers, and thus informs the analyses, but the important insights are gained without pursuing the analysis that far (Blandford and Young, submitted; UM/WP30 in Deliverable 10).

Secondly, the semi-formal use of the IL, together with the use of hand-simulation of the cognitive model to predict properties of interactive behaviour has led us to a more rigorous analysis of the relative contributions of knowledge and architecture. Sometimes only a few basic properties of the architecture are relevant; at other times cognition depends upon fine details of the architecture. We have analysed examples of interaction with complex devices which reflect differing degrees of dependence on the user's cognitive architecture, and on internal and external knowledge. This increased understanding of the roles of the knowledge and cognitive architecture is an important step in the development of a unified theory of how a user interacts with a device. This work is presented in UM/WP33 (included as part of Deliverable 10), which is currently being revised for journal submission.

Such a unified story contributes to both interface design and our understanding of cognition. For design, the most important aspect is the knowledge analysis, as it provides a basis for asking whether users will possess the knowledge needed for using a device, and employing that in turn as a means for predicting, diagnosing, and helping suggest remedies for any problems of usability. For cognition, this work offers a route for dealing coherently with the difficult topic of interactive cognition, i.e. cognition which involves interacting with external environments and artefacts, where the determinants of behaviour are partly within and partly outside the person.

Cognitive Task Analysis

We spent some time at the start of the project consolidating the results of the cognitive modelling from Amodeus-1. We regarded the development of a structural method for gathering up descriptions of user's goals, task sequences and interface design as an essential step in the construction of a general purpose automated modeller of user cognition. A paper (May, Barnard & Blandford, 1993) showed how structural descriptions of interface designs can be used to model user tasks, visual interface objects and screen layouts. An experiment was designed to test a number of hypotheses arising from the structural description technique, and the results were presented at HCI'93 (May, Tweedie & Barnard, 1993). This work provided the framework for the subsequent development of our technique and its encapsulation as tutorial materials for transfer exercises with the Transfer and Assay research package (RP4).

Novel work in the first year extended the modelling approach developed in Amodeus-1 to make it more applicable to dynamically changing interface designs in two ways. The first examined the 'rules of thumb' that have evolved in cinematography to help film editors cut together different camera shots in acceptable and understandable ways. We proposed a cognitive model of film-watching that explains why these rules work, and we extrapolate from it to the design of interfaces with displays that need to be updated or refreshed without confusing the user (UM/WP9 in Deliverable 2). This work continued throughout the project (May & Barnard, 1995). The second area of work deals with the cognitive blending of different sources of information. We modelled a number of phenomena that have been studied in cognitive psychology (UM/WP10 in Deliverable 2), and used this work to help us model multimodal and multi-stream interfaces (Barnard & May, 1995). In the second year of the project we continued this work, in particular relating it to the work of the system modelling groups (RP1). Daniel Salber from the PAC group in Grenoble spent three months in Cambridge, collaborating with us on an experimental investigation of the factors affecting the comprehension of deictic reference in videophone communication (Barnard, May & Salber, in press; UM/WP19 in Deliverable 6). Empirical evidence of this form is of both theoretical and practical interest, informing our understanding of how readily people adapt their communication styles, while providing specific information of relevance to the design of shared media spaces, and the analysis of the common exemplars that involve deixis, EuroCODE and MATIS.

As well as providing a tool for the presentation of our research, the development of animations of ICS have given us some insight into the problems faced by the designers and users of heavily interactive systems. Tweedie & Barnard (1992) describes how we have found multimedia technologies to be an invaluable asset in presenting complex dynamic theory, and discusses the process by which these new technologies—are moving into the researchers workplace by describing how the multimedia presentation device has aided communication of theory. In Green (1994) we explored the relationships between the cognitive representations of tasks and knowledge structures, and subsequent performance and the development of device knowledge, both within the HCI domain and in problem solving studies. It is argued that the ICS framework does more than simply re-express the known phenomena but sheds new light on them.

In a more argumentative paper (May & Barnard, in press; UM/WP21 in Deliverable 6), we noted that the relevance of HCI theory to industry is being questioned, and that the emphasis is shifting away from providing generalised support to systematic evaluation methods. We proposed that evaluation methods retaining a theoretical element would provide the necessary conceptual support to enable designers to identify, comprehend and resolve usability problems, and would also be less constrained in their breadth and depth of application. We presented an ambitious vision of a 'supportive evaluation' tool, based on our expert system tool, described three brief design scenarios, drawn from our Amodeus work, and discussed the role of cognitive modelling in the context of design.

In addition to addressing the issue of cognitive modelling as a whole, we have also taken the opportunity to step back and review the progress that we have made in the development of our own approach. This has been done within the context of a book chapter for an edited book bringing together work from Esprit Basic Research and RACE. The book (Byerley, Barnard & May, 1993) described the product design context for usability research and practice, focusing in particular on the problems and opportunities arising from the advanced communication services which are expected to be in business and domestic markets within 20 years. The breadth of the readership of this chapter has meant that we had to be explicit about the aims and objectives of approximate modelling of cognitive activity, and how it can be used within a design context.

2.2.4 Integration With Other Approaches

The success of the Amodeus project in bringing together HCI researchers from different disciplines can be seen in the wide variety of papers that the User Modellers have contributed to over the course of the

project. Of the published papers and project working papers registered with the project co-ordinators, 83 have at least one User Modeller as an author, but only 49 are solely User Modelling documents. The other 34 have been prepared in active collaboration with members of the other research packages.

In the first year of the project, collaborations arising from scenario modelling in Amodeus-1 were carried through to publication (Young, Barnard, Blandford and Harrison, 1994; Young & Abowd, 1994). Following the experience with the Amodeus-1 'matrix' approach to scenario modelling, where each of the system and user modelling techniques were applied individually to evaluate particular design or usability scenarios, the project developed a more iterative and interactional approach called 'collational comodelling' (reported in ID/WP36). This allows the different techniques to build on each others' modelling, with the user modellers, for example, asking the system modellers for detail about the way that the system would respond to or interpret a user's actions, and the system modellers similarly asking the user modellers how a user would react to or perceive a system event (such as a screen change). We have found that combining the modelling approaches in this way allows the strengths of each technique to complement the others by providing information that is lacking or poorly specified.

Together with the PAC system modellers from Grenoble, the PUM and CTA modellers have developed the 'User CARE' properties (Coutaz *et al*, 1995) which correspond to the Complementarity, Assignment, Redundancy and Equivalence with which the user can choose between different modalities in a multimodal interaction (this work is reported in Deliverable 9). These properties correspond to a similar set of 'System CARE' properties, and provide a way of ensuring that there is a formal match between the modalities that the system provides and those that the user expects, prefers or requires.

The scenario modelling work on the EuroCODE and CERD exemplars has been used to produce two major pieces of work that integrate the modelling with design representations. The EuroCODE modelling has provided the basis for an analysis of Accessibility and Availability in Shared Media Spaces, using the 'QOC' design Rationale notation as an integrating expression (Bellotti *et al*, submitted). Together with the CERD analyses, it has also been drawn on to complete an overview of integration techniques for multidisciplinary HCI modelling (reported in ID/WP48). These papers are included in Deliverable 11.

Further integration between system modellers and user modellers occurred at a meeting in Cararra, Italy, where the 'Part-Whole' problem in perception was discussed and analysed using concepts derived from Interacting Cognitive Subsystems (ICS), the psychological framework that forms the basis of CTA. The crucial role that a person's knowledge and expectations about the world play in governing the perceptions that they form from the environment was emphasised in an animated, computerised presentation.

A cross-modelling exercise involving the CTA approach and the Formal System Modellers from York Computer Science Department and Rutherford Appleton Laboratories has taken the concept of an 'interactor', which has previously been used to specify the system side of an interaction, to develop a formal specification of the user side of the interaction. This has been achieved by representing ICS as a set of logical axioms, and by using these to reason formally about the conjoint user-system interaction. This paper proposes that formal system models can be combined directly with a representation of human cognition to yield an integrated view of human-system interaction: a syndetic model. Aspects of systems that affect usability can then be described and understood in terms of the conjoint behaviour of user and computer. An extended version has been prepared for journal submission (Duke, Barnard, Duce & May, submitted; presented in Deliverable 11).

2.2.5 Transfer And Application

Programmable User Modelling

One of the main focuses of effort for PUM in the third year was on developing and testing training materials for transferring the technique to software engineers. One of the points about the PUM approach that has been made repeatedly is that the process of analysing what knowledge a user needs in order to achieve goals with a particular device often yields more useful insights than observing the behaviour of the running model. With this in mind, for Transfer exercises with the Transfer and Assay Research Package (RP4) we developed tutorial material about the PUM technique that centred on the knowledge analysis phase, rather than the development of running models. This involved developing a clearly stated set of heuristics to guide novices writing IL descriptions, and producing exemplar knowledge analyses of a range of interactive devices for teaching purposes. In close collaboration with members of RP4, and with the cooperation of many other people at the University of York and the Free University, Amsterdam, we developed and tested an approach to transferring the IL to trainee

software engineers. The training material, *Introduction to the PUM Instruction Language*, is available as UM/WP29. In assessing our training, we addressed three specific questions:

- Does using the IL make a discernible difference to the kinds of usability assessments made?
- How do trainee software engineers use IL after one day's training? and
- How could the training be improved?

To provide answers to these questions, various types of data, including the IL descriptions and reports produced by the subjects and video data, were collected and analysed, to establish what the outcomes of this training were, and whether there was any discernible effect on the students' subsequent analyses. Conclusions include the fact that students were able to grasp most of the important concepts in the IL, though the more subtle points generally eluded them. Since these subtle points, which involve making a very clear distinction between the state of the device and the user's knowledge of that state, are the most important when it comes to analysing a design, the students' post-test reports generally failed to identify the more subtle usability problems with the devices analysed. However, there was a measurable, if small, shift from the initial to the final analyses, indicating some influence from the IL construction process. Although it was generally judged to be fairly effective, we have identified various ways in which the training could be improved. Results of this study are reported in TA/WP34, which is currently being revised for journal submission, and which is included as part of Deliverable 12.

Cognitive Task Analysis

A considerable proportion of the effort towards dissemination has been carried out in providing an 'encapsulation' of CTA for the Transfer and Assay research package. This has taken the form of the development of a set of notations for the representation of information structure, using the concepts of psychological subject, predicate and structural transitions over time. A 'guidebook' that describes the use of these notations in the construction and evaluation of computer displays has been prepared together with an *Exercise Companion* that provides the answers to the exercises within the guidebook. These have been used in an Assay exercise at Copenhagen University (reported in TA/WP35 and included in Deliverable 12), and will form the basis for a Tutorial at *Eurographics* '95 at Maastricht in August. The guidebook is to be published as May, Scott & Barnard (1995), and is included as part of Deliverable 10.

The remaining encapsulation work has supported the further development of ICSpert, an automated reasoning tool for CTA. We had decided to move from Xi+, the expert system tool that supported the development of ICSpert in Amodeus-1, to a more flexible tool that provided better reasoning algorithms and tools for the development of graphical interfaces on Macintosh computers. Unfortunately the software company withdrew the Macintosh version of the product, and we have had to return to a Windows based platform. The delay caused by this has limited the amount of redevelopment work that we have been able to complete. Nevertheless, we have produced a running system that builds configurations of the cognitive resources required by ICS for any two tasks, and then determines the requirements for multimodal blending, differentiation of outputs in multiple modalities, and reasons about the degree of interleaving that is required, and the interference that results. While the current system is of much more limited scope than the Xi+ version, important benefits over the previous shell are already apparent in the better interface facilities and in the ability for consultations to be made 'iteratively', with minor changes being possible without starting from the beginning. This work is reported in UM/WP34, and is included in Deliverable 10.

2.2.6 Future Plans

Collaboration with the formal system modellers required the description of the ICS architecture to be made much more concrete, in that it was necessary for the previously textual 'principles' to be specified precisely in logical notation. We anticipate that this will be helpful in communicating the architecture, and hence the CTA technique, to other psychologists. A conference presentation, which used an animated Macromedia Director presentation, showed how the well specified set of transformation processes and image records required by the ICS Propositional and Implicational subsystems could account for a wide range of 'Central Executive' functions. This animation has been included within the extended 'AnimICS' package, which has continued to develop over the past twelve months. We have recently acquired a more powerful version of the software that is used to build and run AnimICS, and hope to complete a new version of the software by the end of the AMODEUS project extension. The animation's would then be made available for both Macintosh and PC computers via the World Wide Web. At present several future project proposals are in active preparation. Two of these make direct use of AMODEUS-2 results as a basis for further development

of interdisciplinary models. A third concerns the further transfer of material to support the design of advanced multimodal displays. A fourth proposes to take the kind of animated material developed from the CTA approach and explore its possible use in medical training.

2.2.7 References

- Barnard, P. & May, J. (1995) Interactions with Advanced Graphical Interfaces and the Deployment of Latent Human Knowledge. In F. Paterno' (ed.) Eurographics Workshop on the Design, Specification and Verification of Interactive Systems, Berlin: Springer Verlag.
- Barnard, P., May, J. and Salber, D. (in press) Deixis and Points of View in Media Spaces: an empirical gesture. *Behaviour and Information Technology*
- Bellotti, V., Blandford, A., Duke, D., MacLean, A., May, J. & Nigay, L. (submitted) Controlling Accessibility In Computer Mediated Communications: A Systematic Analysis Of The Design Space.
- Blandford, A.E & Young, R. M. (1993) Developing runnable user models: Separating the problem solving techniques from the domain knowledge. In J.L. Alty, D. Diaper & S. Guest (eds) People and Computers VIII. pp. 111-122. CUP: Cambridge
- Blandford, A. E. & Young, R. M. (1995) Separating User And Device Descriptions for Modelling Interactive Problem Solving. In K. Nordby, P. Helmersen, D J Gilmore, and S Arnesen (eds): Human-Computer Interaction: Interact'95. Chapman and Hall, 1995. PP. 91-96.
- Blandford, A. E. & Young, R. M. (submitted) Applying Programmable User Models to real design problems.
- Byerley, P.F. Barnard, P.J. & May, J., editors (1993) Computers, Communication and Usability: Design issues, research and methods for integrated services. (North Holland Series in Telecommunication) Elsevier: Amsterdam.
- Coutaz, J., Nigay, L., Salber, D., Blandford, A., May, J. & Young. R. (1995) Four easy pieces for assessing the usability of multimodal interaction: the CARE properties. In K. Nordby, P. Helmersen, D J Gilmore, and S Arnesen (eds): Human-Computer Interaction: Interact'95. Chapman and Hall, 1995. PP. 115-120.
- Duke, D. J., Barnard, P. J., Duce, D. A, & May, J. (submitted) Syndetic Modelling.
- Green, A. J. K. (1994) An Exploration of the Relationships between Task Representations, Knowledge Structures and Performance. Interacting with Computers, 6, pp 61-85
- Laird, J., Congdon, C. B., Altmann, E. & Swedlow, K. (1990) Soar User's Manual: Version 5.2. Technical Report CMU-CS-90-179, Computer Science Department, Carnegie Mellon University, Pittsburgh, PA.
- May J. and Barnard, P. (1995) Cinematography and interface design. In K. Nordby, P. Helmersen, D J Gilmore, and S Arnesen (eds): *Human-Computer Interaction: Interact* '95. Chapman and Hall, 1995. PP. 26-31.
- May, J., and Barnard, P. J. (in press) Towards supportive evaluation during design. Interacting with Computers, 7.
- May, J., Barnard, P.J., and Blandford, A. (1993) Using Structural Descriptions of Interfaces to Automate the Modelling of User Cognition. User *Modelling and Adaptive User Interfaces*, 3(1)
- May, J., Scott, S, and Barnard, P. (1995) Structuring Displays: a psychological guide. Eurographics Tutorial Notes Series, EACG: Geneva.
- May, J., Tweedie, L. A. & Barnard, P. (1993) Modelling User Performance in Visually Based Interactions. In J.L. Alty, D. Diaper & S. Guest (eds) People and Computers VIII. pp. 95-110. CUP: Cambridge.
- Tweedie, L. & Barnard, P.J. (1992) The interactive talk: a new tool for presenting complex theory. *Psychology Software News*, *3*, 43-45.
- Young, R. M. & Abowd, G. D. (1994) Multi-perspective Modelling of Interface Design Issues: Undo in a Collaborative Editor. In People and Computers IX: Proceedings of HCI'94. G. Cockton, S. W. Draper, & G. R. S. Weir (Eds). CUP: Cambridge, pp. 249-260.

Young, R. M., Barnard, P J., Blandford, A E. & Harrison, M D. (1994) The Unselected Window Scenario. Presented at CHI'94 Research Symposium. Boston, USA. pp. 1-11

2.3 Integrational And Design Expressions (RP3)

2.3.1 Introduction and Overview

This Research Package (RP3) was primarily directed at the project aim A: establishing a set of related frameworks for expressing different aspects of the design of user-system interaction. It did this by addressing specific objectives 1, 2 and 3: (1) The development of an Interaction Framework (IF), within which claims concerning relationships between user, system and domain concerns can be precisely expressed. (2) The development of Design Rationale (DR), within which the considerations underlying design reasoning and choice can be explicated. (3) The development of a classification of concepts relevant to the different types of design-oriented expression (DSD, formerly COSITUE). It also contributes to objectives 7 and 8, concerning the means of encapsulating mediating expressions and assessing how designers understand and benefit from them.

Partners in York Computer Science and APU were responsible for the development of the Interaction Framework, with the main effort focused towards the early part of the project. RXEP were responsible for the development of QOC/DSA (Questions, Options, Criteria / Design Space Analysis), a design rationale framework. During the first half of the project, partners in IDA developed aRD (Argumentative Design), a technique derived from QOC for use in an Action Design setting. In the second half of the project, IDA effort moved to demonstrating the integration of multiple design representations through computer based tools. CCI were responsible for DSD (Design Space Development). In the early part of the project this focused around the classification of design concepts (referred to as COSITUE), but through the course of the project was developed to take a broader account of design rationale and the design process, hence the renaming.

In addressing the specific objectives, much of the first year's effort focused on individual development of each of the contributing approaches. This was important to get to the stage where each approach was well enough developed to explore the complementarity among them. Since the QOC/DSA Design Rationale work was the most mature, some of its effort also went towards broader project goals of developing a fairly large common exemplar to be analysed by all project partners in the second year of the project. In year two the focus moved towards integration with other parts of the project as a major element, particularly in the context of the shared exemplars but also at the conceptual level. For one of the common exemplars, a large QOC design space and supporting material was developed around issues of accessibility and availability in media spaces. This was used as a basis for applying the modelling techniques and as the focus for integrating the results of the analyses. The development of this exemplar as well as its use was therefore a major undertaking within RP3. The COSITUE framework was augmented to include representations of design rationale and was renamed DSD. The primary focus during year three was on the consolidation of work carried out in the first two years of the project. Much of the emphasis was on articulating the frameworks for practical application to design and the relations among the frameworks. The integration of modelling approaches within the large QOC design space was further developed in close collaboration with RP1 and RP2, and DSD was used to explore integration of modelling representations in the context of a second common exemplar in the domain of air traffic control.

In addition to the above, a range of broader based integrational efforts took place throughout the project to provide the necessary context for the more specific developments. In year one, some preliminary work was done to relate the design frameworks to each other. In addition to the application of each approach to common exemplar material we considered the position of each approach on a set of more conceptual issues. In years two and three, a demonstrator was developed to explore the relationships among the design frameworks from a tool based perspective and to explore issues in the technical integration of multiple representations. In years two and three a variety of new approaches were also developed to integrate user and system modelling techniques. Finally, in year three, all members of the project contributed to producing a survey of integrational techniques which were developed in the course of the project.

The rest of this section proves a little more detail on the above developments, organised around each of the main foci of activity.

2.3.2 Interaction Framework

Interaction Framework (IF) is being developed by partners at APU and York Computer Science. It was fully funded only for the first 15 months of the project, and developed work begun in the first Amodeus project.

IF provides a notational framework which is neutral with respect to user or computer system details so that appropriate interactional requirements may be employed in the design and understanding of interactive systems. An interaction involves two or more agents (users or computer system-based) who are engaged in communication. It can be described at different levels of detail; at each level the interaction can be viewed as passing though a sequence of states where the post-condition of one state satisfies any pre-conditions of the next. Each state involves the agents to the interaction engaging in events, which may be interspersed with choice points where one of the agents to the interaction can influence the future course of that interaction. We have explored alternative notations for describing both particular interaction trajectories (as either sequences of states of the interactive system or traces of events) and the space of possible interactions (in terms of states, events and choice points). These concepts have been used as a basis for expressing requirements of the properties of the interaction which can be used to guide the design of interactive systems.

In the first year of the project, IF explored the formal expression of interactional requirements in terms of events and tasks, and on the mapping from such interactional requirements to computer system requirements, which are needed to inform the design of computer systems (Blandford, Harrison and Barnard, 1993a). It also produced analyses of common exemplar material (Blandford, Harrison and Barnard, 1993b) and an IF description of the interaction space to guide the modification of the design of a prototype Intelligent Tutoring System (Blandford, 1992). In year two, development focused on interaction requirements that cannot be expressed solely either in user or system terms. In particular it explored properties of interactive systems that contribute to a notion of freedom in the interaction. These properties include initiative, potential, history and invariance. (Harrison, Blandford and Barnard, 1993) (Although not a formal part of Amodeus, the initiative property is being further explored at the University of York by Jason Good, a PhD student partly funded by RXEP). A more general and informal paper on interaction framework was also written during year 2: "Understanding the properties of interactions" (Blandford, Harrison and Barnard, 1993). An overview of the IF work was produced in the later stages of the project and has been accepted for journal publication. This paper outlines the theoretical basis of the approach, defines a range of interactional properties, and illustrates their significance to the design of interactive systems. It also discusses the use of Interaction Framework in design practice, illustrating how the identification of interactional requirements on a design can guide the designer in developing a system that satisfies those requirements. A further contribution is an illustration of the integrational role that IF serves, in providing a common framework for taking account of system, user and other concerns (Blandford et al., 1995).

2.3.3 QOC/DSA Design Rationale

The QOC/DSA Design Rationale work is being carried out by partners RXEP and continues work originally developed in the first Amodeus project (see MacLean et al., 1991). It consists of a technique called Design Space Analysis (DSA) which uses a notation called QOC (Questions, Options, Criteria). A key characteristic of the approach is that the output of design is conceived of as a design space rather than a single artefact. QOC is a semi-formal notation which represents a design space in terms of alternative design options, and the reasons for choosing among them. Questions highlight key issues in the design space. Options can be thought of as 'answers' to Questions. Criteria are the reasons that argue for or against possible Options. Two main themes have characterised this work throughout the course of the project. The first has involved creating a larger design space than has been done before, and using this as a common exemplar for project-wide analysis and a basis for a major integration effort. The second has been in exploring and developing ways of making practical use of the approach in design practice.

We selected the domain of communication and interaction in audio-video media spaces as the focus for the common exemplars which were developed around QOC/DSA. Reasons for this choice were that it represents state of the art multimedia systems, we had good access to developers of this kind of system through RXEP, and the maturity of such systems was such that it was an opportune moment to systematise current design knowledge. In year 1, we produced some initial design spaces in this

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domain which were used as exemplars for analysis within RP3 (Bellotti and MacLean, 1993a, b). At the beginning of the second year, this was augmented and refined in collaboration with members of the EuroCODE project (Esprit 6155), who were designing a related media space system. This involved close collaboration with the EuroCODE designers and our aims were threefold: a) to provide useful support to the EuroCODE project. b) To provide material for other members of Amodeus to analyse and feed back to the EuroCODE designers and c) to develop DSA/QOC, particularly in areas of coping with a large design space in the context of a real design project, and in acting as a mediating representation among other design inputs (i.e. the Amodeus modelling). Interim results of this work were produced at the end of year 2, one focusing primarily on the contribution of the modelling analyses and their integration into the design space (Bellotti and MacLean, 1994) and one, in collaboration with RP4, on the processes of creating and using the design space and on evaluating the effectiveness of the analyses (Bellotti, Buckingham Shum and MacLean, 1994). The preliminary input to these reports was expanded and the results written up for publication in year 3. In collaboration with RP4, a conference paper was produced which evaluates the processes of creating and using the design space and the modelling analyses (Bellotti et al. 1995a). In collaboration with modellers from RP1 and RP2 additional analyses were carried out to build on and re-examine the earlier analyses. This included producing some analyses based on initial modelling produced by other groups - for example, system modelling based on the results of user modelling analyses. The paper based on this work has been submitted for journal publication (Bellotti et al, 1995b).

The second thread focused on the continuing development of techniques for using DR in design practice. One contribution to this in the first half of the project was the work done by IDA on aRD (Argumentative Design), which was derived from the QOC notation. It was evolved for use within an Action Design framework to support group processes in design. It provides a specific way of focusing on what issues need to be addressed (Questions in QOC terminology; Change Needs in aRD terminology). A description of the approach is described in Sjöberg (1994). Sjöberg and Timpka (1993) give an example of its application to one of the RP3 shared exemplars, and conference publications of its use to support group processes in design appear in Timpka and Sjöberg (1994), Sjöberg and Timpka, (1995). A tutorial originally developed in Amodeus 1 has been refined in the course of Amodeus 2, and presented three times to the annual British Computer Society HCI conference, as well as to a number of other University and industrial audiences, both in the UK and abroad. A summary of the process model around which the tutorial is organised is published in a book chapter (MacLean et al., 1993). Heuristics (the DRESTIK guidelines) for when to produce explicit design rationale were also produced. These are based on activities within the design process, such as disagreement among group members, issues raised at review etc. (Carey and MacLean, 1994). We also explored the use of DSA/QOC within another collaborative project in which possible user interfaces for educational hypermedia systems were being developed. The main goal, over a period of 12 months, was to explore how to make best use of QOC, where it worked well, and some of the difficulties encountered. Descriptions, and a video, of the process and lessons learned have appeared in conference and journal publications (McKerlie and MacLean, 1993; McKerlie and MacLean, 1994). Descriptions of how QOC was used to help structure design information from a variety of relatively informal design representations such as scenario descriptions, sketches and story-boards was published in a book aimed at practitioners (MacLean and McKerlie, 1995), and an earlier report gives detailed examples of the design representations used (MacLean and McKerlie, 1993).

2.3.4 Design Space Development (DSD)

CCS joined the Amodeus project at the start of Amodeus 2. The goal of the work was to develop a broad and practical design support framework based on an understanding of the properties common to the design spaces of IT artefacts. During the three years of the project, work has gone through three broad phases, as follows:

In Year 1, the design support framework was developed conceptually through application to a large, realistic in-house design process, i.e. the design of an application-oriented spoken language dialogue system prototype (Bernsen 1993a, 1993b), as well as to shared Amodeus 2 material (Bernsen 1993d). The result was a frame-based notation for explicitly representing an artefact as it develops in design space during design specification. The framework was named *COSITUE* after its analysis of design spaces as having, among others, the following aspects: Collaboration, Organisation, System, Interface, Task, User and user Experience (Bernsen 1993c, 1993e).

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During Year 2, the framework was developed into its present format partly through application to shared Amodeus 2 design material such as the ECOM and CERD cases (Bernsen and Ramsay 1994b, 1994c, Ramsay and Bernsen 1994), and partly through being used as an integral part of the RP5 information mapping methodology that was developed in the same period by CCS and Leuven (Verjans and Bernsen 1994). The COSITUE framework was re-named *Design Space Development* (or DSD), partly because design spaces are being analysed in terms of more aspects than the COSITUE aspects mentioned above, and partly because the framework came to integrate the representation of design space *structure*, *process* and *reasoning* (Bernsen 1994, Bernsen and Ramsay 1994a). Thus, a particular DSD frame represents the structure and contents of the design space at a certain point in time during artefact design. A series of DSD frames represents the development of the artefact design process. And DR frames selectively represent design reasoning on particular design problems. The DR frame notation used by DSD is different from the notation used by QOC/DSA in that a QOC representation encourages alternative solutions to be retained in the primary view onto the design space whereas DSD emphasises evolution across frames to represent the design space.

During Year 3, DSD was used to represent how the various Amodeus 2 modelling approaches tackled a series of shared design problems with the CERD system (Ramsay and Bernsen 1995a, 1995b). However, three other developments have been important to DSD progress. The first was the development towards practical application of DSD. DSD has been applied in a Danish industrial design project in which one of the DSD developers from CCS acted as consultant together with consultants from the modality theory and information mapping group at CCS (RP5 of Amodeus 2). The company's designer expressed the wish to use DSD himself in other design processes (Ramsay 1995). A manual to support the application of DSD is in preparation and expected to be ready at the formal end of Amodeus 2 (Bernsen, Dybkjær and Ramsay, in preparation). The second development during Year 3 was theoretical. Work on comparing the DR representation used in the framework of DSD with the QOC/DSA representation quickly expanded to address the general problem of how to design a practically useful DR representation. No existing DR approach has yet been successfully transferred from research to industry for use on a day to day basis. Bernsen and Ramsay are preparing a study of the proper roles, aims and means of DR approaches to systems design support to address this problem. The study is expected to be ready at the formal end of Amodeus 2 (Bernsen and Ramsay, in preparation). The third development during Year 3 is a hypertext implementation of DSD which we hope to have ready by the formal end of Amodeus 2.

2.3.5 Developing the Context for Integration in RP3

In year 1, some preliminary work was done to relate the design frameworks to each other (Blandford, Harrison and Barnard 1993b; Bernsen and Klausen, 1993; and Sjöberg and Timpka, 1993). In addition to the application of each approach to common exemplar material we considered the position of each approach on a set of more conceptual issues (Blandford et al., 1993c) of each approach, its role in design practice and its relationship to models to help us identify useful dimensions on which to compare and contrast the approaches. In years two and three, a demonstrator was developed at IDA to explore the relationships among the design frameworks from a tool based perspective and to explore issues in the technical integration of multiple representations. The goal was to focus on issues of information representation to help us better understand relationships among the different frameworks, rather than necessarily produce a usable tool. The initial work developed a screen-based prototype called Jackie which illustrated the integration of DSA/QOC, DSD and aRD to express system and user modelling outcomes from a subset of the year 1 exemplar analyses (Löwgren et al., 1994). The next step in year 3 explored the underlying mechanisms which could provide the functionality to support the behaviour envisaged in the Jackie demonstrator. A report outlining the issues and requirements was produced (Löwgren et al., 1995). A system named Walter, was developed with an argumentative structure providing an underlying common framework on top of which DSA/QOC, DSD and aRD design representations can all be implemented, thus allowing the design to be viewed and developed from whichever of the frameworks is most appropriate for the particular problems being tackled.

2.3.6 Other Approaches to Integration

The primary emphasis of the work in RP3 has been on developing design frameworks to provide an integrative "glue" for relating the other approaches to the design context. However, throughout the project, a number of pieces of work have been done which are clearly integrative in nature, but are

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generally narrower and more local in their scope than the full-blown design frameworks. (In some respects, the Interaction Framework is of this character, even although it was originally included as one of the RP3 representations). All members of the project contributed to producing a survey of the full set of integrational techniques which were developed and explored in the course of the project (Amodeus-II Consortium, 1995). This includes the original core RP3 approaches as well as a variety of new approaches which have emerged during the course of the project.

A collaboration between RP1 and RP2 developed a set of properties to provide a simple way of characterising and assessing aspects of multimodal interaction. These are known as the CARE properties (for Complementarity, Assignment, Redundancy, and Equivalence). They are formally defined and provide a basis for understanding how system CARE properties interact with user CARE-like properties in the design of a system (Coutaz et al., 1995).

A technique known as collational co-modelling was developed and explored in two settings, one via email exchanges (Young et al., 1994) and one face to face during a project workshop (reported briefly in Amodeus-II Consortium, 1995). The approach involves direct communication between modellers, and iteration of the modelling, together with an attempt by a "collator" to pull together an emerging, multi-disciplinary story. In contrast to the design frameworks, it is exploring the integration of modelling input without recourse to a mediating representation. However, it is not yet clear how best to organise the collation of the results. It may well be that the structure provided by a design framework such as DSA/QOC or DSD could help support collation, but this has not been explored as yet.

Finally, development has been carried out on an approach known as *syndetic modelling*. This provides specifications that span the state and behaviour of both user and system agents. As such it sits between Interaction Framework and software architectural models such as the PAC agent approach. It expresses both a system model and a model of cognition (specifically, the ICS model underlying the CTA approach to user modelling). Once both models are in a common language they can be combined by the simple expedient of creating a third model that includes both - the syndetic model. In this model features of the system - for example perceivable states and actions - are mapped onto the cognitive resources of the user. This approach allows direct (and formal) comparison between the capabilities and limitations of the two parties in an interactive system. A number of reports have been produced on this approach. It has been applied to the design of gestural interfaces (Duke, 1995) and the current state of the work has been submitted for journal publication (Duke et al., 1995).

2.3.7 References

- Amodeus-II Consortium (1995) Integration Techniques for Multidisciplinary HCI modelling: A Survey. (D. Duke, Ed.) Amodeus II: ID/WP48
- Bellotti, V. (1993) Integrating Theoreticians' and Practitioners' Perspectives with Design Rationale. In proceedings of INTERCHI'93, Amsterdam, April. ACM: New York. (Also Amodeus II: CP30)
- Bellotti, V., MacLean, A. (1993a) Designing for Communication and Interaction in a Ubiquitous Computing Environment. Amodeus II: ID/IR1
- Bellotti, V., MacLean, A. (1993b) A Design Space for Ubiquitous Computing Systems. Amodeus II: ID/IR2
- Bellotti, V., MacLean, A. (1994) Integrating and Communicating Design Perspectives with QOC Design Rationale. Amodeus II: ID/WP29.
- Bellotti, V., Buckingham Shum, S. and MacLean, A. (1994) Assaying Multidisciplinary Modelling Using QOC as a Mediating Design Expression: The EuroCODE AV Exemplar. Amodeus II: ID/WP30.
- Bellotti, V., Buckingham Shum, S., MacLean, A. & Hammond, N. (1995a) Multidisciplinary Modelling In HCI Design. In Theory and In Practice. In Proc. CHI'95 Denver USA. May 7-11, April 1995. Also, Amodeus II: CP77.
- Bellotti, V., Blandford, A., Duke, D., MacLean, A., May, J. and Nigay, L. (1995b) Controlling Accessibility In Computer Mediated Communications: A Systematic Analysis of The Design Space. Amodeus II: ID/WP47

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- Bernsen, N.O. (1993a): Design of a spoken language dialogue system. Amodeus 2: RP3/WP3.
- Bernsen, N.O. (1993b): CO-SITUE illustrated by a study in early artefact design. Amodeus 2: RP3/WP4.
- Bernsen, N.O. (1993c): The structure of the design space. In Byerley, P.F., Barnard, P.J., & May, J. (Eds.): Computers, Communication and Usability: Design issues, research and methods for integrated services. Amsterdam: North-Holland, 221-244. (Also Amodeus II: BC 9)
- Bernsen, N.O. (1993d): CO-SITUE representation and analysis of shared material for AMODEUS-2 modelling: RAVE and Portholes. Amodeus 2: RP3/WP15.
- Bernsen, N.O. (1993e): Structuring design spaces. INTERCHI'93 Adjunct Proceedings, Amsterdam, April, 211-12. (Also Amodeus II: CP35).
- Bernsen, N.O. (1994): A short history of the DSD (Design Space Development) approach. Amodeus 2: RP3/IR7, 1994.
- Bernsen, N.O. and Ramsay, J. (1994a): Design structure, process and reasoning. The advancement of a tool for the development of design spaces. Amodeus II: RP3/WP28, 1994.
- Bernsen, N.O. and Ramsay, J. (1994b): AMODEUS-2 shared modelling exercise: DSD modelling technique report on the EuroCODE exemplar. Amodeus II: ID/IR8.
- Bernsen, N.O. and Ramsay, J. (1994c): 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. Amodeus II: TA/WP16.
- Bernsen, N.O., Dybkjær, L. and Ramsay, J.: A manual for the Design Space Development (DSD) framework. Amodeus II Working Paper (in preparation).
- Blandford, A. (1992) Modelling the interaction between educational systems and students. Amodeus II: ID/WP1
- Blandford, A., Harrison, M.D., Barnard, P.J. (1993a) Integrating user requirements and system specification. To appear in: Byerley, P.F., Barnard, P.J., & May, J. (eds) Computers, Communication and Usability: Design issues, research and methods for integrated services. (North Holland Series in Telecommunication) Elsevier: Amsterdam (1993). (Also Amodeus II: BC7)
- Blandford, A., Harrison, M.D., Barnard, P.J. (1993b) AV Connections: an initial analysis based on the Interaction Framework. Amodeus II: ID/WP18
- Blandford, A., Barnard, P., Bellotti, V., Bernsen, N.O., Harrison, M., Klausen, T., MacLean, A., Sjöberg, C., Timpka, T. (1993c) Towards Conceptual Integration. Amodeus II: ID/WP19.
- Blandford, A. Harrison, M. D. and Barnard, P. J. (1994) Understanding the properties of interactions. Amodeus II: ID/WP25
- Blandford, A. E., Harrison, M. and Barnard, P. (1995) Using Interaction Framework to guide the design of interactive systems. To appear in: International Journal of Human Computer Studies. (Also Amodeus-II: JP17).
- Byers, D. (1995) Walter: An Integrative Platform For Representing Argumentative Design Notations. Amodeus-II: ID/WP50.
- Carey, T. and MacLean, A. (1994) Guidelines for Design Rationales with lifecycle benefits: a case study. Amodeus II: ID/WP27.
- Coutaz, J., Nigay, L., Salber, D., Blandford, A., May, J. & Young, R. (1995) Four Easy Pieces For Assessing The Usability Of Multimodal Interaction: The CARE Properties. In Proceedings of INTERACT '95. K. Nordby, P. Helmersen, D J Gilmore, and S Arnesen (eds): Human-Computer Interaction: Interact'95. Chapman and Hall, 1995. pp. 115-120. 25-29 June 1995, Lillehammer, Norway. (Also, Amodeus-II: CP78).
- Duke, D. J. Reasoning About Gestural Interaction. In Computer Graphics Forum, Vol 14(3). NCC/Blackwell. Conference Issue, *Proc. Eurographics'95*, Maastricht, The Netherlands, Aug 28 Sep 1. 1995. (Also Amodeus II: CP84).
- Duke, D. J., Barnard, P. J., Duce, D. A, & May, J. (1995) Syndetic Modelling. Amodeus-II: ID/WP49. (Submitted for publication).

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- Harrison, M. D. Blandford, A. E. and Barnard, P. J. (1994) The Requirements Engineering of User Freedom. In Proc. Eurographics Workshop on the Design, Specification and Verification of Interactive Systems, Bocca di Magra, June 1994. (Also Amodeus II: CP53).
- Löwgren, J., Sjöberg, C., Hägglund, S., Timpka, T. (1994) Technical Integration of the RP3 Design Expressions The Jackie Demonstrator. Amodeus II: ID/WP32.
- Löwgren., J, Sjöberg., C, Hägglund., S, Timpka., T, & Byers., D. (1995) Technical Integration Of Semi Formal Design Notations — Experiences From Tool Development. Amodeus-II: ID/WP51.
- McKerlie, D. & MacLean, A. (1993) QOC in Action: Using QOC to Support Design. In SIGGRAPH Video review Series, Issue 88. (Also Amodeus II: V1)
- McKerlie, D. & MacLean, A. (1994) Reasoning with Design Rationale: Practical Experience with Design Space Analysis. In *Design Studies*, 15, 1994, pp. 214-226. (Also Amodeus II: JP20)
- MacLean, A., Young, R., Bellotti, V. & Moran, T. (1991). Questions, Options, and Criteria: Elements of Design Space Analysis. *Human-Computer Interaction*, Vol. 6 (3&4). [Special Issue on Design Rationale: John M. Carroll and Thomas P. Moran (Eds.)], 201-250. (Also Amodeus: JP1)
- MacLean, A. & McKerlie, D. (1993) Design Space Analysis and Use Representations. Amodeus II: ID/WP21
- MacLean, A., Barnard, P., Bellotti, V., Bernsen, N.O., Blandford, A., Harrison, M., Klausen, T., Sjöberg, C., Timpka, T. (1993) Looking at 'AV Connections' from the perspective of Integrating and Design Expressions. Amodeus II: ID/WP20.
- MacLean, A., Bellotti, V., Shum, S. (1993) Developing the design space. To appear in: Byerley, P.F., Barnard, P.J., & May, J. (eds) Computers, Communication and Usability: Design issues, research and methods for integrated services. (North Holland Series in Telecommunication) Elsevier: Amsterdam (1993). (Also Amodeus II: BC8)
- MacLean, A. and McKerlie, D. (1995) Design Space Analysis and Use-Representations. In: Scenario-Based Design: Envisioning Work and Technology in System Development. pp. 183-208. Edited by J. M. Carroll, Wiley, New York, 1995. (Also Amodeus-II: BC14).
- Ramsay, J. and Bernsen, N.O. (1994): DSD modelling technique report on the CERD exemplar. Amodeus 2: RP3/IR10. In Buckingham Shum, S. (Ed.): Preliminary Modelling of the CERD Flight Sequencing Tool. Amodeus II: TA/WP23, 1994.
- Ramsay, J. and Bernsen, N.O. (1995a): Traceability support for modelling in the design process Using design space development. Amodeus 2: RP3/WP45.
- Ramsay, J. and Bernsen, N.O. (1995b): Catalogue of design rationale representations: A source document for ID/WP45. Amodeus 2: RP3/WP46.
- Ramsay, J. (1995): Promoting plant-computer interaction developing a design space for greenhouse monitoring and control. Amodeus II: TA/WP44.
- Sjöberg, C., Timpka, T. (1993) Initial aRD analysis of a common exemplar: RAVE and Portholes. Amodeus II: ID/WP22.
- Sjöberg, C. (1994) Voices in design: Argumentation in participatory development. Linköping Studies in Science and Technology, Licentiate Thesis no 436, Linköping University.
- Sjöberg. C., & Timpka. T. (1995) Inside Multi-Disciplinary Design In Medical Informatics: Experiences From the Use of an Argumentative Design Method. In Proceedings of the Tri-Annual World Conference in Medical Informatics, MEDINFO'95, Vancouver. (Also Amodeus-II: CP76).
- Timpka T, & Sjöberg C. (1994) Voices of Design: The Dynamics of Participatory Information System Design. In Trigg R, Anderson S. I, Dykstra-Erickson E. A. (eds) In PDC '94: Proceedings of Participatory Design '94, pp 75-85. Chapel Hill NC USA, 27-28 October: CPSR, 1994. (Also Amodeus-II: CP75).
- Verjans, S. and Bernsen, N.O. (1994): PaTerm: A case study in information mapping. Amodeus II: TM/WP6.
- Young, R. M., Blandford, A E., Coutaz, J., Duke, D. and May J (1994) Collational Co-Modelling: An Introduction and an Example from the CERD Interface. Amodeus-II: ID/WP36

2.4 Transferring and Assaying Design Expressions in Use (RP4)

2.4.1 Introduction

Research package 4 (RP4) is concerned with rather different kinds of issues than the other research packages. In short, RP4 investigates the outcomes from these packages from a practitioners perspective. The project organisation with such an independent assessing group is unusual in the HCI research community. As far as we are concerned, this approach has not been adopted by any international research group developing HCI modelling techniques. The approach ensures adequate resources in coverage of application concerns and ensures a high degree of independence in the assessments.

As to application concerns, the current project takes a large step ahead in relation to the preceding project Amodeus I, where the practical design aspects were dealt with by studying user interface design practice and consequently relating it to modelling concerns. In the current project, modellers and designers are interacting and the modelling techniques even applied by designers.

Thus aim (C) in the Technical Annexe is central to RP4:

To assess how integrational frameworks, modelling techniques and the substantive principles they convey may successfully be transferred to and used by the design community.

Accordingly, the two objectives central to RP4 are:

To develop means of encapsulating expressions for successful transfer to designers, based upon the use of common exemplars.

To asses how designers understand and benefit from model-based and mediating forms of expressions.

These objectives break further down to 9 tasks all of which have been dealt with in the project. In the present brief report, space doesn't allow focussing on these tasks, let alone detailed accounts of the activities in the three years. Rather, the work of this research package will be presented in four main components, reflecting in part the advances over time and in part the nature of the activities undertaken.

In Amodeus II we adopted a four-stranded approach which is reflected in the following four sections. The first strand is developing a conceptual foundation for our work. A key feature of the Amodeus II project is collaboration with real design projects. This is reflected in the second strand, comprising the project-wide "common exemplar" activities where user interface design issues from development projects are imported into the Amodeus project, analysed by the modelling groups, and the results subsequently fed back to the designers by RP4. Working with design projects is, however a double-edged sword. On the one hand it provides the ideal testbed for both modelling and transfer techniques and on the other hand the collaboration with the projects is subject to the organisational turbulence of industrial development projects. This has in part motivated the third strand where we conducted focussed transfer studies of a number of individual modelling techniques to students. Finally, the fourth strand addresses development of design decision support aids for user interface designers.

2.4.2 Developing a Conceptual Foundation

We first developed a conceptual framework for identifying opportunities and obstacles in communicating modelling approaches to designers using encapsulations. We define an encapsulation as follows: Re-expression of the representations with which modellers work in order that designers can comprehend and apply the results of the modellers' analyses - or for some approaches, go on to use the technique themselves.

The next step was identifying key research questions: are the modelling techniques comprehensible, are they usable, are they useful? In order to contextualise these questions we developed a framework with *gulfs* that were to be bridged: the *cost gulf* (how easy is it to encode information in the formalism of the modelling technique?), the *payback gulf* (is it useful to reason with the formalisms?), and the *consultancy gulf* (is the technique useful?). The gulfs were related to stages of software development and the degree of modelling technique automation. We also developed a specific version of the gulfs conceptualisation for each modelling technique that helped us clarify key issues in the communication between the modellers and the designers (Buckingham Shum and Hammond 1994a, 1994b).

As a starting point we also considered computer-based learning as it provides a rich perspective on theoretical and practical aspects of transfer. The variety of these approaches provides a range of 2.10

possibilities for communicating modelling to design, such constructive approaches and reflective approaches, not just expository approaches (Hammond, 1993).

As the project developed, a need arose to clarify the foundation for transfer and assay and also to outline certain procedures in transfer and assay studies. The motivation is the close interdependency between the parties involved: the designers, the modellers, and the "assayers", giving rise to social and ethical issues. This work established a framework for making explicit the concerns and commitments in transfer and assay studies (Jørgensen and Aboulafia, 1994).

The above-mentioned conceptual developments were supplemented early on in the project by bringing modellers and designers together in a workshop. Modelling techniques were presented to the designers who in turn presented typical user interface design problems that were analyzed on the fly by the modellers. This workshop provided a substantiation of the design perspective:

- how does the models improve what I already do?
- how do the models fit into my design process?
- · how do the models relate to each other?
- who is supposed to use the techniques
- · what skills are needed to use the techniques?
- how much modelling is model-based, how much is craft skill?

This proved valuable in guiding further work (Aboulafia et al., 1993; Buckingham Shum and Hammond, 1993).

2.4.3 Industrial collaborative exercises

The project as a whole has worked with three major "common exemplars". These are large-scale industrial collaboration exercises, where user interface design issues from development projects are imported into the Amodeus project, analysed by the modelling groups, and the results subsequently fed back to the designers by the assayers. The first common exemplar was ISLE: A hypermedia learning support environment. Two design scenarios were extracted (creating and retrieving annotations) and analysed by the modelling groups. Their analyses were compiled into a report and a workshop with design team members was held. Moreover, the designers' reactions were fed back to the modellers who in turn were given the opportunity to respond. In addition to specific feedback to the individual modelling techniques as to contents and presentation, we learned some more general lessons on modelling and on running transfer and assay studies, such as the importance of having the modellers present in order to have face-to-face discussions, and understanding the organisational design context (Shum, 1994).

The second common exemplar exercise was termed EuroCODE. In this project a mediaspace for distance collaboration was designed. This exercise was unique in that it included evaluation of QOC design space analysis as a medium for designers to communicate with each other and with modellers. Once again scenarios were selected and analysed by the modellers. This time their analyses were expressed and integrated as a QOC design space that enriched the designers' initial skeleton QOC design space; this was then fed back to the design team. The modelling-enriched QOC was intelligible to those designers who were already familiar with the skeletal QOC. Thus all design representations are situated artifacts that are most useful when their context and history is known. The designers found that QOC provided a good overview, but is it also a very terse notation. Thus the QOCs need to be enriched with other representations, e.g. modelling reports, screenshots, or concrete examples (Bellotti et al., 1995).

In connection with this common exemplar, we held a short workshop at the conference CHI'94 with leading international media space designers. We presented the modelling analyses and elicited feedback. The workshop validated the cognitive usability analyses and we found that design culture is important, especially regarding designers' exposure to formal notations and techniques.

The third common exemplar is CERD - an air-traffic control tool for sequencing flights approaching British airports. CERD is a touch-screen based system and is part of a larger system that is now operational. The system has been developed by the software engineering company Praxis plc, Bath, UK for the Civil Aviation Authority. Praxis is one of the world leaders in the use of formal methods in software engineering and was therefore an ideal partner, not least for the system modellers. Once again scenarios were identified, this time by the Human Factors designer of the CERD project. These were analysed by the modelling groups. Two workshops were held with the Human Factors designer

and chief software engineer. They found the modelling approaches insightful and considered some potentially usable. However, as industrial practitioners they also identified a number of obstacles which remain to be overcome in making these approaches viable. This study provided evidence that involving designers in discussions with modellers and even perform modelling in situ ("co-modelling") is an excellent strategy for communicating the nature of HCI modelling techniques, and is to be recommended as a vehicle for modelling transfer (Buckingham Shum & Hammond, 1995).

In connection with the common exemplars we developed material for information dissemination to the HCI research community and to user interface designers. This consisted of executive summaries of the individual modelling approaches and a set of worked examples, mainly drawn from the common exemplars. The material was available over the Internet and a good number of copies have been requested (Buckingham Shum et al., 1994).

2.4.4 Transfer of Specific Modelling Approaches

In the common exemplars studies, the modellers themselves conducted the modelling analyses and we studied the designers' needs and reactions. However, several modelling techniques became so mature that it proved feasible to develop encapsulations that could be used by other parties than the modellers. These kinds of studies are reported in this section. In the studies reported we have generally used HCI students or software engineering students as designers. From an industrial transfer perspective this is not ideal. However, many of the students did have design experience - and by using students we were training the next generation of designers at the same time.

In the studies we have focussed on one modelling technique at a time. The selection of the techniques was mainly guided by their encapsulation maturity. In the studies we have in general investigated the comprehensibility, the usability and the utility of the techniques.

From the Amodeus I project an encapsulation of ICS modelling was available as an expert system. We took the opportunity to run a focussed transfer and assay study early on with this encapsulation. The key question guiding this work was: "Can the ICS expert system be used without knowledge of the underlying ICS modelling concepts?" The expert system was presented to ergonomics Masters students and they were given a small interface evaluation problem to be solved using the expert system. We found that deep knowledge about ICS is not required to use the modelling tool, but the students had difficulty in answering several key questions. This was consistently accounted for by the students' lack of understanding that characteristics of users, tasks, and interface are represented as structural relationships (Buckingham Shum and Hammond, 1994a).

The Design Space Analysis approach was investigated focussing on students' perceptions of the approach. The motivation for this study is the vast amount of tools, techniques and methods available in the marketplace for user interface designers - and they are the ones who eventually pick and choose. Following three weeks of training, twenty-three students with some design experience worked with Design Space Analysis for two weeks on a design task. The students were able to make good use of the approach, although they reported both positive and negative perceptions. In particular they found it useful for organising and documenting, but less so for communication and reflection (J¢rgensen and Aboulafia, 1995).

The ICS modelling group developed a 60-page display guide (May et al., 1995) intended to help people to use psychological principles to chose the visual appearance of interface objects, their arrangements and their dynamic behaviour. A key feature in the guide is two types of diagrams that supports interface designers to analyse the visual properties of displays. Numerous exercises accompany the material in the guide. The understandability of the guide and the exercises were tested in pilot studies, while the main study - run over five weeks with training sessions by the ICS modellers - investigated if the students were able to apply the principles on real display problems. The conclusions so far are tentative as the students efforts varied considerably and the analysis is still in progress. The handbook was seen as relevant and applicable, but also limited in scope. The students were able to apply the principles to design problems with some success (Aboulafia et al., 1995).

A study of the learnability and utility of PAC-Amodeus was also conducted, a software engineering approach to designing agent-based user interface architectures for multi-modal systems. Three exercises were run with students and software engineers. Certain aspects of PAC were easily grasped, but training could be improved to address common confusions between PAC and for instance, object hierarchies and toolkit functions. A clear requirement was also identified to demonstrate more explicitly the links between a PAC model and commercially available interface builders and toolkits (Nigay et al., 1995).

The final focussed study involved PUMS instruction language denoted "IL" - a language for describing and analysing interface designs. Before embarking on the training in IL, the software engineering students analysed a design example and wrote a short report on it. After the training, the students analysed another design example to see if there was any discernible effect on their analyses. The students were able to grasp most of the important concepts in IL, though the more subtle points generally eluded them. There is, however, a measurable, if small, shift from the initial to the final analyses, indicating some influence from the IL construction process (Blandford et al., 1995)

2.4.5 Developing a Design Decision Aid

The fourth strand is concerned with the applicability of fuzzy knowledge models and fuzzy reasoning to the problems of encapsulation and communication. The purpose of the work is twofold. Firstly to investigate the role of a Designer's Decision Aiding System (DDAS) for designers as a means for encapsulation and transfer, and secondly to implement a prototype of a Design Aid to help designers with interface design problems such as: which modelling approaches to use, which part of the design space is addressed, and when to use an approach.

To this end a methodology based on Soft Systems Thinking, fuzzy reasoning, and test score semantics has been developed. This has resulted in the development of a prototype version of DDAS. The main steps in the methodology are:

- 1 making a "rich picture" of the problem space. This involved obtaining from the modellers their views of the design process, what constitutes the design space and how their approach fitted within it.
- 2 Elicit propositions about the modelling approaches per se such as "CTA highlights the sources of ambiguity" and "PUMS records relevant device knowledge". These propositions are claims about the potential of the modelling approach.
- 3 These claims were taken as evidence of problem areas in the design space, e.g. ambiguity, as for example when a button has two functions and it is not clear to the user which function is operational when.
- 4 A collection of such problem descriptions was made and the modellers asked to assess their modelling approaches' ability to deal with these problems. They were invited to use numerical scales or qualifying statements such as "a lot, a little", etc.
- 5 In addition, the links between the problems themselves and their relation to one another within the whole design space were noted (the relevant subsystems).

This work constituted the contents of the knowledge base. The organisation of the knowledge base required that the problem descriptions be accessible to the user, who browses these descriptions and chooses those which are most representative of his problem. Effort was spent on ensuring that the problem descriptions were expressed in such a way that they would be understood by designers and to remove jargon. The descriptions are arranged according to a generality-specificity criterion, and for most descriptions, a relevant example drawn from the work on the exemplars is available.

The architecture of the DDAS tool has two knowledge modules: A design space (a knowledge base containing the set of all relevant subsystems) and the design problem space (which contains the subsystems selected by the designer to be evaluated). There are also two functional components: functions generating the design problem space in a dialogue with the designer, and functions for test score semantics. In addition there is a communication and control component.

A designer interacts with the system in the following way. The problem descriptions are presented to the designer who chooses those most relevant to his problem. He can assign to these chosen problem descriptions various degrees of importance, depending upon how relevant he considers them to be. The system also prompts him to consider problem descriptions which are linked to those he has considered, so that he browses, but in a guided way, the problem space. Once the final set of problem descriptions are chosen, the system recommends to the designer the most appropriate technique from the modelling approaches to deal with his particular problem as he has identified it using DDAS. The recommendation is arrived at by taking the set of selected problem descriptions, the degrees of importance assigned by the user to each problem description in the set, and the strength of the links of the problem descriptions back to the modelling techniques. These different values are assigned fuzzy values and are manipulated using various aggregation operators.

The usefulness of the system in Amodeus is that it provides a means of transfer of the modelling techniques in direct relation to the concern of the designer. That is to say, the designer with an HCI-

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related problem to solve may look to DDAS to provide him with aid to decide which technique(s) is most useful to him in his present circumstances. In addition, a beneficial feature of the system is that it encourages designers to think about their problems and to understand them better. It is also a great advantage that the problem descriptions are expressed in natural language which allows the designer more degrees of freedom, while at the same time the evaluation procedures are not constructed around quantifying processes (as for instance in most multi-criteria decision support systems) thus ensuring that the initial freedom is retained to a large extent until the end of the decision making process.

The system is generalisable to other situations where problems exist, where tools and methodologies exist to help out in those problems, but where a means of helping the problem owner decide what is good for him is lacking (Darzentas et al., 1995a, 1995b, 1995c; Spyrou and Benaki, 1995).

2.4.6 Conclusions and Prospects

The encapsulations developed for transfer and assay

Throughout the project a large number of encapsulations have been developed. Many of these were envisaged at the outset; but through the close interaction with practitioners we have identified a need for "lightweight modelling" techniques that don't require knowledge of the underlying theory and can be performed without running the underlying "machine" (e.g. a cognitive architecture). The project did develop a number of these encapsulations and performed transfer and assay studies of them.

A key factor in the development of these encapsulations has been a focus on modellers' craft skill versus their role as experts' doing full-blown modelling - a theme brought up in the early designer-modeller workshop. In the work with the common exemplars it became clear that the experts' modelling involves a lot of "informal" work in addition to the "core" full-blown modelling, such as homing in on the right level of detail, selecting the right focus, and stopping at the right time. These issues have along the way come to the fore and been articulated - and in turn paved the way for the "lightweight" modelling encapsulations.

Modes of transfer and assay of the encapsulations?

The focus in the project on the common exemplars as primary transfer and assay vehicles was useful and fully justified. We learned a lot from these; not only on issues in the transfer of HCI modelling and the needs and requirements of the software industry, but also about integration of the modelling techniques. However, the envisaged close interaction with the development projects was inevitably subject to organisational turbulence and did not always manifest sufficiently. A key theme here is the nature and timing of designer-modeller interactions: e-mail discussions and reports written months after the actual design has taken place as opposed to timely and intensive face-to-face sessions with designers.

We therefore supplemented the common exemplars approach with the focussed studies with single modelling techniques and students as "designers" using the encapsulations - with the inevitable pros and cons; one of the latter being training the next generation of designers. But considering the nature of our project (we are in fact a Basic Research project) and that many of the modelling technique still are at an early stage of their development, this shift was reasonable and served as a forcing function for the creation of the lightweight modelling techniques.

Were the encapsulations understandable, usable and useful?

As to the common exemplars exercises, the modellers provided a genuine and explicit user-centered focus (supported by modelling backing if required) that was acknowledged by the designers in general. In several cases the modellers spotted issues or plain errors that the designers had overlooked. The designers had, however, reservations as to the amount of effort involved in relation to the benefit gained.

In the focussed studies, some of the lessons learned inevitably address the details of each study, such as a particular teaching strategy. But the main general lesson learned is that we could track a positive influence in the students' performance and that they found the encapsulations interesting and relevant to user interface design.

A word of caution regarding evaluation of modelling techniques is in place. Inevitably the student designers employed never got round to be anything but beginners and were therefore presented with simple design problems where the issues are faily easy to spot. A systematic investigation of the

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performance of intermediates - or even experts - is desirable, but has been outside the scope of this project. And doing it in the future would be both difficult and costly.

Many of the modelling techniques were at an early stage of their development in the project. As long as the modellers themselves performed the modelling in the common exemplars and we organised the designer-modeller interaction, the modellers themselves were largely in control of the interaction. But as we approached the lightweight encapsulations where the assayers ran studies, ethical and social issues in the project cropped up - which we then addressed. This is an indication that it has been a little early to perform substantial evaluations of some of the modelling techniques.

Prospects

As to the nature of the transfer and assay strategy, we suggest a blend of the two transfer modes employed that will enjoy the advantages of both. It will be critical to establish an intensive and long-term designer-modeller interaction, many iterations of modelling and design, precise timing between modelling and design, and a substantial engagement and potential feedback to both camps. Piggybacking would be beneficial here: build on existing development strategies, exposure to formal methods, receptivity towards HCI modelling, and design culture.

As to the modelling techniqes, the first steps have been taken towards encapsulations that can be applied by designers with some success. A substantial platform has been developed and the need is there in the marketplace.

A decision aid for helping problem owners to choose from an array of tools what (or which) would be the most useful to them is a system which can have applications in many areas. This work has been presented to the Decision Support community who have shown interest in it and the Aegean intends to extend the work to other areas of application, to refine the elicitation process, and to continue testing other aggregation operators.

2.4.7 Selected References

- Aboulafia, A., Nielsen, J, and J¢rgensen, A. (1993): Evaluation Report on the 'EnEx1' Design Workshop. Amodeus II Report TA/WP2.
- Aboulafia, A., J¢rgensen, A., May, J., Scott, S. and Barnard, P. (1995): Transfer and Assay of the Guide Designing Displays: A preliminary Report. Amodeus II report TA/WP43.
- Bellotti, V., Buckingham Shum, S., MacLean, A., and Hammond, N. (1995): Multidisciplinary Modelling in HCI Design .. In Theory and Practice. Proc. ACM CHI'95: Human Factors in Computing Systems, Denver, Colorado, 146-153. New York: ACM Press. Amodeus II report CP77.
- Blandford, A.E., Buckingham Shum, S., Young, R.M. (1995): Adding a viewpoint: Training Software Engineers to Apply a User Modelling Technique. Amodeus II Report TA/WP34.
- Buckingham Shum, S., and Hammond, N: (1993): The 'EnEx1' Modeller-designer Workshop: Implications for Encapsulation. Amodeus II Report TA/WP4.
- Buckingham Shum, S., and Hammond, N: (1994): Argumentation-Based Design Rationale: What Use at What Cost? Int. Journal of Human-Computer Studies, 40, pp. 603-652. Amodeus II Report IP9
- Buckingham Shum, S., and Hammond, N: (1994a): Delivering HCI Modelling to Designers: A Framework and Case Study of Cognitive Modelling. Interacting with Computers, 6, 311-341. Amodeus II report JP10.
- Buckingham Shum, S., and Hammond, N: (1994b): Transferring HCI Modelling & Design Techniques to Designers: A Framework & Empirical Work. Proceedings of HCI'94: People and Computers IX, 21-36. Cambridge University Press, 1994. Amodeus II report CP54.
- Buckingham Shum, S. and Hammond, N. (1995) Transfer and Evaluation of HCI Modelling for the CERD Air Traffic Control Tool. Amodeus II Report TA/WP41.
- Buckingham Shum, S., J¢rgensen, A., Aboulafia, A. and Hammond, N. (1994): Communicating HCI Modelling to Practitioners. Conference Companion Proceedings of CHI'94, 271-272. New York: ACM Press. Amodeus II report CP51.

- Buckingham Shum, S., J¢rgensen, A., Hammond, N. and Aboulafia, A. (eds) (1994): Amodeus HCI Modelling and Design Approaches: Executive Summaries and Worked Examples. Amodeus II Report TA/WP16.
- Darzentas, J., Datzentas, J.S., and Spyrou, T. (1995a): Designing a Designer's Decision Aiding System (DDAS). To appear in Journal of Decision Systems, 4, 1. Amodeus II report TA/WP38.
- Darzentas, J., Spyrou, T., and Tsagaris, C. (1995b): Evaluating Option-Related Text Descriptions for Decision Aiding. Proc. Euro Working Group on Decision Support Systems, May 1995. Amodeus II report TA/WP39.
- Darzentas, J., Darzentas, J.S., Spyrou, T., and Benaki, E. (1995c): Implementing a Designer's Decision Aiding System (DDAS). Proc. Euro Working Group on Decision Support Systems, May 1995. Amodeus II report TA/WP40.
- Hammond, N. (1993): The Relevance of Computer-Based Learning to the Transfer of HCI Modelling to Design. Amodeus II Report TA/WP7.
- J¢rgensen, A. and Aboulafia, A. (1994): Transfer and Assay: Concerns and Commitments. AMmodeus II Report TA/WP27.
- J¢rgensen, A. and Aboulafia, A. (1995): Perceptions of Design Rationale. Nordby, K., Helmersen, P.H., Gilmore, D.J., and Arnesen, S.A. (eds): Proc. Interact'95, Lillehammer, Norway, 61-66. Chapman and Hall. Amodeus II Report CP81.
- May, J., Scott, S. and Barnard, P. (1995): Designing Displays A Psychological Guide. Eurographics Tutorial Notes Series. EACG: Geneva. Amodeus II report UM/WP31.
- Nigay, L., Salber, D., Buckingham Shum, S., and Coutaz, J. (1995): Teaching Trainee and Professional Designers to use the PAC-Amodeus software Architecture Modelling Technique. Amodeus II Report TA/WP42.
- Shum, S. (ed) (1994): Preliminary Modelling Report on the ISLE Design Scenario. Amodeus II Report TA/WP17.
- Spyrou, T. and Benaki, E. (1995): DDAS A Designer Decision Aiding System Version 2.3. Amodeus II software SYS7.

2.5 Modality Theory and Information Mapping (RP5)

2.5.1 Introduction

Work on modality theory development was added to AMODEUS-2 in November of 1993. The work on modality theory carried out at CCS and ESADG during the past 20 months of AMODEUS-2 relates to the following TA objectives.

General Aim (A) To establish a set of related frameworks for expressing different aspects of the design of user-system interaction. The proposed work on modality theory will provide a framework for expressing the representational aspects of interface design.

General Aim (B) To extend the scope of basic modelling techniques to provide analytic leverage on the problems of user-system interaction with sophisticated interactive technologies. The information mapping methodology of modality theory will be extended to address the potentially complex representational issues involved in the design of multi-modal multi-media (M4) systems.

General Aim (C) To assess how mediating expressions, modelling techniques and the substantive principles they convey may successfully be transferred to and used by the design community. We will work towards the goal of assessing the usability of information-mapping techniques in interface design.

In addition, the work has added one specific objective to the eight specific objectives on the AMODEUS-2 research agenda:

Specific Objective (9) The development of modality theory, i.e. a systematic framework for the analysis of input/output modalities of information representation and a methodology for applying the theory in practical interface design.

The work performed has pursued the following objectives::

- 1. To establish a taxonomy of the unimodal modalities which go into the creation of multimodal output representations of information for human-computer interaction (HCI). When coupled with concepts appropriate to modality analysis, this should enable the establishment of sound foundations for describing and analysing any particular type of unimodal or multimodal output representation relevant to HCI;
- 2. to establish a corresponding taxonomy and related analyses of the unimodal input modalities which go into the creation of multimodal input representations for HCI. This should enable the establishment of sound foundations for describing and analysing any particular type of unimodal or multimodal input representation relevant to HCI;
- 3. to establish a "grammar" for how to legitimately combine different unimodal output modalities, different unimodal input modalities, and different input and output modalities for the usable representation of information at the human-computer interface;
- 4. to develop a methodology for applying the results of the steps above to the analysis of the problems of information mapping between work/task domains and human-computer interfaces in information systems design;
- 5. to use results in building, possibly automated, practical interface design support tools.

These objectives form the research agenda of modality theory which addresses the following, general information mapping problem: Given any particular set of information which needs to be exchanged between user and system during task performance in context, identify the input/output modalities which constitute an optimal solution to the representation and exchange of that information (Bernsen 1995a, cf. Bernsen 1993).

The CCS/ESADG AMODEUS-2 RP5 activities will be described below following the research agenda of modality theory.

2.5.2 Achievements

Objective 1 on the research agenda of modality theory has been achieved. A consolidated theory of output modalities is now in place (Bernsen 1994a, 1994b, 1994c, 1994d, 1995a, 1995c; May 1994, cf. also Verjans 1994).

Objective 2 on the research agenda has been achieved to the extent that a taxonomy of input modalities has been developed at the so-called "generic" level of abstraction (Bernsen 1995b). It follows from the

principles used in the generation, that about two thirds of the "atomic" level taxonomy have been achieved as well. This is because these parts of the input taxonomy will be identical to the output taxonomy presented in Bernsen (1995a). What remains to be done is to develop the atomic-level input taxonomy to cover kinaesthetic input modalities. The plan is to complete this work before the formal end of the AMODEUS-2 project. A state-of-the-art paper on input modalities will be very helpful to this end (Verjans 1995). What remains to be done on Objective 2 of modality theory is very important and unfortunately cannot be done within the time limits of AMODEUS-2. This is to develop a full modality analysis of input modalities corresponding to the one which has been developed for output modalities. Funding for this work will be sought elsewhere.

Objective 3 on the research agenda presupposes consolidated results on Objectives 1 and 2. Funding for this work will be sought elsewhere.

Objective 4 on the research agenda has been achieved based on a series of interface design case studies (Verjans and Bernsen 1994, Bertels 1994, Bernsen and Verjans 1995a). A consolidated methodology for information mapping is now in place (Bernsen and Verjans 1995b, Bernsen and Verjans 1995c). In addition, a first assay and transfer test has been made of the methodology. The methodology was applied to a Danish industrial interface design project in which the CCS modality theory group acted as consultants. Two papers describing the case are currently being completed (Bernsen, Jensager and Lu 1995, Jensager and Bernsen 1995). A paper describing the role of DSD in the process has been completed (Ramsay 1995).

Objective 5 on the research agenda of modality theory aims at "complete transfer", that is, at making the results of basic science, such as modality theory, independent of those who created them. The aim thus is to package these results in a way which makes them usable by practical designers independently of the presence of consultants with extensive knowledge of the science base. Towards this aim, two versions of a hypertext/hypermedia modality workbench and theory demonstrator have been developed (Bernsen, Lu and May 1994, Bernsen and Lu 1995, Lu and Bernsen 1995). The problem of creating a rule-based design support tool from the workbench is discussed in Bernsen (1995d). After AMODEUS-2, funding will be sought for preparing a book and a CD-ROM version of input/output modality theory, for turning the information mapping methodology into a transferable walkthrough method, and for specialising the approach to areas such as the design of multimedia applications.

2.5.3 References

- Bernsen, N.O. (1993): 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, N.O. (1994a): Foundations of multimodal representation. A taxonomy of representational modalities. *Interacting with Computers* Vol. 6 No. 4, 347-71.
- Bernsen, N.O. (1994b): A revised generation of the taxonomy of output modalities. *Esprit Basic Research Project AMODEUS-2 Working Paper* RP5-TM-WP11 (submitted).
- Bernsen, N.O. (1994c): Modality theory: Supporting multimodal interface design. In *Proceedings from the ERCIM Workshop on Multimodal Human-Computer Interaction*, Nancy, November 1993. ERCIM Workshop Reports 94-W003 1994, 13-23.
- Bernsen, N.O. (1994d): Modality Theory in support of multimodal interface design. In *Proceedings of the AAAI Spring Symposium on Intelligent Multi-Media Multi-Modal Systems*, Stanford, March, 37-44.
- Bernsen, N. O (1995a): A toolbox of output modalities. Representing output information in multimodal interfaces. *Esprit Basic Research Project AMODEUS-2 Working Paper RP5-TM-WP21* (submitted).
- Bernsen, N. O. (1995b): A taxonomy of input modalities. *Esprit Basic Research Project AMODEUS-2 Working Paper RP5-TM-WP22*.
- Bernsen, N.O. (1995c) Why are analogue graphics and natural language both needed in HCI? To be published in the *Focus on Computer Graphics* Series by Springer Verlag.

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- Bernsen, N.O. (1995d) Information mapping in practice. Rule-based multimodal interface design. To appear in *Proceedings of the First International Workshop on Intelligence and Multimodality in Multimedia Interfaces: Research and Applications*, Edinburgh, July.
- Bernsen, N.O., Jensager, F., Lu, S. (1995) Designing interfaces by information mapping. An industrial case study. *Esprit Basic Research Project AMODEUS-2 Working Paper RP5-TM-WP18* (forthcoming).
- Bernsen, N.O. and Lu, S. (1995) A software demonstrator of modality theory. In Bastide, R. and Palanque, P. (Eds.): *Proceedings of DSV-IS'95: Second Eurographics Workshop on Design, Specification and Verification of Interactive Systems*, Toulouse, June. Springer-Verlag 1995.
- Bernsen, N.O., Lu, S. and May, M. (1994): 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, N.O. and Verjans, S. (1995a) Designing interfaces by information mapping. A case study of the CERD design. *Esprit Basic Research Project AMODEUS-2 Working Paper* RP5-TM-WP13.
- Bernsen, N.O. and Verjans, S. (1995b) From task domain to human-computer interface. An information mapping methodology. *Esprit Basic Research Project AMODEUS-2 Working Paper* RP5-TM-WP17 (submitted).
- Bernsen, N.O. and Verjans, S. (1995c) Information mapping. Knowledge-based support for user interface design. In *Proceedings of the CHI '95 Workshop on Knowledge-Based Support for the User Interface Design Process*, Denver, Colorado May.
- Bertels, A. (1994): Eliciting Designer Knowledge: A Study of the Interface Design Activity. *Esprit Basic Research project AMODEUS-2 Working Paper* RP5-TM-WP8.
- Jensager, F. and Bernsen, N.O. (1995): Monitoring and control interface design through information mapping. *Esprit Basic Research project AMODEUS-2 Working Paper* RP5-TM-WP19 (forthcoming).
- Lu, S. and Bernsen, N.O. (1995): The taxonomy workbench. A multimedia database system for analysing representational modalities. In *Proceedings of the 4th International Conference on Interface to Real and Virtual Worlds*, Montpellier, June (forthcoming).
- May, M. (1994): Analogue atomic modalities. *Esprit Basic Research project AMODEUS-2 Working Paper* RP5-TM-WP7, 1994.
- Ramsay, J. (1995): Promoting plant-computer interaction developing a design space for greenhouse monitoring and control. *Esprit Basic Research Project AMODEUS-2 Working Paper RP4-TA-WP44*.
- Verjans, S. (1994): Computer semiotics as a basis for integrating different views in human-computer interaction. Master's thesis. Esprit Basic Research project AMODEUS-2 Working Paper RP5-TM-WP10, 1994.
- Verjans, S. (1995): State-of-the-art for input modalities. *Esprit Basic Research Project AMODEUS-2 Working Paper RP5-TM-WP20*.
- Verjans, S. and Bernsen, N.O. (1994): PaTerm: A case study in information mapping. *Esprit Basic Research project AMODEUS-2 Working Paper RP5-TM-WP6*.

3. Co-ordinator's Concluding Statement

The AMODEUS group have now been working together through two projects and nearly seven years of active collaborative research set in a unique interdisciplinary and international context. The conclusion of the second project must be viewed in a wider context, including the state-of-art seven years ago and the cumulative achievements of both AMODEUS-1 and AMODEUS-2.

At the outset of the AMODEUS research agenda, interface designs were undergoing a transition from predominantly text-based or simple direct manipulation interfaces into a rapid phase of advanced graphical interface design. Tools from system science and software engineering to support modelling were highly restricted, and applicable largely to simple tasks with lexical or iconic command-based interfaces. The complexity of design problem solving, and the processes associated with it, was clearly acknowledged, as was the need to accommodate input from many different contributory sciences and applied disciplines. There were also a number of formative ideas about bringing together different types of concepts so that they could have an impact in practical design contexts. Very little serious study had been undertaken to examine how to achieve integration and how effective any integration would be. The aims of the first AMODEUS project were both to develop modelling approaches to populate the constantly developing landscape of interface design, and to research how that information might best be inter-related and assimilated within design processes.

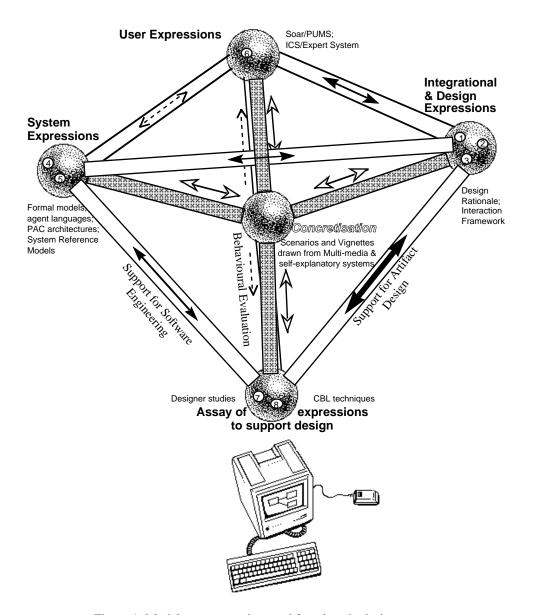


Figure 1. Models representations and functions in design support.

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At the end of the first project, it was clearly understood that there was no single, or universal way of integrating information from diverse perspectives or disciplines. There was however, a clear conclusion that modelling approaches provided information that should be viewed as a space of knowledge resources over which integration can occur. The precise form of integration naturally depended upon the specific purpose to which the information would be put in the course of design, development or evaluation and the context of design itself. A very small design team trail-blazing a new class of application would require different forms and styles of integration than would a large team operating in a safety critical application using formal methods. Through the communal analysis of a very broad range of behavioural and design scenarios, AMODEUS-1 contributed a clear view of what these purposes were and how modelling approaches might best be configured to meet specific local needs. The "Atomium" figure above was presented in the Technical Annex for AMODEUS-2 and identifies support for artifact design, support for software engineering and support for behavioural evaluation as three broad classes of functions for which different forms of information need to be integrated.

Two factors restricted our ability to draw wider conclusions from AMODEUS-1. One was that the issues addressed within the scenario-based approach were necessarily limited to small scale design problems. The second was that the modelling approaches and integration techniques were used by the "owners" of the technique and not by the designers and design teams who might ultimately benefit from their application. The objectives of AMODEUS-2 were formulated to address these issues whilst also developing the underlying techniques to keep abreast of interface developments. Five new groups joined the team, either at the beginning of the second project or part-way through, adding to the conceptual and methodological strengths of the project as a whole, and more than compensating for the departure of two of the commercial groups who contributed to AMODEUS-1. As AMODEUS-2 started, those issues at the heart of leading edge interface design had become re-focused around dynamic graphic, gestural and multimodal interfaces often allied to developments in communication technologies and computer-supported co-operative work. These considerations were reflected in the particular set of exemplars which the AMODEUS-2 team studied.

Over its three year time course AMODEUS-2 has, in large measure, achieved its three main objectives. It has established a set of integration frameworks for expressing different aspects of design; it has extended the scope of basic modelling techniques; and it has examined the problems associated with the transfer and use of these techniques. Although there have been some minor course corrections, the specific objectives set for the individual research packages have also been achieved. The individual achievements of the modellers and theory developers as well as those for the integrators and those concerned with transfer have been documented in the opening executive summary and throughout this report. In this concluding statement it seems appropriate to stand back and focus upon some of the wider achievements of the team as a whole.

The study of human-computer interaction has, since its inception, been "sold" as an interdisciplinary enterprise in need of strong support at the point of application from the cognitive and computing sciences. In the field as a whole true interdisciplinarity has always proved elusive. People from different disciplines have frequently worked together applying their own methods and ideas collaboratively in the same context. This may take the form of a domain-based specification of requirements, a software engineering solution to the design and a human factors evaluation of "behavioural" efficiency. Practical methods might, for example, include a structured programme for input from the contributing members of a product development team. Within AMODEUS, it can be argued that interdisciplinarity has gone beyond the "skin deep". There is very real evidence that techniques, such as syndetic modelling, have become truly interdisciplinary in nature; they could not be the way they are without a multidisciplinary blend of concepts. This does not, of course, mean that there is "one sort of interdisciplinary integration" - we have re-iterated throughout the project that the appropriate form of integration depends upon the purpose for which the information in required in the cycle of requirements specification, design, implementation and evaluation. Indeed, a wider message from the project as a whole is that there is advantage in having access to diverse perspectives and the fundamental problem lies not with achieving some form of integration but with the management of diversity within the design context. Indeed, whereas DR/QOC and DSD are semi-formal notations for bringing information together over the course of a design process, the DDAS tool from the Aegean and the Walter demonstrator from the IDA group at Linköping are clear examples of tools for the management of diversity. The Walter tool, for instance, was developed with an argumentative structure providing an underlying common framework on top of which DSA/OOC, DSD, and aRD design representations can all be implemented. This effectively supports interdisciplinary integration, whilst nonetheless allowing the design to be viewed and developed from whichever of the framework is appropriate for the particular problems being tackled. Equally, syndetic modelling, interaction framework or even collational co-modelling can each be regarded a means for managing diversity and bringing very different forms of principled added value to a design process.

There are also drawbacks to true interdisciplinarity being achieved and sustained within a field such as HCI. Maintaining, let alone achieving, an interdisciplinary agenda is very hard work, it requires a strong commitment, and is subject to numerous misunderstandings due to different use of terminology and different inherent priorities associated with individual issues. Equally, neither the academic nor the commercial system explicitly rewards it. In academic contexts, at best one seldom gets high level credit for publishing in outlets associated primarily with another discipline, at worst the outlets themselves find it hard to accommodate material which is both novel and interdisciplinary. Referees who welcome departures from their own party line are an all too rare commodity. It is therefore important to acknowledge the contribution of the Basic Research programme in supporting a large and long running enterprise of this sort. It would not have been possible in any other context. Equally, it is important to acknowledge the high rate of sustained published output of interdisciplinary papers that the project has achieved. In spite of the breadth and depth of the problems, a long running project enables an "Esprit de Corps" to develop that carries it through difficult phases.

The problems of transferring basic development into practical contexts is an equally hard nut to crack. Over the last three years AMODEUS-2 can be said to have achieved its objective of assessing how techniques might best be transferred to, and used by, the design community. It has not, of course, solved the underlying problem. Transfer clearly requires a strong and continuing commitment by both parties to the process. We have been fortunate, in some instances, to have had access to specific design teams and processes. We have also been fortunate in gaining access to educational contexts for the study of transfer. Nonetheless, in a time during which the European IT industry has been going though a period of significant economic recession, the real opportunities for substantial and open collaboration between Basic Research and commercial enterprise have remained at best piecemeal. Throughout the process the value of specific people and commitments cannot be under-estimated for sustaining contact between research groups and design projects. Indeed, our original plans emphasised the use, comprehensibility and value of the material to be transferred. While this is a pre-requisite for the actual deployment of methods in the design workplace, that process of deployment is a social process and the value of a "link person" in the uptake of new technology has been observed in practice before (e.g. Long, Hammond, Barnard, Morton & Clark, 1983). This part of the process should be given far greater emphasis in any future research into alternative means of transfer. We may well design and build modelling tools and design aids of great brilliance and power. However, if the process of deploying that technology is flawed then it will take a long time for its true value to be appreciated (see also Landauer, 1995).

The recent period has in large measure been characterised by industry retreating from supporting and participating in long-term research activities to concentrate on shorter-term revenue earning activities. In spite of this concentration, there is an increasing quantity of hard evidence that the design strategies currently in use still fail to produce products that lead to real productivity gains for their ultimate enduser organisations. Equally, the evidence suggests that design processes that study their users thoroughly for both their interface usage and for the effective user-oriented deployment of the technology within an organisation can indeed deliver very real productivity gains (see again Landauer, 1995). Perhaps only when commercial organisations fully grasp the real economic consequences of a short term view, will the "pull" develop from the commercial side to encourage the kinds of links that will support rapid and effective transfer of basic research.

Equally, most new techniques that do develop in an academic context are "owned" by someone who will most likely be interested in "pushing" their particular technique - whether it be a modelling approach, a human factors methodology or a means of achieving "discount usability". Indeed, the academic process encourages a form of collective mental combat in which the intellectual owners of ideas sing the praises of their own tools and techniques, whilst seeking to minimise or to hide any flaws and weaknesses. At the same time it is regarded as an integral part of the process to expose the flaws and weaknesses in other's ideas. However, in a rapidly moving domain such a HCI there tends to be too little time and too few resources for the systematic testing of the work of others. As a result, most tools and technique are tested by their "owners", who obviously have an interest in seeing it come out well from any evaluation. Clearly, this is neither a recipe for balanced progress nor an ideal landscape within which an interdisciplinary journey is best undertaklen. The AMODEUS group chose a research paradigm in which interdisciplinary research could be persued through the co-operative analysis of agreed examples. It also chose to have an independent group arbitrate on the effectiveness for practitioners of the owner's tools and techniques. There is, of course, a cost in terms of time, effort and commitment. However, if interdisciplinarity and the transfer of basic material though to application is to flourish, then co-operation, commitment and open minds will certainly facilitate the process.

AMODEUS has been an exciting and rewarding project to be a part of, and, in its seven year history more than seventy people have collaborated in writing papers that carry some form of AMODEUS

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acknowledgement. It is perhaps apposite to end by noting one last trend. Seven years ago many of us looked across the North Atlantic to the United States as a core reference point for novel developments in HCI theory and design practice. An undoubted gain is that many of us now see European groupings as our primary reference point. That would not have come about through the literature or even through discussions at conferences or in networks. It was undoubtedly built up from having a large number of people working together with a clear group dynamic and having a common sense of purpose of the sort that project-based research provides. We would all like to thank the European Union for supporting the work through the programme of Basic Research and, in particular, thank the series of project officers and assessors for their valuable feedback and encouragement.

Landauer, T.K. (1995). The Trouble With Computers, Cambridge, Mass: MIT Press

Long, J., Hammond, N.V., Barnard, P., Morton, J. and Clark, I.A. (1983) Introducing the interactive computer at work: The users' views. *Behaviour and Information Technology*, Vol. 2, 39-106.

Appendix 1 Deliverables Summary Sheet

Deliverable	Parent	Organisation(s)	Due date	Date of
No.	Workpart	responsible		finalisation
YEAR 1 D1	RP1 System Modelling First Theory of Interactors; analysis of the relationship between the reference models	YORKCS CNUCE LGI	30.6.93	25.5.93
D2	RP2 User Modelling Extending the User Modelling Techniques	MRC-APU CCI	30.6.93	9.6.93
D3	RP3 Integration & Design Development of Integrating and Design Expressions	RXEP YORKCS APU CCI IDA	30.6.93	4.6.93
D4	RP4 Transfer & Assay Transferring and Assaying Design Expressions in Use	YORKPSY CUP UoA	30.6.93	30.6.93
YEAR 2 D5	RP1 System Modelling Refined Version of the Theory of Interactors and First Draft of the Reference Model	YORKCS CNUCE LGI	30.6.94	20.6.94
D6	RP2 User Modelling Interim Report on the Application of the User Modelling Techniques to the Shared Exemplars	MRC-APU	30.6.94	30.6.94
D7	RP3 Integration & Design Report on the Analysis of the Shared Exemplars by the Design Frameworks	RXEP APU, CCI, IDA, YORKCS	30.6.94	22.6.94
D8	RP4 Transfer & Assay Transferring and Assaying HCI Modelling and Design Approaches	YORKPSY CUP UoA	30.6.94	16.6.94
D14	RP5 Modality Theory Modality Theory and Information Mapping	CCI ESADG	30.6.94	30.6.95
Year 3 D9	RP1 System Modelling Theoretical Framework with Reference Model and Multi-agent Presentations	YORKCS CNUCE LGI	30.6.95	30.6.95
D10	RP2 User Modelling User Modelling Techniques and their Relationship to Design	MRC-APU	30.6.95	30.6.95
D11	RP3 Integration & Design Relationships among the Design and Integration Frameworks	RXEP APU, CCI, IDA, YORKCS	30.6.95	30.6.95
D12	RP4 Transfer & Assay Modelling Encapsulation, Ideational Transfer and Designer Studies	YORKPSY CUP UoA	30.6.95	30.6.95
D13	All Research Packages Final Report	MRC-APU	30.6.95	23.7.95
D15	RP5 Modality Theory Modality Theory and Information Mapping	CCI ESADG	30.6.95	30.6.95

Appendix 2 Exploitation of Results Report

With a Basic research project such as AMODEUS, there are five main routes through which the results of the research programme can be exploited: (1) direct uptake of specific results by commercial organisations; (2) indirect uptake into commercial organisations through programme of continuing training and professional development of existing staff; (3) indirect uptake though the acquisition of new staff; (4) direct exploitation may also occur though the use of AMODEUS results as foundational material for new research projects and, of course, (5) wider uptake of results through publication and access to the knowledge created for diffuse purposes in research and education. Several AMODEUS post-docs have joined academic departments and commercial organisations in both Europe and the USA. Form these teachers and practitioners, we can expect knowledge to diffuse further.

Since the means and the process of transfer have both been an object of study within AMODEUS-2, many of the deeper issues have already been covered in the main body of this final report. It therefore seems appropriate here to concentrate upon those areas for which there is hard evidence of developing exploitation.

Uptake of results

As a Basic Research project our objectives did not include the production of pre-competitive material for direct exploitation by commercial enterprises. Indeed, for any given commercial organisation to consider drawing upon more than a limited proportion of AMODEUS tools and techniques would be unthinkable. The full panoply of AMODEUS techniques would be both prohibitively expensive and time consuming in their application for any given development project. There is nonetheless substantial evidence of indirect and smaller scale uptake of AMODEUS results by both industry and by academia. Some of the commercial concerns and development projects with whom we have collaborated are directly involved in follow-on proposals that will utilise AMODEUS results as foundational material. These proposals directed at both national and EU funding programmes have been mentioned in the individual sections of the final report. Equally the composition of some of those follow-on proposals indicates that new academic and commercial partners are keen to collaborate with AMODEUS partners on a variety of extensions to individual research packages. In addition, the system modellers from York, the software architects from Grenoble, and the user modellers from APU Cambridge have developed a full range of tutorial material which has been presented at the prominent international conferences that occur both in the USA and Europe (e.g. CHI, Eurographics, the Interact series, the BCS HCI series and more). These are attended by participants from both commerce and academia. The elective nature of these tutorial sessions indicate a continuing "market for" the knowledge produced by the AMODEUS team. In addition, both as a part of the AMODEUS research programme, and independently of it, a variety of masters courses across Europe have now incorporated AMODEUS material within their teaching programmes. Indeed, an increasing number of textbooks are now making reference to the work of the project and describing the techniques it has developed. This implies that the uptake of AMODEUS results within the teaching and research community is likely to feed through to commerce with the next few generations of new employee intake with specialist qualifications in HCI.

The main route to influence and exploitation for basic research has to come through the wider dissemination and publication of results. Here we can call upon a firm foundation of evidence. By far the greater part of AMODEUS research has already found its way into the published literature through conference publications, journal publications, chapters in research texts and practical handbooks for the design and development communities. Several books have arisen directly out of the work of the project and more are in preparation. At the end of the three year programme for AMODEUS-2 we have 112 external publications and many more are under review or in the "preparation" pipeline. This is nearly three times the output of AMODEUS-1 at an equivalent stage.

Exploitation through electronic resources

As a part of the last three year programme we have also been testing new forms of electronic transmission by making the bulk of our material available over the Internet through anonymous FTP directories and through an AMODEUS entry on the World Wide Web. This part of the project was designed to fulfil two aims. First, it was a live experiment in computer supported co-operative work. Documents were no longer prepared and distributed in paper form but were electronically made available for use throughout the project. This result in substantial economies in the management of the project - virtually eliminating the need for mass duplication of all documents and minimising postage, courier and facsimile costs. However, having set the system up for project internal reasons of economy, a means of wider dissemination essentially came for free and it is here that perhaps the work

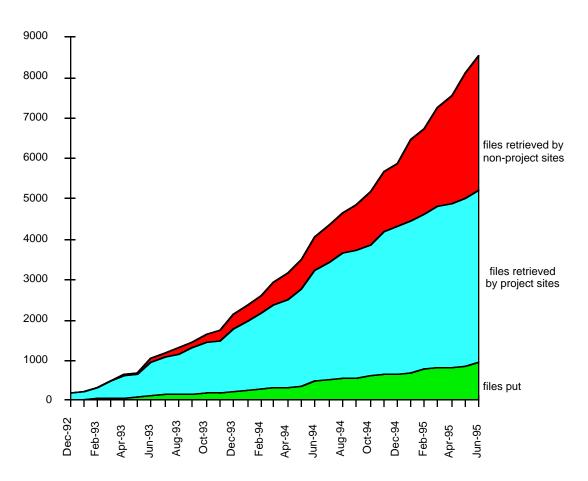


Figure 2 Overall growth of use of the FTP archive from project and non-project sites

of AMODEUS will now have its largest impact and potential for exploitation. As good researchers, a system of monitoring accesses to the FTP archives was set up and we have recently analysed the data on project internal and external accesses to the FTP archive - not only in number, but by geographical location and type of organisation. It seems appropriate to conclude this exploitation of results report with a brief presentation of the relevant statistics.

The FTP archive system was set up at the co-ordinator's site and went live some six months into the project: we therefore have thirty months worth of "data" for analysis. The existence and public availability of the archive was initially posted on electronic networks and reference to it was included in many subsequent AMODEUS publications. Around eighteen months into the thirty month period a full AMODEUS entry was posted on the World Wide Web (WWW): this contained rich links to the FTP archive as well as summary material. Entries and cross links on the WWW have been regularly maintained and updated by Dr May of APU Cambridge who designed the WWW entry. As material moves from the status of a pre-print report to fully published status, copyrighted material is removed from direct access and replaced with an abstract and reference to the published version, and an email link to the authors.

Figure 2 shows the overall growth of access over the thirty month period. During the opening few months there were relatively few accesses and they were overwhelmingly (90%) by members of the AMODEUS team. Growth of use has been dramatic, and for the last six months by far the greater proportion of accesses have come from sites who are not associated with the AMODEUS team.

Figure 3 pursues the point about relative access by the AMODEUS team and by other sites. This shows the number of files retrieved in each of the three project years (M0 to M1, M1 to M2, and M2 to M3). The situation changes from one of predominant access by project sites, to one of predominant access by non-project sites. The area of each pie-chart is proportional to the number of accesses in each year, and indicates that the growing use of the FTP archive is now due to the continued growth in non-project access, as project access has reached a stable level.

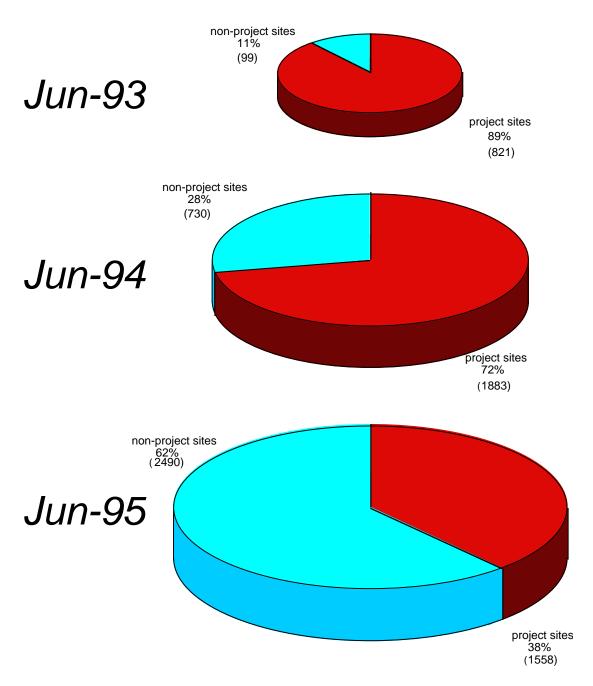


Figure 3 Gross Changeover in proportion of accesses by project and non-project sites.

Figure 4 shows a yet more detailed breakdown. There is again, of course, a substantial trend for the proportion of accesses by non-AMODEUS sites to increase as the project progresses. However, this overall trend is perturbed by periods in which there is a high proportion of AMODEUS accesses. These occur on or around AMODEUS milestones and meetings. Both patterns in these data indicate that electronic transfer appears to be a highly successful route for the economic support of both project-internal collaborative communication and as a broader means of knowledge dissemination.

Figure 5 shows the breakdown of access to the FTP archive by geographical region. These figures relate to access by non-project sites alone and are taken over the whole 30 month period. Just over two thirds of all these accesses are accounted for by sites within EU countries. A further quarter come from North America and the Pacific Rim. Figure 6 shows a breakdown by type of organisation accessing the database. It is evident from this figure that by far the greatest proportion of accesses come from academic institutions. Given that most of the papers are of an academic nature this is hardly surprising.

Proportion of files retrieved monthly by project and non-project sites

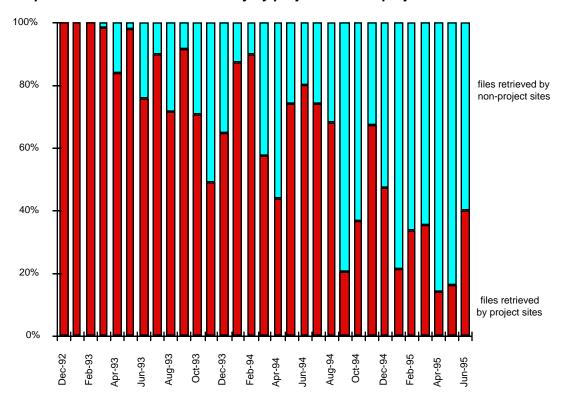


Figure 4 Fine detail of change in proportions of access.

However, it is nonetheless noteworthy that nearly 20% are from commercial organisations and that these tend to be rather more heavily represented in the more recent accesses to the system. Also many of the unclassifiable accesses are clearly not from regular academic addresses and are therefore likely to be from some form of user population, or smaller commercial organisations unknown to the project. Current trends suggest that, as the availability of the information increases, so will access by commercial enterprises. At present access by government organisations remains low but this probably simply reflects the fact that governmental bodies tend to lag other organisations in advanced use of technologies.

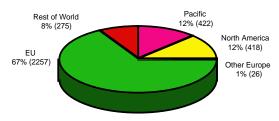


Figure 5 Files retrieved by non-project sites around the world.

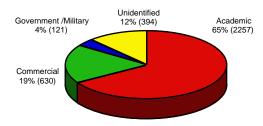


Figure 6 Files retrieved by different types of organisation (excluding project members)

The fact that the archive has been extensively used to retrieve documents obviously does not mean that the material reported therein has or will be exploited. It could just be that it is sucked out automatically and left in 'mirror sites' unused. However, as with attendance at tutorials, the taking of individual documents is an elective activity, often preceded by access to abstracts or 'readme' files. In this respect we can at least assume that there was some reason to take a copy of the document. Access and availability on this scale is clearly comparable already to availability through journal publication. Indeed, it is often remarked that the average readership of a journal article is very modest indeed. Our preliminary analysis of the gets for individual files indicates that access is indeed selective but is well distributed across all the research packages. Although there is one non-project site that has extracted all AMODEUS documents, that pattern is clearly the exception rather than the rule.

As time goes by our active research of what is posted on the WWW also indicates increasing cross-linkages from other web sites to the core AMODEUS home page in Cambridge: we have located 44 other WWW pages that contain links to the AMODEUS home page, 16 of these being pages managed by non-project members. The increasing availability of these cross-linkages makes it more likely that people searching the WWW for information on a relevant topic will find the AMODEUS project material. If not evidence for exploitation per se, this provides evidence that the enabling conditions for the electronic support for exploitation of research results is developing with an astonishing rapidity.

The FTP and WWW facilities, once created, are available 24 hours a day to anyone with an Internet connection. Once the project ceases to produce new material, the facilities will take very little effort to maintain, and it is planned to leave them in an accessible state (at least, until disk requirements at the Co-ordinating site dictate otherwise). The evidence presented here of increasing cross-linkage within the WWW, and of increasing growth in file retrieval by non-project sites, indicates that AMODEUS material will continue to be easily accessible, and widely accessed, long after the end of the project itself.

Use of some computing facilities, like the Internet, is sometimes regarded as an "energy sink" which diverts researchers and practitioners from more productive activity. The evidence from our experiment suggests that, however modest its scope, the FTP transfer facilities and WWW pages have been positively beneficial for the internal management of our project programme of work and hopefully has functioned for the benefit of those on the outside surfing in.