How To Integrate Concepts for the Design and the Evaluation of Adaptable and Adaptive User Interfaces

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Abstract: Adaptation and adaptability are on their way to become common features of user interfaces that claim to provide access to users with different abilities (user interfaces for all). Facing this fact one should expect a sound conceptual and technical background for adaptable or adaptive system design and evaluation. Unfortunately, neither a common terminological framework, nor a comprehensive framework for design *and* evaluation exists. However, both framework developments should be enforced, in order to avoid further diversifications of concepts and methodologies. In this paper we detail and exemplify an enforcement procedure to establish a terminological and methodological framework. The procedure is based on an epistemological and semantic analysis. It combines conceptual and empirical research in an unifying way. First results for adaptation and adaptability are presented.

1. INTRODUCTION

Design principles and usability measurements, such as adaptation, are widely used in the course of user interface development and evaluation. They are part of styleguides, e.g. [Microsoft, 1996], international standards, e.g. [ISO 9241 - Part 10, 1990], or directives, e.g., [EU, 1990]. They are also part of design and evaluation methodologies, e.g. [Page et al., 1996] and EVADIS II [Oppermann et al., 1992], respectively. Few frameworks exist

1. to operationalize multi-dimensional principles of software ergonomics,
2. to bridge the gap between design and evaluation.

Multi-dimensional principles, such as task conformance and adaptation, can be considered from a technical, organizational, social, and cognitive perspective. For a discussion on task conformance these perspectives have been elaborated in [Stary et al., 1996]. In most of the cases, these perspectives are handled separately throughout design or evaluation, instead of unifying them. As a consequence, for instance, organizational issues remain untouched when windowing systems are adapted to be used in certain problem domains. Although for structured development and evaluation such a separation might improve techniques from the syntactic point of view, from the user's perspective the user interface has to be considered as an intrinsic whole [Stary, 1995]. Few approaches exist

- for *development* that focus on semantic integration [Wilson, 1993, Stary et al., 1997], and
- for *evaluation* that recognize the different dimensions of interaction, even when failing to measure them explicitly [Oppermann et al., 1992].

There still remains the gap between design and evaluation. The concept User Interfaces for All [Stephanidis, 1995] has been introduced to meet the increasing demand for structured development and evaluation in the field of assistive technologies. User Interfaces for All rely on *adaptation* as the key principle for accessible technologies, namely through providing user interfaces for a variety of end users in a flexible way. In addition, *proactivity* addresses the accessibility of user interfaces at design time, in order to finally guarantee the utmost utilization of an artifact. It requires to consider user groups, individual preferences and abilities at design time. Hence, proactivity has to be considered the key to bridge the gap between design and evaluation. Proactivity leads to implementation-independent descriptions (specifications) of any technical system, in order to check whether the intended users (or user group) could be empowered through the artifact or not.

Adaptation as well as proactivity should lead to a reduction of development costs that are usually to be paid by the end users due to their particular needs with respect to the utilized technologies and the application domain. Design in the context of User Interfaces for All is understood to focus on user needs and characteristics that should deliver the measurements for testing usability. Comprehensive design support has then to provide not only the representation of user characteristics but also the assignment of these characteristics to particular styles of interaction or metaphors (requiring interaction styles).

User Interfaces for All are considered to be designed at a semantic, syntax, and lexical layer where the adaptability of an application has to be considered. At the semantic layer the information content of an application is the crucial factor. It has to be evaluated whether the data specified for interactive manipulation as well as the control in- and outputs are required for task accomplishment. The syntax layer concerns the structure of the information provided for user control and task accomplishment. Certain rules at this layer have to be followed to enable consistent and robust behavior. These rules establish the ‘grammar’ of the probably individual ‘language’ for interaction. At the lexical layer the semantic and syntactic information is further refined to concrete data types that have to be provided for interaction (audio, visual, spatial etc.). The actual channels for communication are specified to enable physical interaction between the application and the intended end users.

Figure 1 does not only provide an overview of the framework but also demonstrates the crucial role of adaptation: It has not only to be considered in the context of the problem domain addressed by an application, but also in the context of its users (see also semantic and syntax layer mentioned above). In addition, the utilization of the concept changes from being a principle (for design) to representing a measurement (for evaluation) as the development proceeds.

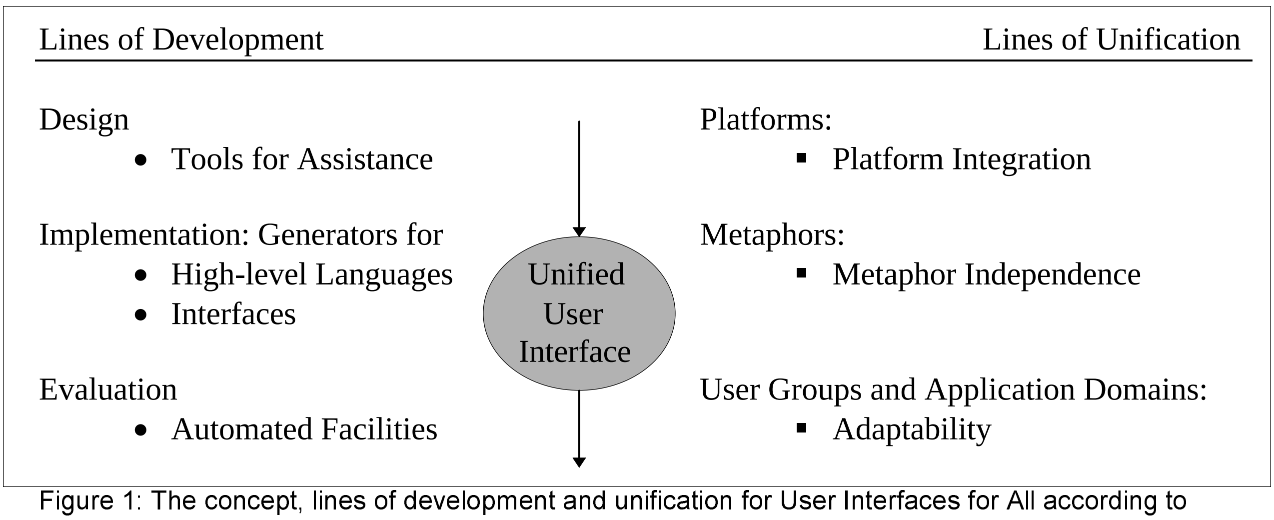

Figure 1: The concept, lines of development and unification for User Interfaces for All according to [Stephanidis, 1995]

Traditionally, the understanding of adaptation is based on the interpretation stemming from software ergonomics: If organizational modifications or changes in the problem domain occur, or mental representations of users change, the computer system should (re)act and provide the adequate behavior. In addition, on user demand, the computer system should be able to support adaptive behavior, i.e. the application should represent the user in a way that errors can be avoided by appropriate application actions. That kind of knowledge is usually constituted by developing a user model, representing the problem domain as well as the interaction domain of the application. However, claiming to support a variety of end user with different abilities, requires more than the traditional understanding of adaptation, in order to reflect universal accessibility. The latter requires a facilitator to accomplish this task and implement this principle [Stephanidis et al., 1996]. As a consequence, a clear understanding of adaptation has to be developed, before issues of accessibility can be addressed from the methodological perspective.

In order to clarify this understanding we strengthened our attempts towards:

1. Conceptual analysis, and
2. Empirical findings.

The conceptual analysis has been based on reviewing existing literature on the topic of adaptation and adaptability, trying to find some relationships and corresponding concepts between the specifications of user- and/or task-oriented flexibility. Empirical research has been based on a method that has been developed exclusively for this purpose and already applied for task conformance, namely qualitative content analysis. This method allow to reflect common understandings and conceptual diversifications of developers and users. Figure 2 shows the methodological framework for this study.

In order to increase the understanding of adaptation and adaptability for design and evaluation, first, the conceptual, and secondly, the qualitative content analysis provides the basics for determining the semantics (meaning) of the principles and measurements. This specification of meaning leads to analytical definitions of principles. The definitions are required for the development of reliable, objective, and valid techniques. Figure 2 illustrates the addressed quality-improvement cycle. In a first step, the principles and measurements, that are part of standards, as well as techniques for design and evaluation are identified. For each of the principles and measurements, the descriptions as well as their utilization in different techniques have to be acquired, compared, and analyzed. This second step is termed qualitative content analysis. In case the use of the principles and measurements in different techniques leads to different descriptions, further activities are required to insure a high quality of techniques. These activities comprise an explicit identification of the meaning (= analytical definition) through an analysis of the meaning (e.g., [Bortz et al., 1995]) of each involved principle or measurement in a technique. Meaning analysis increases the transparency of the following operationalization, since it provides the terminological and conceptual framework for the development of techniques for system development and evaluation. Figure 2 shows this transition and its result on the right side. Once the semantics of a principle or measurement has become transparent, the operationalization of principles and measurements can be performed effectively.

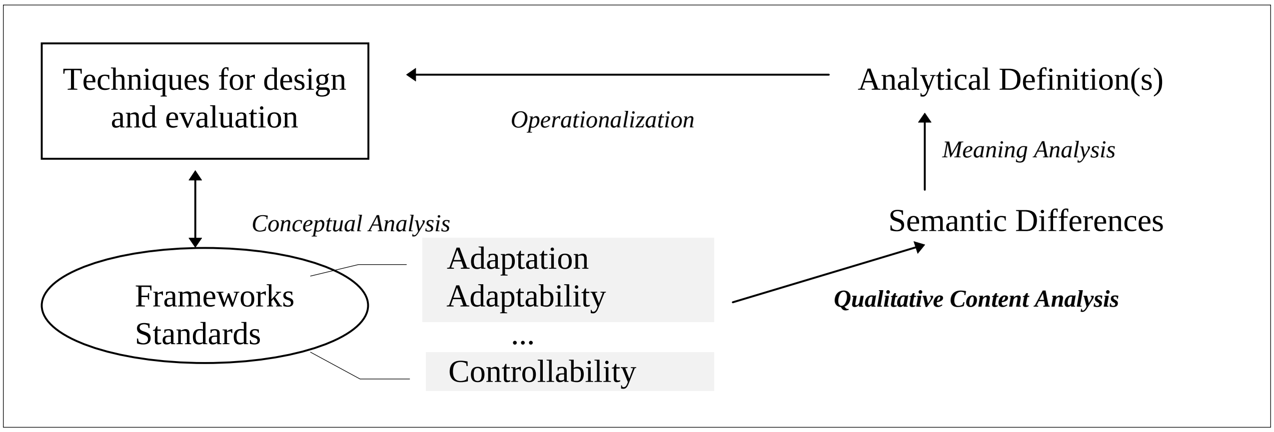

Figure 2. Methodological Framework for Analysis, Integration, and Continuous Improvement

In this paper we present preliminary results of both, the conceptual and empirical analysis, in order to demonstrate the utility of that type of investigation for further research and development. In section 2 we present the analyzed concepts. Section 3 deals with the qualitative content analysis of several methodologies for evaluation. Based on the results presented an analytical definition of adaptation has to be provided, in order to develop standards and techniques with an increased selectivity of the principles and measurements. The presented analyses have been performed on several conceptual approaches for design as well as techniques for user-interface evaluation, some of them containing different interpretations of adaptation. The results should be used for further integration and unification of concepts, methods, and methodologies, in particular for design and evaluation, as intended by the framework of User Interfaces for All.

2. CONCEPTUAL ANALYSIS

In the following we review the existing conceptions of adaptation as well as its relationships to other principles for dialogue design.

Adaptation in terms of individualization has to be considered to be one of the key principles for user interface design and evaluation, e.g. [ISO 9241, Part 10, 1990]: 'Dialogue systems are said to support suitability for individualization if the system is constructed to allow for *adaptation* to the user's individual needs and skills for a given task.' In EVADIS II (p.43) [Oppermann et al., 1992] this principle has been elaborated as follows:

- 'Parts of the dialogue which are developed with certain user characteristics in mind (such as normal color vision or low level experience level) support individualization if they can be modified to support users who differ in these characteristics (such as color blindness or high experience level).
- The user should be able to adapt the dialogue system to support his/her individual strategies of planning, problem solving , and information processing strategies.
- The dialogue system should allow for individual preferences with regard to structural, procedural, and physical aspects.
- The dialogue system should allow the user for choosing among alternative forms of representation according to the complexity of the information to be processed.
- Explanations (e.g. error messages, help information) should be adaptable according to the individual level of knowledge of the user.

- The user should be allowed to incorporate his/her own vocabulary to establish individual naming for objects and actions. It should be also possible for him/her to add individualized functions within the semantics (personal macros) or even beyond the semantics (personal functions) of the application.
- Regarding the speed of interaction the user should be able to influence the speed of operation.
- He/she should be able to adapt the dialog speed to his/her own individual working speed.
- Individual preferences for selecting among the dialogue techniques should be supported when applicable with regard to the user task.
- The overall objective should be to provide mechanisms which allow the system to be adapted to the individual
    - knowledge and experience of computer
    - knowledge and experience of task design
    - language and culture
    - perceptual / motor abilities
    - cognitive abilities

of the user.'

Besides the obvious relationship of adaptation to task conformance (as has been introduced by several others, e.g., [Benyon, 1987, Hoppe, 1988; Norcio et al., 1989; Tyler et al., 1989; Browne, 1990]) in EVADIS II another link is made, namely relating adaptation to controllability [Oppermann et al., 1992, p. 45]. They argue that individualization has its origin in *controllability*:

'The controllability principle requires provisions in the following areas:

1. speed of interaction
2. tools (static and dynamic usage)
3. dialogue flow
4. application feedback and level of interaction
5. presentation and formats
6. critical situations (error, destructive)
7. input / output equivalency.'

With respect to *tools* they focus on:

- 'Tools used in a dialogue should be configurable by the user. Furthermore, the user should be able to select the dialogue tools for the current task at hand.
- The user should be able to receive information required for planning his/her task progress concurrently in any dialogue step. Thus, requesting global information on scope, structure, and status of the application should not disrupt the current activity.'

The *flow of control* should be characterized by:

- The user should be able to interrupt the dialogue at any time, task permitting. He/she should be able to decide after an interruption (e.g. on the basis of interim results) whether the dialogue should be continued from the point of interruption, whether some interaction activities should be reserved, or whether the whole dialogue should be canceled with the possibility to define certain conditions for restarting the dialogue. The last option might be realized via a general escape mechanism, which should be possible at any time of the dialogue and should work observing user transparent switching rules according to the structure and/or the hierarchical organization of the task.'

- *Feedback* should be provided in a way that 'the level of interaction, e.g. the amount of feedback, input, information exchange from and to the application' is 'under the control of the user'.
- 'The *way* the input/output data are *presented* (format and type) should be under the control of the user, thus offering the possibilities to avoid unnecessary input/output activities. If the control of the amount of data displayed is of use for a particular task, the user should be able to exercise such control.'
- '*Critical situations*, e.g. caused by user errors of application errors, should be accompanied with enough information and dialogue tools allowing the user to recover easily, and if required to recover lost data. The application should prevent the user from making destructive actions that were not intended.'
- And finally, 'where *equivalent* input/output *devices* exist the user should have the control to select either one'.

The relationship of adaptation to controllability is also supported by early definitions of adaptability, e.g. [Trigg et al., 1987]: According to their understanding 'the need for adaptable systems stems from a common complaint of users that their systems don't "fit" either the particular task they are doing [- here again, an explicit link to task conformance is given], their style of working, or their personal sense of aesthetics.' (ibid., p.724) With the help of adaptable systems users should be enabled to produce 'new system behavior without help from programmers or designers'. (ibid., p.724) They term a technical system '*adaptable* if it enables user-customizable behavior. Thus, adaptable systems can be used in diverse task domains by users having diverse styles'.

According to [Trigg et al., 1987] (p.724) there are four ways for a technical system to behave adaptable:

1. 'A system is *flexible* if it provides generic objects and behaviors that can be interpreted and used differently by different users for different tasks.
2. A system is *parametrized* if it offers a range of alternative behaviors for users to choose among.
3. A system is *integratable* if it can be interfaced to and integrated with other facilities within its environment as well as connected to remote facilities.
4. A system is *tailorable* if it allows users to change the system itself, say, by building accelerators, specializing behavior, or adding functionality.'

In a similar way, but in a broader sense [Browne et al., 1987] understand adaptive technical systems: Adaptive systems are technical 'systems which "behave" differentially depending on the current user of that system' (p. 1081). The same authors give four different and independent dimensions of adaptable systems [Trevellyn et al., 1987, p.103]:

1. 'contextual adaptation allowing users to navigate gracefully through tasks
2. [changing] levels of guidance / feedback, and

3. changes based on a user's knowledge of similar systems.'

Some approaches address the users in an explicit way, namely the personality and cognitive style. In this context the question of active and passive system behavior becomes crucial. For instance, [Benyon et al., 1993] term adaptation that is requested by the user or prompted by the system 'customization', whereas 'adaptation' is an automatic procedure performed by the software. [Browne et al., 1990] term a software *adaptive* in case it offers the ability to change its own characteristics automatically (eventually after user consultation), thereby adapting itself to the users' needs. *Adaptable* in contrast, denotes the provision of end users with tools that enable the users to change the software features and as such, the behavior of the application. Hence, adaptability is considered as a prerequisite to achieve adaptivity [Thomas et al., 1993]. Vice versa, adaptivity is based on adaptability. It has also to be noted that adaptation and adaptivity have been used synonymously.

Adaptivity leads to architectural considerations of software. Several components have been identified for (automatic) adaptation [Hoppe, 1988; Norcio et al., 1989; Browne et al. 1990, Benyon et al., 1993, Sukaviriya et al. 1993; Thomas et al., 1993]:

- a user model
- a task or domain model
- an interaction model.

In this context [Hoppe, 1989] considers adequate adaptivity to be based on user- and task modeling. In case the focus is only on the user model (assessment of user characteristics, e.g., for constructing a user profile) adaptivity is termed *individualization*. In case the focus is more on the task and the situation the user is dealing with (diagnosis of the user's current needs based on what he/she is actually doing) adaptivity is termed *context-adaptivity*.

The consideration of software architectures for adaptation and adaptability, comprising automatic adaptation, documents the need for software that is 'appropriate to the conjunction of user, task, and environment', as [Brooke, 1991] explains adaptability and adaptation. Hence, a broad understanding is required for adaptation and adaptability. It has to be based on several observations, according to [Totterdell et al., 1987, p. 715f]:

1. 'Adaptation relates a [technical] system to its environment.
2. Changes in the behavior of a [technical] system due to the adaptation should be explainable in terms of the [technical] system's beliefs about environmental objects.
3. The scope for adapatation in any given system is a function of:
   - the ability of the [technical] system to interpret its environment (observe),
   - the [technical] system's ability to display behavioral changes (behave), and
   - the ability of the [technical] system to usefully reorganize its internal structure in response to a change in the environment (learn).'

These observations clearly relate adaptation and adaptability to transparency, another principle in software ergonomics. Hence, in summary, adaptation and adaptability has been considered to be related to:

- task conformance (suitability for the task, task appropriateness)
- controllability
- transparency.

The further results can be summarized as follows:

- Terminologically,
    - Adaptation is closely related to individualization - however, sometimes individualization is used for generating automatic behavior based on user models (in contrast to situation-specific behavior)
    - Adaptation is either used as a general term for meeting particular user or task requirements, or to denote automatic behavior of technical systems. In the latter case, adaptivity and adaptation are used synonymously.
    - When distinguishing automatic behavior from user-controlled accomodation, adaptation is sometimes called customization.
    - Customization is also used synonymously to adaptation.
- Adaption is based on adaptability, naming a set of features to accomodate user needs.
- Adaptation can be achieved through the following features of technical systems:
    - flexibility towards different behaviors
    - parametrization of components to enable flexibility
    - integratability in the sense of openness to other facilities
    - tailorability to be controlled by the user and to add functionality.

3. QUALITATIVE CONTENT ANALYSIS

In the first part of this section we introduce the techniques under evaluation. In the second part we detail the methodological steps of the investigation according to the goals of qualitative content analyses. In the third subsection the results are interpreted for further research.

3.1 Techniques Under Investigation

The inputs to the content analysis have been extracted from the following techniques:

- ABETO [Technology Consulting Nordrhein-Westfalen, 1994]
- BTQ [Beratungsstelle der DAG Hessen, 1996]
- Ergonomics-Checker [Technology Consulting Nordrhein-Westfalen, 1993]
- EU-Con [Stary et al., 1997]
- EVADIS II [Oppermann et al., 1992]
- Evaluation Checklist based on Ravden's Evaluating Usability [Ravden et at., 1989]
- IsoMetrics [Willumeit et al. 1996].

The selection of these techniques was based on the following criteria:

1. *Availability of the technique* in the sense of how difficult it is to get access to the technique and use it practically.
2. *Reference to adaptation or adaptability*: Does it provide a description of the measurement similar to the ones in standards [DIN 66234 Part 8, 1988, ISO 9241 Part 10, 1990]?

For the analysis only the methodological parts of the techniques have been considered, e.g. focusing on the evaluation of software. In case of multiple versions of techniques (e.g., a long and short version) the most comprehensive one has been selected. Table 1 details the investigated techniques, in particular their fundamentals, the total number of questions (items), and the set of measurements for evaluation. Most of the techniques are based on the DIN-standard 66 234 Part 8 or ISO-standard 9241 Part 10. For the Evaluating Checklist no direct explanation of fundamentals have been given. With exception to IsoMetrics and EU-Con (still in progress) no details, e.g. concerning the selectivity of items, about the development of the questionnaires and the selection of questions are available. Further problems are caused by the variety of rating scales: Some of the techniques provide scales for rating (IsoMetrics provides 5, ABETO 7, Evaluating Usability 4). Others provide simple options for answering, such as Yes, No, and Unsure or open questions. The final analysis and interpretation of the results from the evaluation steps are handled in a rudimentary way in most of the techniques (ABETO, Ergonomics Checker, EVADIS II).

Before we focus on the qualitative content analysis of adaptation we will detail the diversity of descriptions for this measurement. Table 1 gives an overview of the selected techniques. IsoMetrics, Ergonomics-Checker, ABETO, and in most of its parts also EVADIS II are based on the description of the adaptation termed as individualization as it can be found in the DIN-standard 66 234 part 8 and in the ISO-standard 9241 part 10 (see section 2). EU-Con and BTQ have been developed to evaluate the EU-Directive 90/270. This directive involves five demands. Two statements refer directly to adaptation: Statement 2: ‘The software should be user friendly and adaptable to the knowledge and the experiences of the user’, and statement 4: ‘The system should present the information in a format and speed, which is adapted to the user’.

In the Evaluation Checklist based on the questionnaire Evaluating Usability [Ravden et al., 1989] adaptation is termed as flexibility and control:

Flexibility and Control: ‘The interface should be sufficiently flexible in structure, in the way information is presented an in terms of what the user can do, to suit the needs and requirements of all users, and to allow them to feel in control of the system.’[ibid., p.64]

According to the goal of our study it has to be investigated, whether the selected techniques provide a theoretically sound operationalization of adaptation based on their descriptive interpretations of this principle.

Techniques	Background	Total # of Questions	Measurements from Software Ergonomics	Measurements from Software Ergonomics (cd.)	Additional Measurements
ABETO	• ISO 9241 Part 10 • EU-Directive 90/270	39	• Task conformance (5) • Self-descriptiveness (4) • Controllability (5) • Conformity with user expectations (5)	• Error tolerance (5) • Suitability for individualization (5) • Suitability for learning (5) • Data safety & security (5)	
BTQ	• EU-Directive 90/270	85	• Suitability for learning (9) • Presentation of information (8) • Self-descriptiveness (10) • Conformity with user expectations (1) • Task Conformance (9) • Design of Dialog (6)	• Controllability (9) • Individualization (8) • Error tolerance • Data safety & security (6) • Effect of software (8) • Input mask (7)	
Ergonomics-Checker	• DIN 66234 part 8	86	Design of Dialogue (49) • Task Conformance (12) • Self-descriptiveness (7) • Controllability (11)	• Conformity with user expectation (6) • Error tolerance (13)	Design of Forms(37) • Data grouping & formatting (19) • Information encoding (8) • Graphical use (3) • Color combination (7)
EU-Con	• EU-Directive 90/270	36	• Statement 1 of the EU-Directive (19) • Statement 2 of the EU-Directive (7) • Statement 3 of the EU-Directive (2)	• Statement 4 of the EU-Directive (2) • Statement 5 of the EU-Directive (6)	• General questions (4)
EVADIS II	• IFIP-Model for Dialog Design (Dzida, 1983) • DIN 66234 part 8 • ISO 9241 Part 10	145	• Availability (2) • Usefulness (3) • Comfort (14) • Clarity (17) • Self-descriptiveness (32) • Conformity with user expectations (13) • Error tolerance (11)	• Suitability for learning (4) • Suitability for individualization (14) • Controllability (26) • Benefits for Cooperation & Communication (5) • Data safety & security (4)	
Evaluation Checklist	-----	120	(89) • Visual clarity (8) • Conformity with user expectations(20) • Compatibility (15) • Informative feedback (8)	• Task Conformance (9) • Flexibility and control (10) • Error prevention & correction (8) • User guidance and support (11)	(31) • System usability problems (25) • General questions on system usability (7)
IsoMetrics	• ISO 9241 Part 10	88	• Task Conformance (17) • Self-descriptiveness (14) • Controllability (13) • Conformity with user expectations (9)	• Error tolerance (16) • Suitability for individualization (11) • Suitability for learning (8)	

Table. 1: The Selection of Techniques

3.2 Procedure

The qualitative content analysis has been based on the questions of each of the techniques for the evaluation of adaptation. It includes two steps. For each technique the identified questions have been cross-checked for mutual semantic correspondence. In order to ensure objectivity the entire set of cross-checks have been performed by two independent evaluators who are experts in the field software ergonomics. Figure 3 shows this first step of the qualitative content analysis. Overall, 570 questions (items) have been analyzed. From this item pool 50 questions have been identified with respect to adaptation, exclusively.

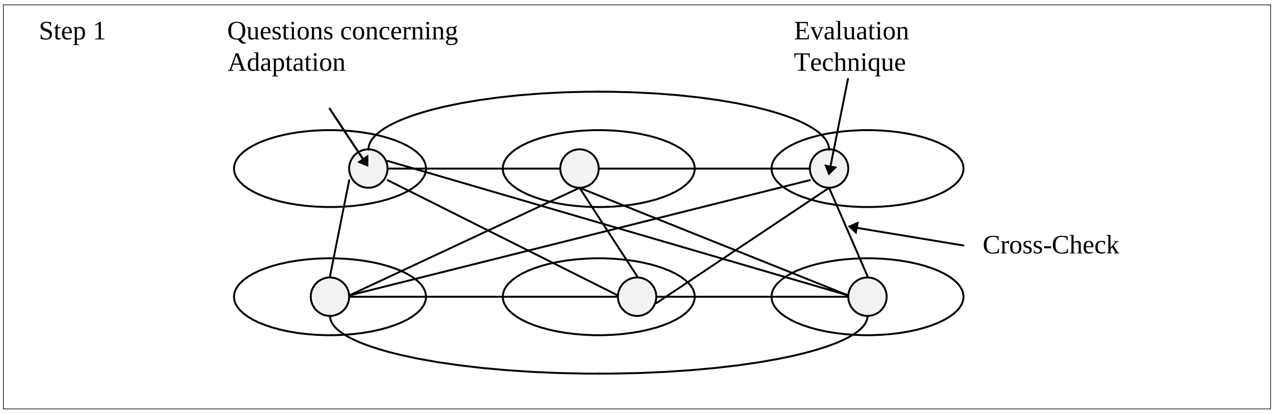

Figure 3: Mutual Cross-check of Techniques with Questions Adaptation Exclusively

Table 3 gives an example for a semantic correspondence of an adaptation-question of IsoMetrics that has also been identified in ABETO. Note that all of the cross-checked questions were related to adaptation termed as individualization.

Questions Concerning Adaptation (A-Questions) in IsoMetrics	**Questions Concerning Adaptation (A-Questions) Found in Other Techniques Addressing Adaptation**
The software can be adapted easily towards my individual style of task accomplishment.	ABETO: The software can be adapted easily towards the personal, individual style of task accomplishment.

Table 2: Example for the Semantic Correspondence of Questions Assigned to Adaptation between Different Techniques

In the second step of the qualitative content analysis the questions of each technique have been checked mutually against those questions of all other techniques that have not been related to adaptation initially. Again, the semantic correspondence of the questions has been checked. Figure 4 details one iteration of this step. The first input to the analysis, namely the set of questions concerning adaptation, remained the same. The difference concerns the second input: In contrast to step 1, the second input is the set of questions of the other technique(s) that is not directly related to adaptation. The second input is the set of questions that have not been involved in step 1. For each of the techniques the set of cross-checks as shown in Figure 4 has been performed, again by two independent experts in the field of software ergonomics. Step 2 has been considered to be completed when all the questions had been cross-checked for semantic correspondence.

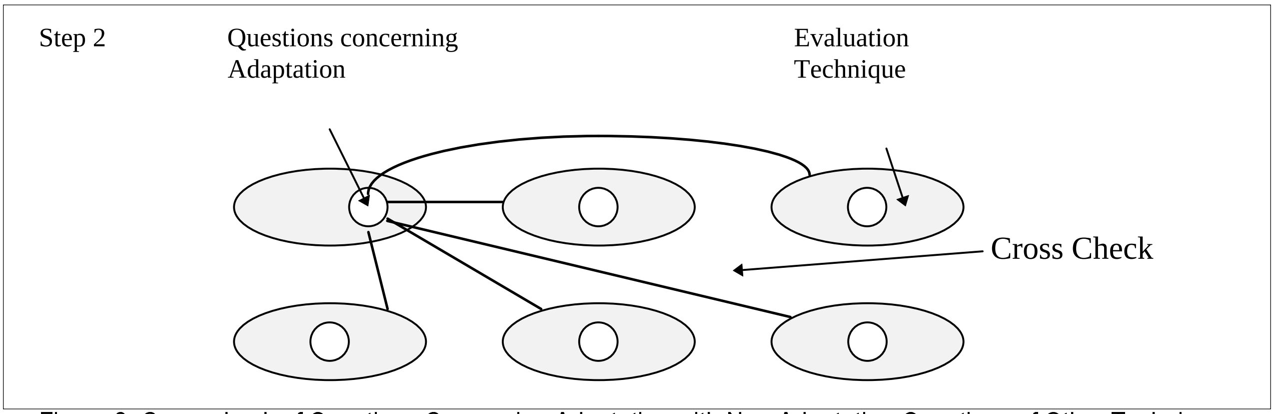

Figure 3: Cross-check of Questions Concerning Adaptation with Non-Adaptation-Questions of Other Techniques

An example of this step shown in Table 3. This step shows all those questions that can not only be assigned to adaptation but also to other categories.

A-Questions in IsoMetrics	**A-Questions in Other Techniques**	**A-Questions Assigned to Other Categories in Other Techniques**
The software can be adapted easily towards my individual style of task accomplishment.	ABETO: The software can be adapted easily towards the personal, individual style of task accomplishment.	Ergonomics-Checker (Task Conformance) Does the software enable individual styles of task accomplishment?
		EU-Con (Statement 1) Do you have to stick to the way the software handles tasks?
		ABETO (Controllability) The software does not inforce a particular sequence of activities.

Table 4: An Example for Semantic Correspondence of Questions Assigned to Adaptation with Questions Assigned to Other Categories of Measurement

3.3 SOME RESULTS

Following the tradition of qualitative studies (e.g., [Bortz et al., 1995]) the results of the previous steps are analyzed in a descriptive-statistical way.

The analysis of step 1 (mutual cross-checks of Adaptations-questions) has identified a semantic correspondence 44 out of 50 questions concerning adaptation exclusively. The remaining six questions show no correspondence. The corresponding questions have been clustered into 17 categories. Each of the categories represents a special aspect of adaptation.

According to the several dimensions of complex design and evaluation principles, each of the categories can be assigned to either the organizational, cognitive, or technical perspective. The following meta-categories can be identified:

- *individual organization of work*: It comprises issues of individualization, task conformance, controllability, and dialog design from the *organizational* point of view.
- *individual design of interaction*: It addresses issues of task conformance, individualization, and controllability from the *technical* point of view
- *individual provision with information*: It captures issues of individualization, controllability from the *cognitive* point of view.

All categories and the issues addressed by the concluding questions can be subsumed to one of the three meta-categories above, and thus, to either the organizational, cognitive, or technical dimension of interaction.

In the second analysis (step 2) 42 non-adaptation questions out of 570 have been identified which show a semantic correspondence with questions assigned to adaptation. Table 4 lists the principles that contained adaptation-questions. The leading category is controllability, followed by task conformance and error prevention and robustness.

Measurement	# Questions	Measurement	# Questions
Controllability	18	Self-descriptiveness	3
Task Conformance	11	Conformity with user expectations	1
Error prevention & Robustness	5	Information Coding	1
Design of dialog	3		

Table 4: Number of Adaptation-Questions Also Assigned to Other Categories of Measurement

Such multiple assignments indicate problems of validity, for some of the evaluation techniques, due to interdependencies between measurements or principles.

4. CONCLUSION

In order to streamline future research in the field of User Interfaces for All we have conceptually and empirically analyzed one of the major principles for accessible user interfaces, namely adaptation. Based on the results the second concern for the development of the User-Interfaces-for-All framework, namely proactivity, can be investigated subsequently (in terms of finding a scheme/language for specification). The reason is given through the fact that the conceptual analysis has been based on *designing* adaptable and adaptive user interfaces, whereas the empirical analysis has been based on techniques for *evaluation*. For proactivity, the gap between *design* and *evaluation* has to be bridged.

The semantic consistency of adaptation has been examined based on several approaches to identify the concept of adaptation and enabling software architectures, as well as on 7 techniques for user interface evaluation. Like most of the results of qualitative analyses the results of this content analysis should be used for further empirical analyses. In our case the follow-up investigation should comprise a meaning analysis of adaptation and adaptability enabling an analytical definition of these principles.

The usability of the proposed methodology for clarifying adaptation has turned out to be extremely useful due to the following facts:

1. The results of the conceptual analysis has been supported through the empirical findings. As a consequence, there is strong evidence that adaptation is not only highly correlated to other principles, such as task conformance, but also might have several instances and layers, such as adaptability being a requirement for adaptivity (i.e. automatic adaptation).
2. The direction for further research has been identified clearly due to the correspondence of the conceptual and empirical results. Hence, a strategy for further operationalization has been developed.
3. The identification of several dimensions, such as demonstrated previously for task conformance, seems to be a requirement and sound basis for further research. For the development of easily accessible user interfaces not only the separation of the organization of work, the cognitive style, and technical features, but rather their integration is a crucial challenge.

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