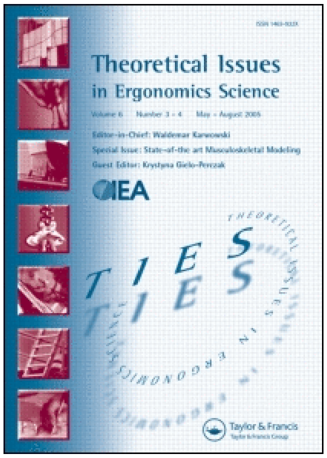

Theoretical Issues in Ergonomics Science
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713697886

Assistance in human-machine interaction: a conceptual framework and a proposal for a taxonomy

H. Wandke [a]
[a] Department of Psychology, Humboldt University Berlin, D-12489 Berlin, Germany

Online Publication Date: 01 March 2005
To cite this Article: Wandke, H. (2005) 'Assistance in human-machine interaction: a conceptual framework and a proposal for a taxonomy', Theoretical Issues in Ergonomics Science, 6:2, 129 - 155
To link to this article: DOI: 10.1080/1463922042000295669
URL: http://dx.doi.org/10.1080/1463922042000295669

Theoretical Issues in Ergonomics Science
Vol. 6, No. 2, March–April 2005, 129–155

Taylor & Francis
Taylor & Francis Group

Assistance in human–machine interaction: a conceptual framework and a proposal for a taxonomy

H. WANDKE*

Department of Psychology, Humboldt University Berlin, Rudower Chaussee 18, D-12489 Berlin, Germany

Many interactive systems offer assistance when users have difficulties in operating or using them. In spite of the overwhelming variety of assistance techniques available, it is often unclear what type of assistance is really needed and how special assistance functions should be designed. The first step towards theoretically solid design decisions is a conceptual framework and a comprehensive taxonomy of assistance. This paper proposes to define assistance as *access to machine functions* and provides a taxonomy based mainly on action stages to be assisted. These stages are: (1) motivation, activation and goal setting; (2) perception; (3) information integration, generating situation awareness; (4) decision-making, action selection; (5) action execution; and (6) processing feedback of action results. In analogy to social assistance, various types of technical assistance are assigned to the six action stages. As additional dimensions to classify assistance, we also discuss adjustment, initiative, presentation media and input modality.

Keywords: Assistance; Help systems; User support; Action stages; Human–machine interaction

1. Introduction

Over the last ten years, the terms ‘assistance’, ‘assistive technology’, ‘user support’, ‘online help’ and similar concepts have become increasingly significant in the development of man-machine systems (MMSs). But the use of these concepts is confusing, and it is often unclear what authors or developers of hardware and software understand by assistance when discussing it as an important component of MMSs. One reason for this unsatisfying lack of clarity is the range of application fields in which the concept of assistance has emerged as an important concept in human-machine interaction. These fields include:

- online help systems in human-computer interfaces
- automatic functions in real-time human-machine systems
- assistive technology for handicapped people
- smart homes
- personal digital assistants.

The following section presents the state-of-the-art or ‘the state of assistance’.

*Email: hartmut.wandke@psychologie.hu-berlin.de

Theoretical Issues in Ergonomics Science
ISSN 1463–922X print/ISSN 1464–536X online © 2005 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI 10.1080/1463922042000295669

1.1 *Online help systems in human–computer interfaces*

Research focused on the content and format of online help systems can be described by such keywords as *active help* (Fischer *et al.* 1985), *adaptive user support* (Oppermann 1994), *intelligent adaptive assistance* (Chiu *et al.* 1993, Thimleby and Addison 1996) *adaptive help* (Wandke 1988), and *contextual help* (Palanque *et al.* 1993). Help functions range from simple tool tips, bubble help, mouse-over help, direct help and similar concepts to extensive online-books in hypertext format including indexes and question-answering mechanisms (Elkerton 1988), right through to animated agents appearing on the computer screen as comic or anthropomorphic figures and explaining to users how to perform tasks or offering them special services (Laurel 1990, Nass *et al.* 1995, Sproull *et al.* 1996, van Mulken *et al.* 1998, Cassell and Vilhjágravelmsson 1999, Cassell *et al.* 2000, Dehn and van Mulken 2000). Very often, these figures have been called assistants. An early prototype of these figures was the butler in Apple's 'Video Knowledge Navigator' (Sculley 1989), whose (simulated) performance is still unrivalled. Other assistants are found not only in office software and online shops like 'Olga' (Sundblad and Sundblad 1998), but also in displays and controls of CNC machines (Zuehlke 2000). Computer games and the Internet are preferred areas of deployment for these characters.

1.2 *Automatic functions in real-time human–machine systems*

Assistance is also of relevance where process control is neither completely manual nor completely automatic. In these cases, a human operator and a computer control the process jointly by various types of task allocation and interaction. The most prominent example of this kind of assistance is the autopilot in aircraft cockpits. In this area, there is a trend towards upgrading assistive systems (called electronic crew members) to support the crew in various tasks (Wittig and Onken 1993, Billings 1997, Wickens *et al.* 1997). For several years, the role played by assistance systems in road traffic has been on the increase, with assistance offered at all three levels of driving: car stabilization, e.g. tracking assistance, electronic stabilization programs, brake assistance (Naab and Reichart 1995); movement control assistance, e.g. distance control (see for example Becker *et al.* 1994, Nirschl and Kopf 1998); and route planning, e.g. various navigation systems (Bengler 1995). Numerous assistive components are also offered for non-driving tasks like opening/closing windows, selecting a radio station, adjusting seat parameters, etc.

Other real-time processes, for example in the chemical industry or power plants, are also equipped with different types of assistance.

1.3 *Assistive technology for handicapped people*

Information technology has produced many aids for handicapped people, of which the automotive wheelchair, controlled by minimal movements of the fingers, head or even tongue, is a prime example. Other assistance systems guide blind people by acoustic signals (Fritz *et al.* 1995, Krueger and Gilden 1997) or transform visually presented material into speech or tactile display (Manzke *et al.* 1998, Roth *et al.* 2000a). Assistance has been developed for text input by motor-impaired persons (Fink *et al.* 1998, Pieper and Kobsa 1999). Some devices already available on the market offer multiple forms of assistance. Of the devices and techniques originally developed for handicapped users, some have proven more generally useful, such as word recognition algorithms for mobile phones with multiple key assignment, which substantially reduce the number of keystrokes for text messages.

1.4 *Smart homes*

The integration of information technology into buildings (Traenkler and Schneider 2001), rooms (Heider and Kirste 2002) and furniture (Streitz *et al.* 2001) can provide much assistance for everyday activities. Examples include heaters that automatically switch off when windows are opened and the outside temperature is low, or safety functions that switch on all lights in all rooms in case of unexpected and suspicious movements and noise. Instead of performing these activities themselves, people are assisted by sensors, computers and actuator devices that behave like servants.

1.5 *Personal digital assistants*

The term 'assistant' has been used explicitly to name a class of devices that support people in personal information management (Weiser 1994, Norman 1998, Holmquist *et al.* 2001). The personal digital assistants (PDAs) currently available usually combine calendar, note-taking and calculator functions, address and phone number databases, sketching and word processing function, e-mail and browsing facilities. Some offer further features like office application programs or telephone functions. There are no limits to the integration of any number of different functions, such as using the PDA as a camera, smart phone, dictaphone, route finder, music player, etc. In contrast to other areas, assistance is mainly provided by recording, storing, organizing, processing and presenting data and information for the user, while automatic interaction with the technical environment and other equipment is still in its infancy (de Haan and Terken 2001, Holmquist *et al.* 2001, Kirste 2001).

2. The need for a conceptual framework for assistance

This analysis of the various fields of application shows that the concept of assistance has become a central issue in human-machine interaction. At the same time, however, it is obvious that assistance is a fuzzy concept, requiring explicit consideration from a cognitive ergonomics point of view. At present, the concept of assistance is being shaped in relatively independent application fields. But these fields of application are growing together and a domain-independent concept of assistance is therefore needed.

The following sections describe two approaches to defining assistance: the first is very extensive, while the second, on which we concentrate in this paper, is more specific.

2.1 *Allocation of functions between humans and machines as assistance in a global sense*

People's wishes are greater than the opportunities for their fulfilment. Many personal goals cannot by achieved by natural actions, thus great dreams remain. But machines can help dreams come true, as was the case for the centuries old 'dream of flying'. Machines also make life easier, helping to perform hard, dangerous, difficult or boring tasks. In this broad sense, every technical device is an assistance

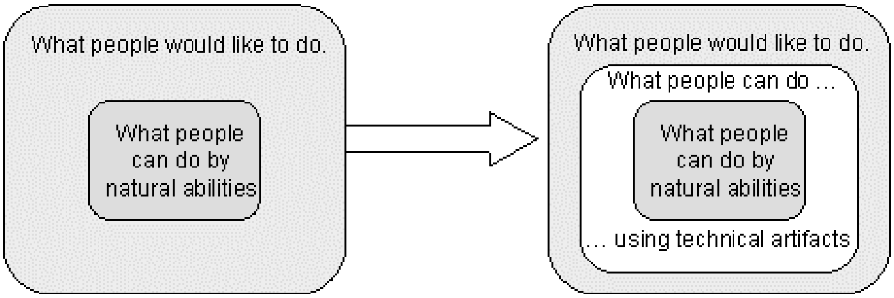

Figure 1. Technical artefacts are generally made to help people achieve more of their potential goals and/or reduce the effort required.

system: a chain saw helps the user cut down trees faster and with less power; a car helps cover long distances rapidly and conveniently; a telephone assists in communicating with a remote person; a word processing program assists in writing and editing a document.

The global sense of assistance is illustrated in figure 1.

It seems reasonable not to define all these devices as assistance systems. Otherwise, literally every technical artefact (from a paper clip to a space craft) would be an assistance system.

A first qualification is therefore necessary: it is only useful to speak of assistance when *interactive* systems are considered. Many technical systems are interactive, often referred to as man-machine systems (Rasmussen 1986, Wickens 1992). Functions in MMSs are traditionally divided into functions performed either by the human operator/supervisor or the machine. The allocation of functions to one of these two agents has been the first pivotal topic of Human Factors research since its foundation as an autonomous discipline (for a review of concepts, research and recommendations, see Grote *et al.* 1995, Parasuraman and Riley 1997, Wei *et al.* 1998). The second pivotal topic is the exchange of information between machine and human operator.

The aim of Human Factors based automation is to optimize the allocation of functions. For assistive technology, we consider neither complete automation nor complete manual or cognitive control (where machines have only force amplifying functions), focusing instead on interactive systems with some functions performed by humans and some by machines. But interactive devices with a number of assigned functions and a dedicated user interface still form too large a set of objects to be identified as assistance systems.

A second qualification of assistance systems is therefore needed. We don't focus on the *allocation* of functions, but on *access* to functions performed by interactive devices. Assistance (in a specified sense) gives *access* to functions assigned to machines. Functions may be not accessible because:

1. They do not exist at all: existence is a prerequisite for all forms of assistance, but existence alone does not ensure assistance.
2. They are not known to the user: if users are unaware that certain functions exist, they cannot use them.
3. Their use requires too much sensory, cognitive or motor effort from the user.

2.2 *Access to functions of interactive devices as assistance in a specified sense*

Assistance as discussed in the various application fields aims at the accessibility of existing functions. Insufficient access to functions (as a result of a task allocation process during design) is one of the most challenging problems in cognitive ergonomics. If users are unaware that certain functions exist at all, if they know that these functions exist but not how to apply them, or if they feel that it is too difficult to apply the functions, then they will not use the technical system or they will use it rudimentarily, ineffectively and inefficiently. As shown by a representative survey in United Kingdom (MORI 1999), the most prominent example of this is computer systems. The popular saying 'computers are good for problems that don't occur without computers' is an illustration of the gap between technological potential and human capabilities. Assistance may serve as a *bridge* between system functionality and human capabilities. The *bridge* is a frequently used metaphor in human–computer interaction (HCI) research, most famously in the gulf model developed by Norman (1986), but also on the cover of a book on usability engineering (Nielsen 1993). A more elaborated bridge metaphor can be found in Rothardt (1990). Like real bridges, assistance systems connect two banks: on the one bank stands a user with interests, habits, goals, knowledge, abilities and skills, but also disabilities, incapacities, situational constraints, etc; on the other bank stands a system with all its known and unknown functionality. Ideally, the bridge connects both banks in such a way that the user can apply all the necessary functions with minimal effort. In figure 2, the disappearing border between natural human abilities and technically provided functions is used as a visual metaphor.

Assistance systems include all the components of a user interface that support the user in solving a task. Generally speaking, a task results from the difference between the current state of the system and the desired state. In the context of using interactive devices, each of a user's goals can be described as an anticipated system state. Solving a task means transforming a current state into an anticipated one (the target state). Since the days of the early GOMS model (Card *et al.* 1983), this description has become standard in cognitive ergonomics. A recent research project called EMBASSI (German acronym for electronic multimedia operating and service assistance) studied tasks like recording a movie on a video cassette (Nitschke and Wandke 2001). The initial state is that devices like TVs and video

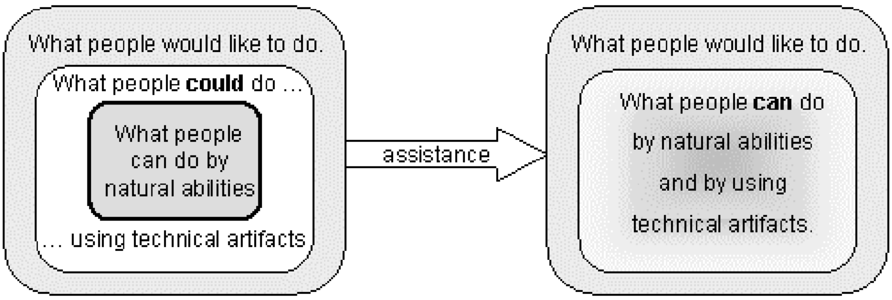

Figure 2. Assistance systems help people to overcome the gulfs of execution and evaluation (Norman 1986). They give access to functions which are assigned to machines, making a smooth or *seamless* (Ishii *et al.* 1994) transition between what people can do naturally and what they could do by means of technical artefacts.

cassette recorders (VCR) are off and information about the programme is not stored in the devices. The user's goal is to have all devices set to a state that will ensure recording of the desired movie. With today's technology, this involves a great many key presses in a prescribed order. Many people are not able to programme their VCR, using it only for replay of rental video cassettes or asking others to make the necessary settings.

With an assistance system it should be easier for all users to solve the task, e.g. by telling their devices "Record the movie with Julia Roberts tonight!" Of course this is not the only kind of assistance which could be offered to users. More basic assistance is offered e.g. by an electronic programme guide-(EPG)-(Herfet *et al.* 2001), where the TV programme is displayed on the TV screen and a movie can be recorded by clicking, pointing on it, or entering a menu number like the conventional show view numbers printed in paper journals. A very advanced assistance systems could record the movie without any action of the user. A pre-requisite for this assistance would be that the systems would compare the actual programme with preference data stored in a data base and would detect that the user is a fan of movies with Julia Roberts.

Recent pilot studies (Nitschke and Rebe 2002) investigate people's usage and acceptance of different types of assistance systems. But before testing various types of assistance, it seems reasonable to theoretically determine their distinguishing features. What are the variables affecting assistance systems? The answer to this question is the main content of this paper.

3. A taxonomy of assistance systems

The literature offers various approaches to the classification of assistance systems. Beside taxonomies based on technical realization aspects (Johannsen 1986), most refer to function allocation in supervisory control of industrial systems. They were developed not for assistance systems, but to characterise degrees of automation. One of the best known is the taxonomy of decision support by Sheridan (Sheridan 1988a, 1988b, 1992, 1997a, 1997b, 2000). Sheridan distinguishes the following ten different degrees of function allocation when a decision on intervention within a process has to be made:

1. Human does the whole job up to the point of turning it over to the computer to implement.
2. Computer helps by determining the options.
3. Computer helps determine the options and suggests one, which human need not to follow.
4. Computer selects action and human may or may not do it.
5. Computer selects action and implements if human approves.
6. Computer selects action, informs human in plenty of time to stop it.
7. Computer does the whole job and necessarily tells human what it did.
8. Computer does the whole job and tells human what it did if requested.
9. Computer does the whole job and tells human what it did and it, the computer decides he should be told.
10. Computer does the whole job if it decides it should be done, and if so tells human, if it decided he should be told. (Sheridan 1988b, p. 171)

Table 1. Taxonomy of assistance systems proposed by Timpe (1998).

Human functions to be supported	Field of application	Typical technologies
Perception	Aviation	Signal based
Sensory-motor functions	Continuous process control systems	Model based
Motivation	Discrete manufacturing systems	Knowledge based
Learning	Road traffic	Connectionist
Thinking	Shipping traffic	...
Problem solving	Rail traffic	
Decision-making	Household	
Language	...	

This taxonomy covers three relevant attributes of assistance: the allocation of functions in a decision process; the allocation of initiative for assistance (either human or computer); and the informing of human by computer (always/on human request/on computer decision/never). But it also has its limitations: it refers only to decision-making and action implementation but not to different action stages; it might be too sophisticated for simpler forms of assistance where no decision has to be taken; and it makes no explicit differentiation between the three attributes, function allocation, initiative and kind of information.

An explicit classification has been presented by Endsley (1996), which is similar to the one introduced by Sheridan.

While Sheridan's taxonomy offers a highly refined graduation, possibly too fine for many assistance systems, typical assistance systems cannot be classified using the ten grades. The 'brake assistant' of a car, for example, does not fit into the schema, although 'assistance' is even part of its name. Decision-making and implementation is *only one stage* in human-machine interaction.

Other authors (Kraiss 1990, Timpe 1998, Hauss and Timpe 2000) have suggested the inclusion of more attributes. Kraiss introduces *human functions to be supported* as a classification attribute, differentiating between human performances like perception, (sensory) motor functions, problem solving, working memory, long-term memory, decision-making and activation. Timpe (1998) uses similar categories but adds two further categories to his classification scheme: application field and typical technologies. His taxonomy is the most elaborate and can be described using the three dimensions (1) human functions to be supported, (2) field of application, and (3) typical technologies as listed in table 1.

While technological categories are of minor relevance for cognitive ergonomics and their application can lead to an indefinite list of fields, the ordering of human functions to be supported offers a coherent classification of assistance systems. However, for developers of assistance systems not trained in ergonomics, it might be difficult to understand the human function properly and design the appropriate assistance system for a specific human function.

Moreover, some of the human functions overlap and are difficult to distinguish. Another drawback of this taxonomy is its non-closure and indefiniteness, as new attributes can be added at will. It therefore seems reasonable to use not human functions but *action stages,* an approach which has been proven successful in human-computer interaction (HCI) research (cf. Norman 1984). Indeed, Sheridan in cooperation with other authors (Parasumaran *et al.* 2000) has also extended his taxonomy in this direction, distinguishing four action stages:

1. Sensory processing.
2. Perception/working memory.
3. Decision-making.
4. Response selection.

Like the ten degrees mentioned above, these four stages are tailored to assistance in operating situations. Professional operators/supervisors control processes by means of a computer system and intervene, for example, when disturbances occur, parameters deviate from scheduled values, or when their goals have been changed.

If a broader range of human-machine interaction should be covered by a taxonomy of assistance, these four stages aren't sufficient. Especially for situations where interactive devices instead of autonomous process have to be used instead to be controlled the approach of Parasumaran *et al.* (2000) needs to be extended in order to cover all kind of possible assistance.

As in other approaches (Norman 1984, Nielsen 1986, Rassmussen 1986, Doerner and Wearing 1995), we distinguish six stages of human action with machines which can be assisted by technical components. The following section presents a short description of the stages and the kind of assistance which can be provided. Examples of existing assistance systems are given as illustrations for the various types of assistance. Since assistance is also a metaphor derived from the field of social interaction (as documented by the wide variety of jobs including the term 'assistant' in their title), examples of assistive services fitting the category in question will also be given to better explain the various types of assistance.

The six stages are:

1. Motivation, activation and goal setting.
2. Perception.
3. Information integration, generating situation awareness.
4. Decision making, action selection.
5. Action execution.
6. Processing feedback of action results.

3.1 *Motivation, activation and goal setting*

In this stage, it is essential that the user reaches a sufficient level of motivation and activation in order to initiate an action. Although motivation and activation are separate factors and their regulation is a different process than goal setting, for pragmatic reasons all three processes should be subsumed into one single stage.

For every human-machine interaction, it should be made possible for users to establish the right goals and to be sufficiently motivated and activated to perform actions in order to reach those goals.

3.1.1 Social assistance. In sports and in professional life, coaches work full-time assisting people in achieving the right motivation and setting relevant goals. Further, fans shouting encouragement for individual athletes or teams support their favourites in terms of motivation and activation.

3.1.2 Technical assistance. We differentiate between four types of assistance for this action stage:

3.1.2.1 *Activation assistance*: this assistance creates or maintains an optimum level of activation. According to the Yerkes-Dodson Law, both hyper- and hypo-activation may result in reduced performance. Technical assistance may try to keep the user at a medium level of activation. Beside the danger of panic reactions, where assistance systems can block any user interference for a limited time (as applied for critical situations in nuclear power plants), the main application is the field of under-activation. Typical examples in this field are assistant systems that help drivers not to fall asleep. They detect signs of fatigue by various methods and sensors, and activate the driver by different measures, from wheel shaking in trucks to multiple animation effects offered by a virtual passenger (Sample 2001).

3.1.2.2 *Coach assistance*: coaching refers to the reinforcement of a motive or the upholding of an ongoing activity. A typical coach assistance is the 'please hold the line' message played automatically to callers on busy phone lines. Users are encouraged not to give up. Sometimes this assistance is combined with music designed to keep the user in a pleasant emotional state.

3.1.2.3 *Warning assistance*: assistance systems can be used to inhibit motives and to prevent actions which the user really doesn't want. Assistance of this kind can be found in many computer application programs which ask questions like 'Do you really want to delete all 38 files?' A simple warning assistance helps drivers to detect non-visible obstacles when backing into a small parking space by generating an acoustic signal.

3.1.2.4 *Orientation assistance*: this type of assistance supports the setting and changing of goals. Especially in problem solving, e.g. trouble-shooting, humans tend to be fixated on a chosen goal and to follow a predetermined strategy, a phenomenon that is sometimes called *cognitive tunnelling* (Dirkin 1983). Assistance systems (based on expert systems) can propose another strategy, such as those studied for trouble-shooting on tool-making machines (Marzi and John 2002).

3.2 *Perception*

Behaviour in human–machine interaction is always a result of interaction between motives and goals on one hand and options for action offered by the machine in a given state on the other. A precondition for the identification of the machine state is that users can receive information from the technical environment. This information must be indicated by signals: such signals may be too weak (in terms of absolute power or in terms of relationship between signal and noise); some may be available for a short time only, e.g. traffic signs during a fast drive; and some are categorically not available to handicapped users, e.g. visual signals in the case of blind people.

3.2.1 Social assistance. The task of social assistants is to provide users with information they are unable to perceive themselves. A typical case of social assistance is the co-pilot who reads the speedometer during take-off and tells current data to the pilot flying. Another classic case is the air traffic controller who informs the pilot about other aircraft or weather conditions the pilot cannot perceive. But social assistance may also take the form of someone accompanying a blind person who reads the screen output on a cash dispenser or ticket vendor.

3.2.2 Technical assistance. There are many assisting systems which support the perception of signals or display information. These systems:

- Amplify signals.
- Transform transient signals into permanent ones.
- Increase the redundancy of signals.
- Transform signals into different modes.

Technical assistance may provide only one of the listed services or combine several to form a complex service. Corresponding to the above list of functions, there are four types of technical assistance system.

3.2.1.1 *Display assistance*: identifying controls is a prerequisite for using them: users must recognize that a knob (e.g. on a car radio) can be not only turned (to control the volume), but also pushed (to switch on/off) or even pulled (to switch to balance control). Norman (1986) popularized the term 'affordances' that was introduced by Gibson (1982) for the design of controls which support the user in identifying their functions.

Sometimes, however, it is even hard for users to recognize a part of a machine as a signal or control element at all, or to differentiate between casing/decoration and interface parts. This problem gained topicality with the fast propagation of Internet technologies. One of the most reported problems (Nielsen 2000) is that users are often unable to recognize a link as such.

Display assistance not only provides signals but also ensures that these signals are recognized as such. In this context, controls can also be treated as signals. Rather than being a separate service offered in human-machine interaction, display assistance is usually an integrated and basic principle of user interface design. A radio with a full-text RDS display is a common application of this type of assistance. An example of display assistance as an extra service for the driver of a car has been proposed by Selker *et al.* (2002), who suggest that traffic signs or pedestrians could be highlighted during night driving by displaying additional visual cues in a head-up display.

3.2.2.2 *Amplification assistance*: if signals are too weak or too small in a certain situation or for certain users, an assistance function can be used to amplify them. For example, partially sighted users can increase font sizes in web browsers, but only if designers don't use fixed values. While the signals here are amplified in an absolute manner, more sophisticated assistance systems reduce noise in acoustic and visual data to present a clear sound or picture (relative amplification), e.g. in image processing systems or high quality earphones for air passengers. Current examples of this type of assistance include vision enhancement systems for driving in darkness or fog.

3.2.2.3 *Redundancy assistance*: whereas amplification leaves the code alphabet and signal dimension unchanged, redundancy assistance adds new features or new dimensions to a signal, and may even create complete new signals in addition to the existing ones. A typical example of advanced redundancy assistance is the presentation of traffic signs on the dashboard of a car (Metzler 1998). If the original sign is temporarily obscured by a truck or covered by soil or snow, then the driver gets the information from the otherwise redundant display.

3.2.2.4 *Presentation assistance*: this type of assistance transforms signals into another code alphabet of the same or different modality. Simple examples of this type of assistance include the selection of either graphic or numeric displays of information, the choice of language on a cash dispenser, the arrangement and appearance of icons on a computer screen, etc. More advanced examples include screen readers which transform visually presented text into audio output or devices which convert graphically presented information into tactile and haptic codes (Roth *et al*. 2000b).

3.3 *Information integration/situation awareness*

Recognition of a given situation requires more than just perception of one or more signals: users must also interpret what they have seen, heard or felt. Interpretation means the assignment of perceived signals to the contents of long-term memory. Assistance for this stage of action involves explicitly offering external explanation of the information displayed. This explanation can be provided on different levels. Firstly, the lexical and syntactic level is relevant. All manner of labels, markings, symbols, legends, etc. help users to understand what a given display means. But users must be familiar with these labels. For example, German drivers should know that a numeric value labelled 'km/h' indicates speed, but they may have trouble using a car where an 'mph' scale is used. The second level is semantic. Independent of nationality, culture and driving experience, all people might have a common understanding of speed, but in human-machine systems, there are often functions, data and labels that are not known to all potentials users. Here assistance could be offered by explanation on a semantic level. 'Torque' and 'Nm' are examples of terms and data for which many drivers need extra explanation. A third level is pragmatic. What are the consequences of driving at a speed of 120 km/h? Assistance can help drivers to understand these consequences. Examples include speedometers that indicate the recommended gear or give an acoustic signal when legal speed-limits are reached.

3.3.1 Social assistance. in this stage, social assistance is typically given by guides or interpreters. Tour guides explain places of interest and exhibition guides elucidate paintings in a museum. Interpreters translate from a foreign language into the listener's native tongue. In both cases, people are enabled to link what they perceive to their pre-knowledge. Social assistance is also at work in technical settings. The co-driver may assist the driver by explaining the situation on an unclear crossing by saying: 'no traffic from right side.' An experienced computer user may explain the meaning of icons and messages on the screen to a novice. For some people, providing social assistance is a full-time job, like help-desk staff or employees helping train passengers to use ticket vending machines (Norman 1992).

3.3.2 *Technical assistance*. There are several assisting systems which support information integration und situation awareness. These systems:

- Declare or label signals and controls.
- Integrate signals and actions into different frameworks.
- Explain signals and controls.

Corresponding to this list of functions, there are three classes of technical assistance systems.

3.3.2.1 *Labelling assistance*. simple and sometimes even trivial assistance is offered by inscriptions and legends. All kinds of textual, iconic or symbolic labels are added to help the user understand what is displayed or the potential purpose of a given button. Often, users don't realize that these labels are indeed necessary to reach the functions behind them. Their relevance only becomes visible in case of absence. A simple example is a TV remote control where frequent key presses have rubbed off the icons. Another opportunity to detect the relevance of labels emerges when labels are obviously unknown.

More advanced assistance is implemented with 'tool tips' or buttons which present their meaning by speech output when pressed halfway and users have their eyes occupied by other objects (e.g. looking through the viewfinder of a camera).

3.3.2.2 *Interpreter assistance*: these systems translate user input and/or system output into the corresponding language. This can be an actual language, like the English information and instruction texts presented by an Italian or Dutch cash dispenser, or it can be the 'language' of a graphical user interface or even the 'language' of mechanical buttons. The most prominent example of the latter is the adaptive remote control which can be used to operate various electronic devices in a living room. The concept of techniques discussed in a recent research project (Richter 2001) goes one step further: Richter and his colleagues developed a universal PDA for handicapped users who can use it as *interpreter* for several public access systems (like ticket vending machines, cash dispensers, information kiosks) and for controlling home appliances. The PDA stores individual data and preferences for optimizing interaction with external devices and for interaction between the user and PDA itself.

3.3.2.3 *Explanation assistance*: explanation is more than labelling and interpreting. It offers additional information which refers to the user's interests and pre-knowledge. Explanation can be understood as answers to potential HOW, WHEN, WHY and WHAT FOR questions from the user. In contrast to pure labelling or interpretation, which is mainly context-independent, it presents information relating to the use context. Well designed help functions and manuals offer explanation assistance. Demo modes with additional comments may also provide this type of assistance. Explanation assistance can often be found in tutorial systems.

3.4 *Decision-making, action selection, and action execution*

The next stage of interaction between a user and an interactive device leads from information reception, integration, interpretation and evaluation into external behaviour. Operators or users have to decide either to wait for further events or to act. In the latter case, they must decide what to do. Of course, users need assistance at this stage too. Indeed, traditional Human Factors research has focused on this stage alone. At this point, the degrees of automation proposed by Sheridan (1997) can be integrated into the general framework of assistance.

Assistance refers here to the selection and partly to the execution of actions. Assistance can be limited to the selection process only, or it can combine support for the current stage and the following stage of action execution.

3.4.1 Social assistance. An appropriate model to explain the various degrees of social assistance in decision-making might be a secretary assisting his/her boss by performing different tasks in scheduling. In a low degree of assistance, he/she keeps the boss's calendar and informs him/her about when he/she has slots free for appointments. More assistance is offered when he/she suggests a specific date, through to completely autonomous appointment-making. The highest degree of assistance could also include him/her refusing requests for unwanted appointments. Another example of social assistance is a driving instructor who usually tells the learner what to do (e.g. to reduce speed), but sometimes he also acts for the learner (e.g. applies his additional brakes). Air traffic controllers work as social assistants for pilots, but the type of assistance they perform varies: in the decision-making stage they usually decide for the pilot and tell him what he should do (change route, flight level etc.).

3.4.2 Technical assistance. The following types of assistance are derived from the Sheridan (1997) approach. They characterize main degrees of assistance. More sophisticated nuances could be used, but with this taxonomy, seven types of assistance seem to be sufficient.

3.4.2.1 *Supply assistance*: this type of assistance offers *all* currently possible options for actions. The user or operator is informed about what he or she can do now (considering contextual conditions like time, physical or social constraints, etc.). Often this type of assistance reduces the number of potential (context-independent) options considerably. An example of assistance in the area of entertainment systems could be a video text table showing only TV broadcasts that begin within the next two hours.

In simple cases, supply assistance can be realized by handbooks and operation instructions which offer a state-dependent description of options for actions.

Since supply assistance presents *all* current options, there is a danger of there being too many. It may be difficult for users or operators to scan a large number of options. This type of assistance may therefore be enhanced by introducing an additional filter mechanism.

3.4.2.2 *Filter assistance*: such systems narrow down the selection, offering just a limited set of possible options that can easily scanned by the user. Various criteria for filtering a large amount of options can be used: e.g. likelihood of success if the action in question is executed, effort to execute the action, user preferences, frequency of execution in the past, etc. Of course, these criteria can be combined in different ways. Filter assistance was studied in an experiment conducted by Nitschke and Rebe (2002). Subjects had to decide which of several thousand movies they wanted to see. Presenting a list of only ten movies filtered out by means of the subjects' previously determined interests yielded positive acceptance data. So called 'electronic program guides' (EPGs) help users find their preferred alternative among a huge number of options. This type of assistance might also be helpful in other domains where consumers are confronted with a multiplicity of complex services and products. Many 'wizards' that help users to install or to execute a computer program belong to filter assistance, in some steps (when only one option is presented) they belong to the next category: adviser assistance.

3.4.2.3 *Adviser assistance*: this type of assistance reduces the number of alternatives to *one*, which is recommended to the user or operator. A navigation system in a car is a typical assistance system offering only one alternative to follow the route. But the driver may still ignore the recommendation. Adviser assistance is normally used when time for decisions and action implementation is limited and when the device and the situation are well structured. In dangerous situations, operators can be obliged to follow the advice (which then becomes a command), as when a pilot has to execute the command of a TCAS system 'advising' him to reduce altitude. But since the difference between voluntary and forced action execution can only be made by non-technical (e.g. legal or organizational) factors, this difference is not used to introduce a new type of technical assistance.

In open situations without time constraints, adviser assistance can be annoying and will not be accepted, e.g. when in an experiment (Rebe and Nischke 2002) *only one* movie was proposed to the user, then it was frequently rejected.

3.4.2.4 *Delegation assistance*: delegation assistance supports not only action selection but also execution. Again only one option is offered. But the user or operator does not have to execute this alternative himself/herself. The system does this automatically if the user agrees. By doing this, the user or operator actively delegates execution to the system. If the operator doesn't agree, the system may recommend another option or wait for further user actions or changes in the environment.

A typical example of this type of assistance has been studied by Polkehn *et al.* (2002), where a car entertainment system proposed a piece of music and then started to play it if the driver said 'yes'.

3.4.2.5 *Take-over assistance*: this type of assistance is very similar to delegation assistance. The difference is that a take-over system executes the proposed action in every case, with the exception that the user or operator can *refuse* the selected alternative within a limited time. This type of assistance can be found in automatic mechanisms for the prevention of lapses in human vigilance. If the operator doesn't respond to a signal, then the system automatically applies a security function.

3.4.2.6 *Informative execution assistance*: here the entire action is executed by the system. The user cannot directly control operation. He or she is in a supervisory role and may switch off this assistance completely, but as long as it is 'on', it controls the process autonomously. The most prominent example of this type of assistance is the autopilot. Nowadays, many assistance systems implemented in consumer products like cars perform informative execution functions: from automatic air-conditioning to cruise control. They all are developed to relieve the driver of secondary or non-driving tasks and to simplify the task of driving.

3.4.2.7 *Silent execution assistance*: this type of assistance is sometimes also called 'background assistance'. The system performs operations automatically without informing the operator. Norman (1992) has criticized systems like autopilots which give the operator no information as 'strong silent types'. Indeed, silent execution can be problematic when the system reaches its limits and the unprepared operator suddenly has to take over process control. But if the system performs the function with high reliability, silent execution can be the best type of execution. Automatic gear changing is a good example of reliable assistance for car drivers. But this example also illustrates the potential problems with informative and silent execution. Users may lose the skills necessary to operate without assistance: drivers of cars with automatic transmission usually become unable to handle clutch and accelerator pedals sensitively when driving an unfamiliar car with a manual gearbox.

3.5 *Action execution*

Although assistance for action execution was already introduced in the last section, it seems reasonable to distinguish between assistance systems that support action execution by delegation or by taking it over in combination with decision-making, and systems which support the *execution of actions by users or operators*. Here we consider assistance systems of the last type. Operator actions might be physically too weak or too strong (sometimes humans tend to overshoot), too late or too time-consuming. In all cases, assistance systems may compensate for human deficiencies but leave the user in overall control.

3.5.1 Social assistance. A good model for assistance in action execution is team work. If an object is too heavy to be lifted alone, a second person can help. But even a light object may be easier to balance and fix in a specific position if a second or third person helps. Many tasks on car assembly lines can be done better if two or more persons coordinate their forces and control movements of large parts.

3.5.2 Technical assistance. According to the general constraints defined in the introductory section, we do not consider technical assistance in a broader sense, but restrict it to human interaction with interactive devices and machines. Seen from this perspective, users have always to operate controls, enter commands and data, push buttons, turn knobs, point and click, etc. These execution processes can be supported by different types of assistance.

3.5.2.1 *Power assistance*: power assistance amplifies the force the user applies to a control element. In driving, brake assistance is a typical example. The system monitors the driver's foot movements on the accelerator and brake pedals and maximizes the pressure when the driver moves a foot in a very short time.

3.5.2.2 *Limit assistance*: limit assistance works in the opposite direction. If an operator executes an action which is too strong or would result in forbidden or undesirable system states, the effect of the action can be limited. Simple examples include electronic limitations of the maximum speed to 250 km/h in powerful cars and bikes. More advanced examples include the tracking or distance control assistance already available in luxury cars. Limit assistance is also used in aircraft, where supervisory automation prevents overly steep climbing with insufficient velocity. Limit assistance gives the user the freedom to do what he or she wants up to certain limits which cannot be crossed.

3.5.2.3 *Dosing assistance*: dosing assistance combines both power and limit assistance and often works according to the closed loop principle. If a given parameter is too low, the corresponding control is increased and if it is too high, it is decreased. The anti-locking brake system is a well-known assistance system in the field of driving. Cruise control and increasingly smart car stabilisation programs like anti-skidding and anti-slipping assistance provide the driver with a 'virtual third or fourth foot' to control each wheel separately.

3.5.2.4 *Shortcut assistance*: this type of assistance helps to cut down long sequences of operations for an action to just a few or even a single step. Here too, driving offers many examples: gear changes can be easily operated with a single fingertip, not to mention opening and closing windows, or multiple adjustments of seats and mirrors, air-conditioning and radio stations. But shortcut assistance is also widely applied in data entry procedures, e.g. word recognition algorithms for text entry into mobile phones via reduced keyboards. People with motor impairments may profit from this type of assistance in a special way. But unimpaired users may also be glad if an assistant system understands the short spoken sentence 'record the thriller tonight' instead of performing a long sequence of key presses (often several dozen) with traditional VCRs. This last example indicates that shortcut assistance is often (but not always) combined with another type of assistance: input assistance.

3.5.2.5 *Input assistance*: input assistance provides the user or operator with different modes for entering commands and data including substitution of key presses by speech entries, or pointing instead of naming. But input assistance can also be provided by *combining* several modes into a multi-modal input. Again, handicapped people were the first to use this type of assistance, but other people profit to a similar extent.

3.6. *Processing feedback of action results*

This is the last stage of an action cycle. Users or operators have to understand the outcomes of their action and evaluate whether or not this outcome is congruent with their expectations. In MMSs, the outcome of an action often cannot be perceived directly. As a result, users need assistance in (1) realizing the effects of their actions and (2) in interpreting these effects as success or failure. We therefore differentiate between two types of assistance.

From a logical point of view, one might argue that this kind of assistance is the same as for the perception and interpretation stage. But in feedback *after* action execution, users usually have clear expectations of what should happen, while in information assimilation *before* deciding for action, there is no such stringent expectation. We therefore differentiate these kinds of assistance from those introduced above (see 3.3.2).

3.6.1 Social assistance. Providing feedback is one of the main tasks of teachers, trainers, and coaches. In a very simple case, where a driver cannot see the remaining distance to a second car in a parking lot, the co-driver might get out and give feedback, showing the distance by hand movements or spoken words. But social assistance gives feedback not only in terms of objective information, but also by evaluating user behaviour. The driving instructor may tell the learner that the parking distance is too small or too far away from the kerb. A teacher may praise or criticize the action of a learner, helping to further improve his or her performance. Both functions, presenting objective measures and evaluating performance, can also be performed by technical assistance.

3.6.2 Technical assistance. Based on the distinction between providing (1) results only or (2) evaluation, there are two types of technical assistance in this last action stage.

3.6.2.1 *Feedback assistance*: the user should always get feedback concerning any change to a system or process caused by his action. A very simple example is turning on a small LED after a user has inserted a cassette into a VCR. Norman (1989) recounts an anecdote where the presentation of a video at a scientific conference failed with dramatic effects (to the audience's amusement) because it was not indicated that there was no cassette in the recorder.

A more advanced example is a parking assistant showing distances to a car behind as a line of differing length or as a sound sequence with different pause times.

3.6.2.2 *Critique assistance*: the user gets explicit feedback on how well his or her previous action contributed to the achievement of the intended goal. One of the first prototypes of such a critique assistant was demonstrated by Fischer *et al*. (1990). The JANUS system told the user what is right or wrong in his draft of kitchen layout and made suggestions on how to improve the arrangement of kitchen units.

Critique assistance including positive evaluations is potentially helpful in learning situations where the human operator or user is not substituted (completely or partially) by a technical component and where his or her performance should be improved by training. A future electronic version of a driving instructor could comment selected actions of a junior driver with regard to the general goal of efficient and safe driving.

3.7 *Multiple assistance*

All the types of assistance listed for the six stages of action can be combined and offered as a step ladder to the user or operator, where he or she decides what type of assistance is most suited to his or her task, skill level, situation and subjective preferences. Technical systems rarely support a single stage with a single type of assistance: more frequently, various types are offered.

This leads to another problem: how to select the appropriate type of assistance? As in other areas of human–machine interaction, there are three solutions: customization, adaptability, and adaptation. These three approaches constitute an additional dimension in our taxonomy of assistance systems.

3.8 *Adjustment*

3.8.1 Fixed assistance. This approach could be described as 'one size fits all', with a single or combined assistance system that works in the same way for all users and in all situations. Fixed systems are often applied to support very basic processes of human information processing and action, where no significant individual differences can be found and where situations do not vary. Electronic brake assistance in a car is one example. Obviously, a fixed system is the best solution for this application. But fixed systems are sometimes also used in cases where users or situations show larger variations. Fixed help information in computer systems is sometimes too difficult to understand for beginners or occasional users, at the same time as being not informative enough for experienced users.

Among other factors, the fixed system concept has been criticized in connection with the crash of a German Lufthansa Airbus A320 at Warsaw airport after landing in 1993. A fixed assistance system prevented activation of the brakes for nine seconds because wheel speed was too high and load affecting the landing gears was too low.

After this crash Airbus Industries decided to change the system, which can now be customized to the specific demands of the airline ordering an aircraft.

3.8.2 Customized assistance. Customized assistance systems are tailored to the needs of specific groups, for specific tasks, in specific contexts. The adjustment of the system is made during design. For customization, a careful analysis of requirements is needed *before designing* the system.

Like fixed systems, customized ones have one great advantage: they always exhibit the same behaviour. They are consistent and transparent, so that users do not get a surprise when experiencing the assistance. This advantage can be illustrated by means of a car navigation system. A system which always guides the driver by arrows is more reliable than a system which presents arrows on town streets and route numbers and text output on highways. But like fixed systems, customized systems can be annoying when the context of use alters or users change in their experience, skills, activation, etc. The way to cope with such shifts is to transfer the means of adjustment from the hands of the designers to hands of the users (adaptability) or to the hands of the system (adaptation).

3.8.3 Adaptable assistance. Users can adjust the system to their specific needs, tasks, situations and preferences. Such adjustments can be made by *selection* and by *tuning the parameters*. Multiple selections and tuning processes are called *configuration* of an assistance system. Selection can be illustrated by two car drivers: one selects fully automatic gears (silent execution assistance), the other selects a Tiptronic function (shortcut assistance). Selection can be referred not only to the stage of action or the type of assistance within one stage (in the driver's example: action execution), but also to parameters. Users can set threshold levels for the activation of assistance: in a home assistance scenario, for example, the user can set a system to lower the volume of TV speakers, to show information about the caller, and to answer the phone after it has rung five times. Another person could set the system to do this after the first ring. Adaptation by setting parameters is also realized when a driver can adjust a distance control systems to a personally preferred time to collision (Rischke *et al.* 2002). He will be warned by the system on different distances to the car going ahead. With adaptable assistance the control for changes is always in hand of the user.

3.8.4 Adaptive assistance. Here, the adjustment is made by the system itself. Based on real-time parameters or previously stored contextual features, the system changes its parameters or selects different types of assistance for the user. A simple example is the adjustment of assistance based on the processing of a single contextual feature. If a driver needs supporting instructions, a text or graphic will be displayed on a screen if a camera detects that the user is actually looking at the screen (e.g. when stopped at traffic lights). If he or she is looking elsewhere, the instruction will be presented by speech output. But adaptation is also based on a combination of several contextual features (like current speed and archive data on how often the driver looks back at the display when speech output starts). With adaptive assistance, control over changes is always in the hands of the system.

Of course, adaptive assistance and adaptable assistance can be combined, allowing users to easily undo automatic changes to the system. But there must be a final priority ensuring that either the user or the system makes the adjustments.

In this discussion of the different types of adjustment, it becomes clear that a third aspect might be relevant for a taxonomy of assistance: does the system provide support for the user actively or is it a passive system waiting for a request from the user or operator? Assistance systems can therefore also differ in terms of initiative.

3.9 *Initiative*

We distinguish between *active* (sometimes also called proactive) and *passive* assistance. Passive assistance is initiated by the user. Of course, the user must know three things: (1) that he or she needs support in operating or using an interactive device, (2) that there is an assistance system which can supply this support, and (3) how to prompt the system to provide the right assistance at the right time. If the user is unaware of these three facts or if there are constraints in making a request to the system (e.g. lack of time or cognitive capacity) it is advisable to make the assistance active.

Active assistance is initiated by the system. To be active it needs information: when and under what conditions should it offer assistance? In the most simple case, this information is already available on identification of the specific user, or the systems becomes active if a single feature is measured (e.g. a car switches the headlights on automatically when the intensity of external light falls below a threshold value). In more complicated cases, the assistance system must have a diagnostic program to process a variety of real-time and stored parameters characterizing the user or operator, his or her behaviour, the state (and sequences of state changes) of the device and of the environment.

The stored parameters can be obtained in different ways. Users can be asked explicitly for their wishes and preferences, or the system infers the need for assistance from previously registered user behaviour.

Some types of assistance are always active: coaching, activation, warning, orientation, delegation, take-over, informative execution and silent execution assistance must take the initiative when working. Other types can be passive *or* active. Some assistance systems may even be both active *and* passive. In such cases, users can request assistance when the system is not triggered by contextual features. A simple example is the initiative of the system to switch from visual to acoustic display for blind users and the initiative of a sighted user to make the same switch just because his or her eyes are busy elsewhere.

Active and passive forms of assistance both have their advantages and disadvantages. If the initiative is with the user then he or she is the 'master' of the situation, controlling and supervising the technical system. However, he or she must know that assistance is available and have enough time and free cognitive resources to remember this fact and ask for support. If the initiative is with the system (active assistance) then no recall is necessary for the user. Operations initiated by the system are usually much faster and execution more precise. However, users might feel themselves at the mercy of the technical system, especially if the system behaves in an unexpected manner. Often the user has more contextual information than the system and can also better process this contextual information. In such cases, he or she might get frustrated when system operations cannot be stopped or other operations cannot be activated (cf. the Warsaw Airbus crash in 1993).

One of the great advantages of active assistance systems is the very short time in which they can start to execute an operation. This seems especially relevant in safety-critical applications.

3.10 *Presentation media and input modality*

Various media can be used to present information generated by assistance systems to the user or operator. In recent years output media for assistance has become a focal area of research, thanks to the availability of new media like video, animated cartoons and speech (Arafa *et al.* 1999, Nissler *et al.* 1999, Kraemer and Bente 2002). The effect of anthropomorphic figures in particular has been compared with more traditional media like textual screen displays (van Mulken *et al.* 1999). Although the appearance of assistance or the outfit of personalized figures are important to users, other aspects are of greater relevance: what an anthropomorphic figure says and does seem to be more important than how it is dressed.

From a conceptual point of view, a taxonomy based on output media offers nothing really new. Assistance systems can be analysed and designed in terms of presentation media like any other interactive system.

According to generally accepted criteria, the following distinction can be made:

3.10.1 Monomedia presentation. Text, graphics, pictures, sounds and speech are examples of single media used for human–computer interaction (and for presentation of assistance). The number of media is large and increases as new technical developments emerge. The only constraint is that perception of system output must be visual, auditory or tactile/haptic. For future applications of assistance systems further modalities may be interesting.

3.10.2 Multimedia presentation. The combination of several media provides a theoretically unlimited number of presentations. Especially popular are anthropomorphic characters. Sometime only these characters considered as 'real' assistants. This paper argues that the variety of assistants is much larger and not restricted to anthropomorphic characters.

3.10.3 Implicit presentation. Implicit or non-media assistance means the operator experiences the assistance only by its effects. The system operates in the background without informing the user explicitly (silent execution assistance). In some situations, the user or operator might not notice that there is assistance working in the background at all, especially when the system compensates disturbing factors which cannot be perceived by the user.

A similar classification can be applied to the modality of user input. Of course, user input is only relevant if the initiative is on his or her side (passive assistance). According to the taxonomy common in HCI research (Oviatt and Wahlster 1997, Oviatt 1999, Liu *et al.* 2000, Oviatt *et al.* 2000, Seifert *et al.* 2001) we distinguish between:

3.10.4 Monomodal input. Examples include manual actions like handling controls, typing, pointing, clicking, dragging, speaking, gesturing, looking, mimicking, producing sound by whistling, clapping hands or snapping fingers (Ginnow-Merkert 2002).

3.10.5 Multimodal input. Usually two or three, sometimes more modes can be combined for multimodal input to ask an assistance system for support. The 'put that there' approach (Bolt 1980) is the archetype for all kinds of multimodal input.

3.10.6 No explicit input. Active assistance systems operate autonomously and need no specific user input. Input modality is therefore not a feature for characterizing these types of assistance.

Of course, user input modality is an important factor for the design of assistance, but there are no specific considerations needed. With regard to user input, assistance systems can be treated like other components of interactive systems. This factor therefore plays a minor role in our proposed taxonomy of assistance systems.

4. Application of the taxonomy

The creation of scientific taxonomies is often driven by the basic human motive to generate order and regularity in a complex and non-transparent field. In combination with clear definitions of concepts, this is a prerequisite for communication between researchers and technologists in the field. It seems that assistance design is a field where communication to date has been aggravated by fuzzy terms and different implicit perspectives. But the taxonomy can also be helpful for designing concrete assistance systems. In the EMBASSI (electronic multimodal operational and service assistance) project, the author and his co-workers (Wandke *et al.* 2001) developed a software tool to guide engineers in the development of assistance in three application areas: home entertainment technology, driving and public access systems.

When using this tool, developers are asked to perform a requirements analysis and to enter the results of this analysis into a module of the tool. Developers are asked to specify parameters for the planned system's purpose, user characteristics, task features and contextual factors of use. The tool then applies a set of rules to generate the type of assistance most suited to the parameters specified during requirement analysis.

Table 2. Example for applying the taxonomy for design proposals.

Categories provided by taxonomy	Design proposal
Action stage to be supported:	Perception
Type of assistance:	Presentation assistance
Adjustment:	Adaptable (user should select presentation media)
Initiative:	Passive assistance
Presentation media:	Visual or acoustic
Input modality:	Manual control

The taxonomy suggested here proved to be a reasonable structure for rule-based proposals to developers. Ideally, and supposing all necessary parameters have been correctly specified, a proposal for assistance might appear as shown in table 2.

Of course, there may be two or more proposals for each category, provided they comply with the specification made in the requirements analysis. Based on requirements analysis, it is also possible that more than one stage should be supported and the tool can offer two or more proposals. The advantage of suggesting assistance in the abstract categories of the taxonomy is that developers have a higher degree of freedom when making concrete design decisions than in the case of detailed assistance specifications, which are beyond the scope of a computer tool in any case. The computer tool also offers other options which go beyond the described proposals using categories of the taxonomy and which are discussed elsewhere (Koeppen and Wandke 2001).

We hope that the future application of the tool could be a good opportunity to test the validity and usefulness of the proposed taxonomy.

Acknowledgements

This research was supported by grants from the German Federal Ministry of Education and Research (BMBF) as part of the Lead Project Human–Computer Interaction. It is part of the project EMBASSI (electronic multimodal operational and service assistance) supported by BMBF under contract 01IL9041.

References

Arafa, A.Y., Charlton, A.P., Fehin, A.P. and Mamdani, A.A., 1999, Personal service assistants with personality. In *Proceedings of the Eighth International Conference on Human-Computer Interaction*, H.-J. Bulliner and Ziegler (Eds.), Vol. 2, pp. 147–151 (Mahwah NJ: Lawrence Erlbaum Associates).

Bainbridge, L., 1983, Ironies of automation. *Automatica*, **19**, 775–779.

Becker, S., Bork, M., Dorissen, H.T., Geduld, G., Hofmann, O., Naab, K., Noecker, G., Rieth, P. and Sonntag, J., 1994, Summary of Experience with Autonomous Intelligent Cruise Control (AICC). Part 1: Study objectives and methods, Part 2: Results and conclusions. In *Proceedings of the first World Congress on ATT & IVHS*, 30 November–3 December 1994, Paris France, pp. 1828–1843.

Bengler, K., 1995, *Gestaltung und Experimentelle Untersuchung Unterschiedlicher Praesentationsformen von Wegleitungsinformation in Kraftfahrzeugen* (Regensburg: S. Roderer Verlag).

Billings, C.E., 1997, *Aviation Automation: the Search for a Human-Centred Approach* (Mahwah, N.J.: Lawrence Erlbaum).

Bolt, R.A., 1980, 'Put-that-there': voice and gesture at the graphics interface. *Computer Graphics*, **14**, 262–270.

Card, S., Moran, T.P. and Newell, A., 1983, *The Psychology of Human–Computer Interaction* (Hillsdale, N.J.: Lawrence Erlbaum Associates).

Cassell, J. and Vilhjálmsson, H., 1999, Fully embodied conversational agents: making communicative behaviours autonomous. *Autonomous Agents and Multi-Agent Systems*, **2**, 45–64.

Cassell, J., Sullivan, J., Prevost, S. and Churchill, E., 2000, *Embodied Conversational Agents* (Cambridge, MA: MIT Press).

Chiu, Ch.-T., Chiu, Ch. and Norcio, A.F., 1993, An adaptive intelligent help system, in *Proceedings of the Fifth International Conference on Human–Computer Interaction*, pp. 718–723.

Dehn, D.M. and van Mulken, S., 2000, The impact of animated interface agents: a review of empirical research. *International Journal of Human–Computer Studies*, **52**, 1–22.

Dirkin, G.R., 1983, Cognitive tunnelling: use of visual information under stress. *Perception Motor Skills*, **56**, 191–208.

Doerner, D. and Wearing, A.J., 1995, Complex problem solving: toward a (computer simulated) theory. In *Complex Problem Solving: The European perspective*, P.A. Frensch and J. Funke (Eds.), pp. 65–99 (Hillsdale, NJ: Lawrence Erlbaum Associates).

Elkerton, J., 1988, Online aiding or human–computer interfaces. In *Handbook of Human–Computer Interaction*, M. Helander (Ed.), pp. 345–364 (Amsterdam: Elsevier Science Publishers).

Endsley, M.R., 1996, Automation and situation awareness. In *Automation and Human Performance*, R. Parasuraman and M. Mouloua (Eds.), pp. 163–181 (Mahwah, NJ: Lawrence Erlbaum Associates).

Fink, J., Kobsa, A. and Nill, A., 1998, Adaptable and adaptive information provision for all users, including disabled and elderly people. *The New Review of Hypermedia and Multimedia* **4**, 163–188.

Fischer, G., Lemke, A. and Schwab, T., 1985, Knowledge-based help systems. In *Proceedings of CHI '85 Human Factors in Computing Systems*, pp. 161–167 (New York: ACM).

Fischer, G., Lemke, A., Mastaglio, T. and Morch, A., 1990, Using critics to empower users. Human factors in computing systems. In *CHI'90 Conference Proceedings*, April 1990 (Seattle, WA) pp. 337–347.

Fritz, S.R., Michel, H., Petrie, A., Raab and Strothotte, T., 1995, MoBIC: user needs and preliminary design for a mobility aid for blind and elderly travellers. In *The European Context for Assistive Technology*, I. Placencia-Porrero and R. Paig de la Bellasca (Eds.), pp. 348–351 (Amsterdam: IOS Press).

Gibson, J.J., 1987, *The Ecological Approach to Visual Perception* (Mahwah NJ: Lawrence Erlbaum Associates).

Ginnow-Merkert, H., 2002, Interface als emulation des natuerlichen environments. In *Bedienen und Verstehen.4. Berliner Werkstatt Mensch-Maschine-Systeme*, R. Marzi, V. Karavezyris, H.-H. Erbe und K.-P. Timpe (Hrsg.), 10–12 October 2001, ZMMS-Spektrum, Band 13 der VDI-Fortschrittsberichte (Mensch-Maschine-Systeme) pp. 249–260 (Duesseldorf: VDI-Verlag).

Grimmer, W., Adelt, P.J. and Stephan, E.R., 1995, *Die Akzeptanz von Navigationsfuehrungsystemen der Zukunft. Eine AXA DIREKT Verkehrstudie*, (Bonn: Deutscher Psychologen Verlag).

Grote, G., Weik, S., Wafler, T. and Zolch, M., 1995, Criteria for the complementary allocation of functions in automated work systems and their use in simultaneous engineering projects. *International Journal of Industrial Ergonomics*, **16**, 377–382.

de Haan, G. and Terken, J.M.B., 2001, Agents and wearables–usability in the COMRIS system. *Computers* and *Graphics*, **25**, 571–579.

Hauss, Y. and Timpe, K.-P., 2000, Automatisierung und unterstuetzung im mensch–maschine-system. In *Mensc– Maschine Systemtechnik—Konzepte, Modellierung, Gestaltung, Evaluation*, K.-P. Timpe, T. Juergensohn and H. Kolrep (Eds.), pp. 41–62, (Duesseldorf: Symposion Publishing GmbH).

Heider, Th. and Kirste, Th., 2002, Supporting goal based interaction with dynamic intelligent environments. In *Proceedings 15th European Conference on Artificial Intelligence*, Lyon, France, 22–26 July 2002, pp. 596–600.

Helander, M. (Ed.), 1988, *Handbook of Human–Computer Interaction* (Amsterdam: Elsevier Science Publishers).

Herfet, Th., Kirste, Th. and Schnaider, M., 2001, EMBASSI—multimodal assistance for infotainment and service infrastructures, *Computer* and *Graphics*, **25**, 581–592.

Holmquist, L.E., Mattern, F., Schiele, B., Alahuhta, P., Beigl, M. and Gellersen, H.-W., 2001, Smart-its friends: a technique for users to easily establish connections between smart artefacts. *LNCS 2001- Ubicomp 2001*, pp. 116–122 (Berlin: Springer-Verlag).

Hoppe, H. U., 1988, Task-oriented parsing—a diagnostic method to be used by adaptive systems, in *Proceedings of ACM CHI'88 Conference on Human Factors in Computing Systems*, pp. 241–247.

Ishii, H., Kobayashi, M. and Arita, K., 1994, Iterative design of seamless collaboration media. *Communications of the ACM* (*CACM*), *Special Issue on Internet Technology*, **37**, 83–97.

Johannsen, G., 1986, Architechture of man–machine decision making systems. In *Intelligent Decision Support in Process Environments*, E. Hollnagel, G. Mancini and D.D. Woods (Eds.), pp. 327–339 (Berlin: Springer).

Kirste, Th., 2001, Situation-aware mobile assistance. In *Frontiers of Human–Centered Computing, Online Communities and Virtual Environments*, R.A Earnshaw (Ed.), pp. 99–115 (London: Springer).

Koeppen, N. and Wandke, H., 2001, Developing a process model for the design of assistance componenets in information appliances. In *8th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design and Evaluation of Human–Machine Systems*, G. Johannsen (Ed.), pp. 41–45 (Duesseldorf: VDI/VDE-GMA).

Kraemer, N.C. and Bente, G., 2002, Virtuelle helfer: embodied conversational agents in der mensch–computer–interaktion. In *Virtuelle Realitaeten*, G. Bente, N.C. Kraemer and A. Petersen (Eds.), pp. 203–225 (Goettingen: Hogrefe).

Kraiss, K.-F., 1990, Entscheidungshilfen in hochautomatisierten systemen. In *Ingenieur-psychologie. Bd. 2 der Enzyklopaedie der Psychologie*, C.G. Hoyos and B. Zimolong (Eds.), pp. 455–476 (Goettingen: Verlag fuer Psychologie Hogrefe).

Krueger, M.W. and Gilden, D. 1997, Know where™: an audio/spatial interface for blind people, in *Proceedings ICAD'97*. Xerox PARC: Xerox. Available online at: http://www.santafe.edu/~kramer/icad/websiteV2.0/Conferences/ICAD97/Kruger.PDF

Laurel, B., 1990, Interface agents: metaphors with character. In *Computers as Theatre*, B. Laurel (Ed.), pp. 355–365 (Reading: Addison-Wesley).

Liu, J., Pastoor, S., Seifert, K. and Hurtienne, J., 2000, Three-dimensional PC: toward novel forms of human–computer interaction. Three-dimensional video and display: devices and systems, *SPIE Critical Reviews* Vol. CR 76, 5–6 November 2000, Boston, MA.

Manzke, J. M., Egan, D. H., Felix, D. and Krueger, H., 1998, What makes an automated teller machine usable by blind users? *Ergonomics*, **41**, 982–999.

Marzi, R. and John, P., 2002, Support fault diagnosis through a multi-agent-architecture. *Mechanical Engineering*, **216**, 627–631.

Metzler, H.G., 1998, Assistenzsysteme in der fahrzeugfuehrung. In *Wohin fuehren Unterstuetzungssysteme? Entscheidungshilfe und Assistenz in Mensch–Maschine–Systemen 2. Berliner Werkstatt Mensch–Maschine–Systeme*, H.-P. Willumeit and H. Kolrep (Eds.), 7–9 October 1997*, ZMMS Spektrum Band 5*, pp. 206–225 (Sinzheim: Pro Universitate Verlag).

MORI 1999, Available online at: http://www.compaq.co.uk/press/releases/archive/temp/2e12.asp 27. (accessed May 1999).

Naab, K. and Reichart, G., 1996, Driver assistance systems for lateral and longitudinal vehicle guidance-heading control and active cruise support. *JSAE Review*, **16**, 220.

Nass, C., Moon, Y., Reeves, B. and Dryer, D.C., 1995, Can computer personalities be human personalities? *International Journal of Human–Computer Studie*s, **43**, 223–239.

Nielsen, J., 1986, A virtual protocol model for computer–human interaction. *Inernational Journal of Man-Machine Studies* **24**, 301–312.

Nielsen, J., 1993, *Usability Engineering* (Cambridge, MA: Academic Press).

Nielsen, J., 2000, *Designing Web Usability: The Practice of Simplicity* (Indianapolis: New Riders Publishing).

Nirschl, G. and Kopf, M., 1998, Untersuchung des zusammenwirkens zwischen den fahrer und einem ACC-system in grenzsituationen. In *ZMMS-Spektrum, Band 5: Entscheidungshilfe und Assistenz in Mensch–Maschine–Systemen*, H.-P. Willumeit and H. Kolrep (Eds.), pp. 169–181 (Berlin: Technische Universitaet).

Nissler, A.J., Machate, A.J. and Hitzges, A.A., 1999, How to get the right outfit for my agent? Classification—and design methodology for a virtual shopping assistant in a 3D world, In *proceedings of the Eighth International Conference on Human–Computer Interaction Vol. 2*, H.-J. Bullinger and J. Ziegler (Eds.), pp. 162–166 (Mahwah NJ: Lawrence Erlbaum Associates.

Nitschke, J. and Rebe, N.O., 2002, Bedienassistenz bei der auswahl von sendungen. *Abstractband 43. Kongress der Deutschen Gesellschaft fuer Psychologie*, 22–26 September 2002, Berlin, Germany (Lengerich: Pabst Science Publishers), p. 136.

Nitschke, J. and Wandke, H., 2001, Human support as a model for assistive technology. In *Intelligent Interactive Assistance and Mobile Multimedia Computing*, A. Heuer and Th. Kirste (Eds.), pp. 130–136 (Rostock: Neuer Hochschulschriftenverlag).

Norman, D.A., 1983, Some observations on mental models. In *Mental models*, D. Gentner and L.A. Stevens (Eds.), pp. 7–14 (Hillsdale, NJ: Lawrence Erlbaum Associates).

Norman, D.A., 1984, Stages and levels in human–machine interaction. *International Journal of Man–Machine Studies*, **21**, 365–375.

Norman, D.A., 1986, Cognitive engineering. *User Centered System Design: New Perspectives on Human–Computer Interaction*, D. A. Norman and St.W. Draper (Eds.), pp. 31–61 (Hillsdale, NJ Jersey: Lawrence Erlbaum Associates).

Norman, D.A., 1989, *The Design of Everyday Things* (New York: Basic Books).

Norman, D.A., 1992, *Turn Signals are the Facial Expressions of Automobiles* (Reading MA: Addison-Wesley).

Norman, D.A., 1998, *The Invisible Computer: Why Good Products Can Fail, the Personal Computer Is So Complex and Information Appliances Are the Solution* (Cambridge, MA: MIT Press).

Oppermann, R., 1994, Introduction. In *Adaptive User Support*, R. Oppermann (Ed.), pp. 3–13 (Hillsdale NJ: Lawrence Erlbaum Associates).

Oviatt, S., 1999, Ten myths of multimodality. *Communications of the ACM*, **42**, 74–81.

Oviatt, S., Cohen, P., Wu, L., Duncan, L., Suhm, B., Bers, B., Holzman, Th., Winograd, T., Landay, J., Larson, J. and Ferro, D., 2000, Designing the user interface for multimodal speech and pen-based gesture applications: state-of-the-art systems and future research directions. *Human–Computer Interaction*, **15**, 263–322.

Oviatt, S. and Wahlster, W., 1997, Introduction to this special issue on multimodal interfaces. *Human–Computer Interaction*, **12**, 1–5.

Palanque, Ph.A., Bastide, R. and Dourte, L., 1993, Contextual help for free with formal dialogue design III. In Media/*Proceedings of the Fifth International Conference on Human–Computer Interaction*, pp. 615–620.

Parasuraman, R. and Riley, V., 1997, Humans and automation: use, misuse, disuse, abuse. *Human Factors*, **39**, 230–253.

Parasuraman, R., Sheridan, Th.B. and Wickens, Ch.D., 2000, A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man and Cybernetics*, **30**, pp. 286–297.

Pieper, M. and Kobsa, A., 1999, Talking to the ceiling: an interface for bed-ridden manually impaired users. In *CHI99 Extended Abstracts, Video Demonstrations*, M.W. Altom and M.G. Williams (Eds.), pp. 9–10 (Pittsburgh, PA).

Polkehn, K., Preuschhof, C. and Kussmann, H., 2002, Simulationsuntersuchungen zur evaluation von assistenzsystemen im KFZ. *Abstractband 43. Kongress der Deutschen Gesellschaft fuer Psychologie*, 22–26 September 2002, Berlin, pp. 97–98 (Lengerich: Pabst Science Publishers).

Rasmussen, J., 1986, Information Processing and Human–Machine Interaction: An Approach to Cognitive Engineering. Vol. 1 Series in System Science and Engineering (Amsterdam: North-Holland).

Reichart, G., 1995, Menschliche und technische Zuverlaessigkeit.In *Verlaesslichkeit von Mensch–Maschine–Systemen, ZMMS-Spektrum Band 1*, H.-P. Willumeit and H. Kolrep (Eds.), pp. 273–289 (Berlin: Technische Universitaet Berlin).

Richter, K. 2001, Remote access to public kiosk systems, *Proceedings 1st International Conference on Universal Access in Human–Computer Interaction*, 2001, New Orleans, USA.

Rischke, S., Schubert, A. and Polkehn, K., 2002, Verbesserung der aktiven fahrsicherheit am beispiel eines abstandsregelungssystems. *Abstractband 43. Kongress der Deutschen Gesellschaft fuer Psychologie,* Berlin, 22–26 September 2002 (Lengerich: Pabst Science Publishers), p. 163.

Roth, P., Petrucci, L., Assimacopoulos, A. and Thierry Pun, T., 2000a, Audio-haptic internet browser and associated tools for blind users and visually impaired computer users. In *COST 254 Intelligent Terminals, Workshop on Friendly Exchanging Through the Net*, C. Germain, O. Lavialle and E. Grivel (Eds.), March 22–24 2000, Bordeaux, France, pp. 57–62.

Roth, P., Petrucci, L., Assimacopoulos, A. and Thierry Pun, T., 2000b, From dots to shapes: an auditory haptic game platform for teaching geometry to blind pupils. In *ICCHP 2000, International Conference on Computers Helping people with special Needs*, July 17–21 2000, Karlsruhe, Germany, pp. 603–610.

Rothardt, G., 1990, *Dialog mit dem Computer* (Berlin: Verlag Technik).

Sample, I., 2001, You drive me crazy. *New Scientist*, **171**, 24.

Sculley, J., 1989, The relationship between business and higher education: a perspective on the 21st century. *Communications of the ACM*, **32**, 1056–1061.

Seifert, K., Liu, J., Hurtienne, J., Baumgarten, T. and Pastoor, S., 2001, Development of an evaluation concept for a multimodal computer system. In *8th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design and Evaluation of Human–Machine Systems*, G. Johannsen (Ed.), pp. 41–45 (Duesseldorf: VDI/VDE-GMA).

Selker, T., Burlson, W. and Arroyo, E., 2002, E-windshield: a study of using. Available online at: http://cac.media.mit.edu:8080/contextweb/CHIwindshield.PDF (27August 2002).

Sheridan, T.B., 1988a, Trustworthiness of command and control systems. In *Man–Machine Systems: Analysis, Design and Evaluation, preprints of the IFAC/IFIP/IEA/IFORS Conference*, 14–16 June 1988, Oulu, Finland, pp. 151–155.

Sheridan, T.B.,1988b, Task allocation and supervisory control. In *Handbook of Human–Computer Interaction*, M. Helander (Ed.), pp. 159–173 (Amsterdam: North-Holland: Elsevier Science Publishers).

Sheridan, T.B., 1992, *Telerobotics, Automation and Human Supervisory Control* (Cambridge, MA: MIT Press).

Sheridan, T.B., 1997, Supervisory control. In *Handbook of Human Factors*. 2nd edition, G. Salvendy (Ed.), pp. 1295–137 (New York: John Wiley & Sons).

Sheridan, T.B., 1998, Task analysis, task allocation and supervisory control. In *Handbook of Human–Computer Interaction*, 2nd edition, M. Helander, T.K. Landauer and V.B. Prabhu (Eds.), pp. 159–173 (Amsterdam: North-Holland Elsevier Science Publishers).

Sheridan, T.B., 2000, Function allocation: algorithm, alchemy or apostasy? *International Journal of Human–Computer Studies*, **52**, 203–216.

Shneiderman, B., 1992, *Designing the User Interface. Strategies for Effective Human–Computer Interaction*. 2nd edition (Reading MA: Addison-Wesley).

Sproull, L., Subramani, M., Kiesler, S., Walker, J. H. and Waters, K., 1996, When the interface is a face. *Human–Computer Interaction*, **11**, 97–124.

Streitz, N.A., Tandler, P., Mueller-Tomfelde, C. and Konomi, S., 2001, Roomware: towards the next generation of human–computer interaction based on an integrated design of real and virtual worlds. In *Human–Computer Interaction in the New Millennium*, J. Carroll (Ed.), pp. 553–578 (New York: Addison-Wesley).

Sundblad, O. and Sundblad, Y., 1998, OLGA—a multimodal interactive information assistant, In *Proceedings of ACM CHI 98 Conference on Human Factors in Computing Systems* (*Summary*), pp. 183–184.

Thimleby, H. and Addison, M., 1996, Intelligent adaptive assistance and its automatic generation. *Interacting with Computers*, **8**, 51–68.

TIMPE, K.P., 1998, Unterstuetzungssysteme als interdisziplinaere herausforderung–einfuehrung in die tagung "wohin fuehren unterstuetzungsysteme? *Wohin fuehren Unterstuetzungssysteme? Entscheidungshilfe und Assistenz in Mensch–Maschine–Systemen 2. Berliner Werkstatt Mensch–Maschine–Systeme*, H.-P. Willumeit and H. Kolrep (Eds.), 7–9 October *ZMMS Spektrum Band 5*, 1997 (Sinzheim: Pro Universitate Verlag), pp. 1–20.

TIMPE, K.P. and KOLREP, H., 2000, Das mensch–maschine–system als interdisziplinaerer gegenstand. In *Mensch Maschine Systemtechnik—Konzepte, Modellierung, Gestaltung, Evaluation*, K.-P. Timpe, T. Juergensohn and H. Kolrep (Eds.), pp. 9–40 (Duesseldorf: Symposion Publishing GmbH).

TRAENKLER, H.-R. and SCHNEIDER, F., 2000, *Das Intelligente Haus. Arbeiten und Wohnen mit Zukunftsweisender Technik* (Muenchen: Pflaum).

VAN MULKEN, S., ANDRÉ, E. and MUELLER, J., 1998, The persona effect: how substantial is it? In *People and Computers XXII: Proceedings of HCI'98*, H. Johnson, L. Nigay and C. Roast (Eds.), pp. 53–66 (Berlin: Springer).

VAN MULKEN, S., ANDRÉ, E. and MUELLER, J., 1999, An empirical study on the trustworthiness of life-like interface agents. In *Proceedings of the Eighth International Conference on Human–Computer Interaction* Vol. 2, H.-J. Bullinger and J. Ziegler (Eds.), pp. 152–156 (Mahwah NJ: Lawrence Erlbaum Associates).

WANDKE, H., 1988, Online-hilfen in der mensch-rechner-interaktion: von ausfuehrlichen erklaerungen zu kurzen stichworten oder umgekehrt? *Zeitschrift fuer Psychologie*, **196,** 147–159.

WANDKE, H., OED, R., METZKER, E., VAN BALLEGOOY, and NITSCHKE, J., 2001, Die entwicklung von user interfaces als arbeitswissenschaftlicher prozess und seine unterstuetzung durch software-werkzeuge. *Zeitschrift fuer Arbeitswissenschaft*, **55**, 1–14.

WEI, Z.G., MACWAN, A.P. and WIERINGA, P.A., 1998, A quantitative measure for degree of automation and its relation to system performance and mental load. *Human Factors*, **40**, 277–295.

WEISER, M., 1994, The world is not a desktop. *Interactions*, **1**, 7–8.

WICKENS, C.D., 1992, *Engineering Psychology and Human Performance* (New York: Harper Collins Publishers).

WICKENS, C.D., MAVOR, A.S. and MACGEE, J.P., 1997, *Flight to the future. Human Factors in Air Traffic Control* (Washington, D.C.: National Academy Press).

WITTIG, T. and ONKEN, R., 1993, Inferring pilot intent and error as a basis for electronic crew assistance. In *Proceedings of the Fifth International Conference on Human-Computer Interaction*, pp. 386–391.

ZUEHLKE, D., 2000, *Human–Machine–Interaction in the Year 2010*, ZMMI, Video, VHS-PAL. (Department of Mechanical Engineering and Process Engineering: University of Kaiserslautern).

About the author

Hartmut Wandke is Professor of Cognitive Ergonomics and Engineering Psychology at the Department of Psychology at Humboldt University Berlin. His research interests are orientation and navigation in networked systems, website usability, user interfaces for information appliances, knowledge management, assistance systems and software tools for analysis, design and evaluation of human–machine interaction.