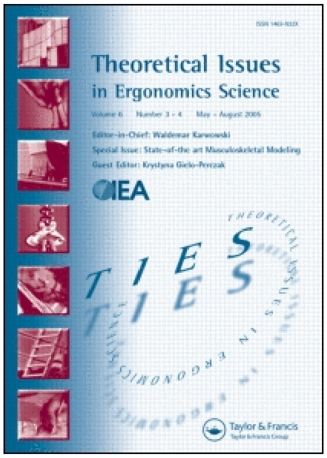

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Attention grounding: a new approach to in-vehicle information system implementation

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Driven by an expected $15–100 billion market, the race to produce in-vehicle information system (IVIS) functions has begun. Although IVIS functions may increase productivity, satisfaction and safety, they may also undermine safety and annoy drivers. Developing IVIS design strategies that minimize driver distraction is a critical challenge in developing successful IVIS functions. Several approaches have been developed to address this challenge. Interference mitigation has been the historical approach to IVIS research. More recently, workload management has emerged as an approach that may mitigate distraction by monitoring and managing the varying demands of driving and IVIS interaction. This paper presents attention grounding as a novel approach that complements previous efforts. Attention grounding uses the concepts of collaborative communication, grounding and dynamical systems theory to address the shortcomings of current approaches. IVIS interaction is considered a collaborative process that is supported with back-channel cues, rather than a series of discrete commands with no consideration of inevitable errors. Back-channel communication augments these commands to develop a shared awareness of the driver, roadway and IVIS state. Attention grounding considers the driver as an active participant in choosing when and how to use the IVIS, rather than assuming the driver's workload must be managed. This conceptualization highlights the role of dynamic changes in attention, such as attentional withdrawal and cognitive tunnelling as causes of distraction, rather than considering only mental overload. Together, these considerations provide a complementary approach to how IVIS might be designed to enhance ease of use and safety.

Keywords: Driver distraction; Ubiquitous computing; Driver support systems

1. Introduction

Just as computers have transformed the office in the last 20 years, they will likely transform the car in the next decade. Recent advances in sensor, wireless, Global Position System and computing technology make in-vehicle information systems (IVIS) feasible. This, combined with societal trends for increased productivity and diffusion of work beyond the traditional office environment, make these systems likely. Computer, software, telecommunications and automotive companies have begun to develop IVIS functions in anticipation of a $15–100 billion IVIS market (Ashley 2001). A provocative estimate of the growth of IVIS devices compares them

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to personal computers. The number of personal computers per 1000 people expanded from six to 200 from 1980 to 1990. A similar trend may occur in the next 10 years, with IVIS-equipped vehicles growing from four per 1000 to 195–200 by 2010 (Juliussen and Magney 2001). Unlike the desktop domain, IVIS functions require timesharing with the safety critical task of driving. As a consequence, IVIS development must consider how these timesharing demands affect driving safety. When implemented appropriately, these technological advances can improve productivity, satisfaction and safety; however, if implemented poorly, these functions will be annoying at best and fatally distracting at worst.

IVIS includes a broad array of potential functions, some of which can compete for drivers' attention to the roadway and others direct drivers' attention to roadway hazards. Specific capabilities include MP3 music catalogues, email, navigation aids, road condition alerts and collision warnings (Lee and Kantowitz 2005). Many of these IVIS functions, such as navigation aids, require complex interactions that might distract drivers (Green 2004). Even without the widespread implementation of potentially distracting IVIS functions, approximately six million traffic accidents cause roughly 42 000 deaths and $150 billion in costs each year (Evans 2004). Between 13 and 50% of crashes are attributed to driver distraction and inattention, resulting in estimates of as many as 10 000 lives lost and as much as $40 billion in damages each year (Sussman *et al.* 1985, Wang *et al.* 1996, Stutts *et al.* 2001). IVIS functions associated with collision avoidance and vehicle control may mitigate distraction. Properly implemented, such systems promise to reduce collisions by directing drivers' attention to roadway hazards. However, drivers may not respond appropriately to such warnings and could be confused if multiple warnings (e.g. side object and curve speed) occur at the same time. Accommodating drivers' attentional limits may be the biggest challenge in IVIS development.

Many IVIS functions are currently available and automotive manufacturers, the computer industry and governments are supporting major research activities to implement additional IVIS functions. However, current research approaches may neglect important research and design issues. This article considers theoretical issues associated with the design of safe and effective IVIS functions by first providing an overview of current approaches to IVIS design. Second, it describes a novel theoretical framework that applies communication theory and dynamical systems theory to the problem of coordinating driver, IVIS and roadway interactions.

2. Current research approaches

Many IVIS functions have the potential to engage drivers in complex interactions. Real-time communication, interactive entertainment, coordination and planning functions are all likely to involve extended dialogues and complex information processing. The particular interaction depends on the implementation, but many involve a dialogue that compels continuous interaction, interpretation of complex messages or complex selections (Monk *et al.* 2000). In addition, as the number of IVIS functions increase, drivers may face the challenge of navigating complex menus to locate desired functionality. Whether implemented with visual displays that require manual responses or with speech-based interfaces that allow the driver's eyes to remain on the road, these systems may introduce substantial potential for distraction.

Substantial research has begun to address the challenge of developing IVIS functions that accommodate drivers' attentional limits. This research can be described in terms of different paradigms or approaches. Each approach addresses certain issues and neglects others. Interference mitigation is the most basic approach to address issues in driver distraction. It focuses on reducing distraction by using human performance guidelines and principles to minimize the demands associated with IVIS interaction and to set predefined limits on how and when the driver can interact with IVIS functions (Campbell *et al.* 1998, 1999). More recently, the workload management approach has begun to address the limits of the interference mitigation approach. Workload management actively manages driver workload by adjusting system functionality based on the current roadway and IVIS demands facing the driver (Michon 1993, Hoedemaeker *et al.* 2002, Green 2004). Describing the broad array of IVIS research in terms of interference mitigation and workload management certainly oversimplifies the situation, but it provides a useful summary of many important research issues confronting IVIS development.

2.1. *Interference mitigation*

Interference mitigation focuses on minimizing the interference between individual IVIS functions and driving. This approach recognizes the difference between human–computer interface design for desk-top applications and human–computer interface design for applications that may be used while driving. The response to these differences is to mitigate the potential interference IVIS applications may pose to driving by using four design strategies. The first strategy is to format information to minimize glance frequency and duration as well as the time that hands are off the steering wheel. Second, in situations in which this will not work, designers limit access to distracting functions to situations where the car is stopped or parked (Dingus and Hulse 1993). A third strategy is to use a speech interface to mitigate the distraction associated with complex interactions. However, speech interfaces are not a panacea and little research has investigated how best to implement speech interfaces for complex IVIS functions. A fourth strategy is to mitigate the effects of distraction with collision-warning systems. Although collision-warning systems have been shown to enhance the safety of distracted drivers (Dingus *et al.* 1997, Kiefer *et al.* 1999, Lee *et al.* 2002), these systems generate many false warnings and so have the potential to annoy drivers. Substantial research has explored each of these strategies and a number of design guidelines have been developed.

Many IVIS-specific guidelines have been developed to minimize the interference between the demands of the IVIS and driving (Campbell *et al.* 1998). These guidelines specify minimum character size to mitigate the effect of reading text messages on driving performance. Efforts have also been made to explicitly consider the particular requirements of IVIS interface design compared to desktop applications (Landau *et al.* 1998). The National Highway and Traffic Safety Administration research programme on collision-warning systems has also made important contributions by demonstrating a substantial safety benefit and identifying how interface and algorithm alternatives can enhance this safety benefit (Dingus *et al.* 1997, Lee *et al.* 2002). An important objective of these warning systems is to mitigate the effect of IVIS interference by alerting drivers to imminent collision situations that might otherwise go unnoticed.

The approach to IVIS design that focuses on interference mitigation has three important limits. First, the interference mitigation approach considers each IVIS function individually and does not consider their integration or their combined effect on the driver. For example, guidelines for a side object collision warning do not consider how this function might interact with a forward object collision warning. Similarly, the research addressing route guidance, communication and planning functions does not consider how these functions might interact with each other or with collision-warning functions. Second, this approach tends not to consider the cognitive demands associated with IVIS interactions to identify how human–computer interaction guidelines must be changed to apply to IVIS design. IVIS interference with driving is minimized by interface design that minimizes the glances away from the road and limits the availability of certain functions. Distraction is often defined by the number and frequency of glances away from the road or by the duration of the interaction. Accordingly, a speech interface is often viewed as the solution to this type of visual and manual distraction. Initial experiments show that even pure speech interaction can degrade driver performance (Lee *et al.* 2001, Recarte and Nunes 2000) and even increase distraction if the quality of the speech is poor (Matthews *et al.* 2003). The cognitive distraction resulting from the mental demands of interacting with the speech interface are sometimes neglected. These cognitive demands undermine drivers' perception and response to the driving environment (McCarley *et al.* 2001, Strayer *et al.* 2003). Third, driving is considered as a uniform demand and the effect of the changing driving context is not considered. For example, a trip-planning task might be considered so complex that it would be available only when the vehicle is parked, regardless of the demands of the current driving context (Campbell *et al.* 1998). The interference mitigation approach makes no distinction between driving on an empty motorway and negotiating a complex and crowded interchange. This might result in drivers using functions in high-demand situations that exceed the nominal driving demands considered by designers. The failure to consider integration of IVIS functions, the limited consideration of IVIS demands and the failure to consider the dynamically changing driving demands could undermine the safety and acceptance of IVIS.

Overall, the interference mitigation approach focuses on creating IVIS functions that are less demanding and easier to use. Paradoxically, the easier functions are to use, the more frequently people might use them and the more the overall safety might suffer. Each interaction poses less risk, but the number of interactions might increase, leading to greater overall risk. This usability paradox is an important challenge that current approaches do not address. The real challenge then becomes how to create IVIS functions that are safer and easier to use, without inducing a greater number of risky interactions, so that IVIS enhance overall roadway safety. The workload management approach begins to address this challenge.

2.2. *Workload management*

The workload management concept has become a very popular approach, represented by Motorola's Driver Advocate^{TM}, Delphi's Workload Manager^{TM} and Toyota's Copilot^{TM} (Wheatley and Hurwitz 2001). This approach assumes that a computer and suite of sensors can monitor the roadway, driver and IVIS to assess driver workload. Based on the estimated workload, the workload manager prioritizes and routes IVIS information to the driver at appropriate times to avoid dangerously high workload and dynamically limits access to IVIS functions according to the state of the driver and roadway. For example, a workload manager might route an incoming phone call to voice mail if the driver is approaching a demanding intersection. Workload management considers how best to integrate functions for communication between the driver and the IVIS functions, allowing the IVIS functions to share information and modulate the information presented to the driver. For example, in a collision situation, the collision-avoidance system might communicate with the email system regarding the severity of the situation, allowing the email system to prohibit the driver from receiving any new messages until the collision situation has passed. This approach might also dynamically adjust the IVIS interface according to the demands facing the driver, presenting a less complex interface when the driving demands are great. A workload manager can also dynamically lock out functionality when the driver and roadway state suggests that the driver is becoming overloaded. The workload management approach represents a promising alternative to the static, guideline-based design of the interference mitigation approach.

The workload management approach has three important limits. First, it considers the driver as a passive recipient of workload rather than as an active force in determining workload. Because of this perspective, the locus of control tends to be with the IVIS. As a result, this approach may fail to capitalize on people's ability to modulate their workload by strategically shedding low-priority tasks (Adams *et al.* 1991, Raby and Wickens 1994). Failing to support drivers' capacity to manage their own may provoke frustration and even confuse and distract. Second, this approach tends to define driver distraction solely in terms of mental overload and so the workload management concept may fail to address situations in which drivers distribute their attention poorly, as in situations that result in cognitive tunnelling, which can emerge in seemingly benign situations with moderate levels of workload. Most IVIS-related crashes occur on dry roads and sunny days (Green 2004). Third, and most importantly, the workload management approach relies on accurate state estimates. Both the driver and the roadway state are highly dynamic and imprecisely estimated. Only a subset of what makes driving demanding will be sensed by a workload manager. Failing to support drivers in managing their workload, considering the distraction as only overload, and depending on imprecise state estimates limits the potential of the workload manager approach.

2.3. *Summary of current approaches*

Two major themes characterize the limits of the interference mitigation and workload manager approaches. First, both approaches rely on the information-processing metaphor for describing distraction (Broadbent 1958, Neisser 1967, Wickens 1992). According to this metaphor, performance depends on the efficiency of information processing as governed by the capacity limits of discrete stages, including perception, cognition and response selection, and execution. Capacity limits and the potential for information overload certainly represent important issues in IVIS design, but so do the factors that influence drivers' willingness to engage in IVIS interactions, the tendency for attentional withdrawal and cognitive tunnelling.

These factors are not addressed by the interference or workload management approaches. An alternative approach that considers the time-dependent evolution of the driver's state may provide a useful complement to the more static representation of information-processing capacity. The dynamic process by which drivers direct their attention represents a critical issue not addressed by the relatively passive and static description of capacity limits.

A second general limit of the interference mitigation and workload manager approaches concerns the dynamic coordination of the IVIS, driver and the roadway. Because these interactions occur in the context of imperfect IVIS technology and unanticipated situations, the drivers' ability to respond to the unanticipated must be supported. Similar to the philosophy developed for other complex socio-technical systems (Vicente 1999), it may be more effective not to manage the workload of the driver but to support coordination of interactions between driver, IVIS and roadway. This coordination depends on shared understanding of driving context as defined by driver, roadway and IVIS constraints. Specifically, many view speech interfaces as a solution to driver distraction, but speech interaction is imperfect and few have investigated the consequences of error recovery on driver performance. In addition, as speed control and collision warnings become more sophisticated, but remain imperfect, it is not clear how to guide drivers to avoid inappropriate reliance. Finally, a fundamental concern with collision-warning systems is that the rate of false alarms will undermine driver acceptance. The interference mitigation and workload manager approaches have not addressed these issues.

3. Attention grounding: a theoretical framework for in-vehicle information system development

The proposed theoretical framework draws upon research considering communication between people to identify how to enhance 'communication' between the driver, the IVIS and the roadway. In particular, the framework draws upon the concepts of collaborative communication developed by Clark and others (Clark and Wilkes-Gibbs 1986, Clark and Schaeffer 1989, Clark and Brennan 1991), as well as system dynamics described by Flach, Jagacinski, Thelen, van Gelder and others (Thelen and Smith 1994, van Gelder and Port 1995, Thelen *et al.* 2001, Flach and Jagacinski 2002). The need for drivers to dynamically direct their attention, based on an evolving context, distinguishes this approach. The underlying ideas of this approach are not entirely new to the domain of cognitive engineering (Brennan 1998, Patterson *et al.* 1999), but they have not been applied to driving. This alternative to minimizing interference and workload management might be termed 'attention grounding'.

Speech theory provides a theoretical basis for the attention-grounding approach. Searle (1976) asserts that there are a limited number of basic functions of language, often occurring at the same time and in the same utterance. Such functions include telling people how things are, getting them to do things, committing themselves to doing things and expressing their feelings and attitudes. The focus of Searle (1976), Goffman (1976) and others on direct communication associated with these functions has been generally accepted in the socio-linguistic community. Recently, however, speech theory has considered conversation as a collaborative process supported by back-channel communication (Goodwin 1986, Clark and Wilkes-Gibbs 1990,

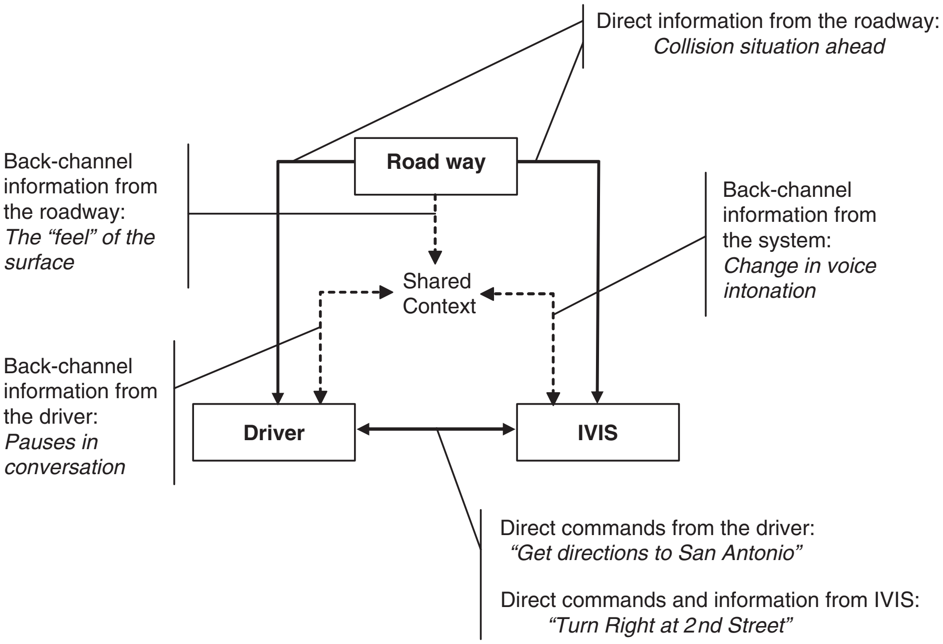

Figure 1. Direct and back-channel communication in driver, in-vehicle information systems (IVIS) and roadway communication.

Cohen and Levesque 1994). Back-channel responses (Schegloff 1982, Clark and Wilkes-Gibbs 1990) refer to the hearer's use of peripheral utterances, such as 'uh-huh' or 'yeah', that do not directly support the functions defined by Searle, but provide feedback that the utterance is being understood and coordinate turn-taking (Clark and Brennan 1991). Back-channel utterances represent a large proportion of conversations—19% by one estimate (Jurafsky *et al.* 1997). Although many speech theorists focus on back-channel communication as speech acts (e.g. uh-huh or hmm), back-channel communication can also take the form of pauses, intonation, gestures and facial expressions.

Back-channel responses support grounding. Grounding is the development of a shared context that supports direct communication. Either as back-channel cues or as clarifying statements, a large proportion of conversations—80% of utterances—support grounding (Traum and Heeman 1996). Without back-channel communication, and the grounding that it supports, the goals of communication are unlikely to be met and direct communication will likely fail. Just as communication between people would fail without grounding, the focus only on direct communication that guides the interference mitigation and workload management approaches might compromise IVIS success.

A critical element of the attention-grounding perspective is the distinction between back-channel and direct communication as shown in figure 1. Currently, IVIS researchers focus on direct communication between the driver, the IVIS and the roadway. The solid lines indicate direct communication in figure 1. As one example, direct communication from the driver to the IVIS depends on the ability of the speech recognition system to understand discrete commands from the driver.

Direct communication from the IVIS to the driver considers the ability of the driver to understand the verbal or visual display of IVIS information. In communicating with the roadway, direct communication involves the ability of the IVIS to detect potential collision situations accurately and for the driver to make appropriate control actions to maintain vehicle control. Facilitating direct communication is essential, but it may not be sufficient to minimize driver distraction and enable productive use of IVIS functions.

Generalizing back-channel communication to describe driver interaction with the roadway and IVIS, back-channel communication can be defined as information sources that complement the formal and direct means of communication and are not the focus of driver attention. Figure 1 shows these back-channel cues as dotted lines. As with conversation, back-channel cues support drivers' understanding of the driving context and help coordinate the timing of interactions. Back-channel communication is already a critical component in driving. For example, drivers respond to the slippery feel of tyres on an icy road to moderate their driving behaviour—not only the information provided by weather reports or even focused observation of the roadway. For those who drive manual cars, the sound and vibration of the motor are essential in knowing when to shift up or down and not necessarily the position of the tachometer, even though few people focus their attention on these cues. Drivers would lose a critical component of how they sense and perceive the driving environment if they did not have such back-channel cues.

Applying the concept of back-channel communication to human–technology interaction is similar to that of peripheral cues described by Weiser and Brown (1996). Peripheral cues provide a context for interpreting the information that is the focus of attention. Adding peripheral cues can have the counter-intuitive effect of reducing information overload. This definition of back-channel cues is also quite consistent with the role of affordances (Gibson 1979, Norman 1988), which help people recognize objects and how they can be used (Brennan 1998). Although the ideas of back-channel communication were initially developed to describe communication between people, the concepts seem relevant to any situation that demands dynamic coordination between multiple entities (Brennan 1998).

Back-channel communication helps support a shared context that makes direct communication more efficient. Human communication is robust because it includes both direct and back-channel communication (Clark and Schaeffer 1987, Clark and Brennan 1991, Cohen and Levesque 1994). In driving, the shared context is the information that the driver and the IVIS share regarding the current state and history of the driver, the IVIS and roadway environment. The shared context is built on back-channel cues, which are cues that do not communicate a specific message but provide information that guides the direct exchange of information. During driver communication to the IVIS, back-channel communication might include pauses and variability in speech that could indicate high demands of the driving environment. Regarding communication from the IVIS to the driver, back-channel communication includes the certainty of the IVIS speech interpretation. The IVIS could signal uncertainty to the driver with changing voice intonation. For communication with the roadway, back-channel communication might convey the changing roadway situation that might evolve into collision situations. According to the framework described in figure 1, driver distraction and frustration emerge not only from failures of direct communication but also through failures of back-channel

	Types of communication	Links between functions	Distraction counter measure
Interference mitigation	Direct communication	No integration or physical integration only	Static interference minimization
Workload management	Direct communication	Functional integration with direct communication	IVIS-centred workload management
Attention grounding	Collaborative grounding	Functional integration with back-channel communication	Driver-centred attention distribution

Figure 2. Overview of three approaches (interference mitigation, workload management and attention grounding) to in-vehicle information systems (IVIS) implementation.

communication that undermine a shared context. IVIS design may need to consider both direct and back-channel communication to be safe and easy to use.

Figure 2 provides an overview of the attention-grounding approach along with a summary of the fundamental differences between it and current research approaches. The interference mitigation and workload management approaches to IVIS design address critical issues as designers move from developing desktop applications to creating in-vehicle applications. However, both of these approaches neglect critical issues that merit consideration. Attention grounding goes beyond workload management by integrating the functions through not only direct communication but also through back-channel communication. Back-channel communication supports a shared context between the IVIS functions and the driver, making interactions with the computer more like interacting with a vigilant passenger. The attention-grounding approach also includes a fundamental shift in the description of distraction and how it might be mitigated. Instead of IVIS-centred workload management, attention grounding employs a dynamic systems approach that focuses on how distraction arises when drivers' dynamic distribution of attention breaks down. Figure 2 shows three unique elements of attention grounding that provide important contributions to IVIS design.

The attention-grounding approach uses a shared context to support robust interactions with imperfect technology, provides back-channel cues to help drivers manage their attention to roadway and IVIS demands and addresses the dynamics underlying the misallocation of attention. The following sections describe how this framework might:

- address the limits of imperfect speech communication by supporting a shared context by using back-channel cues to help drivers understand when errors are likely to occur
- support IVIS integration using back-channel responses to support appropriate coordination of IVIS and roadway interactions

- provide a more complete account of driver distraction that considers how to address distraction that occurs without overload, such as cognitive tunnelling and attentional withdrawal.

3.1. *Enhanced interaction with imperfect speech-based communication with in-vehicle information systems*

Back-channel communication provides a useful way to enhance the interaction between people and IVIS functions—particularly imperfect IVIS functions. Specifically, the concepts of collaborative communication, grounding and back-channel information are particularly important as voice recognition technology (VRT) becomes more prevalent. The technical proficiency of VRT has improved dramatically in the last decade. Databases of phonemes spoken by people of different ages, genders, linguistic cultures and voice quality support increasing precise recognition. Better interpretation is possible because databases contain a greater vocabulary than ever before, allowing the computer to understand many different ways of saying the same thing. Even the logic behind implementation has improved, now allowing users to 'barge in' or interrupt the computer in mid-sentence. This technology has been implemented extensively in customer service phone applications, such as airline reservation applications, allowing customers to navigate reasonably well through complex menu structures. The particular demands of VRT for IVIS make it necessary for the computer to become a joint member in the conversation through recognizing and producing with back-channel cues (Brennan and Hulteen 1995, Brennan 1998). Although computationally intensive, it is technologically possible. For example, it is possible to estimate recognition certainty in systems using VRT (Hazen *et al.* 2002) and this information could be conveyed with back-channel cues. Such an approach was used to facilitate voice interaction with robotic pets, in which back-channel information, prosodic cues, were used to facilitate mutual adaptation (Komatsu *et al.* 2005). A similar approach might be used to provide the driver with back-channel cues regarding the likelihood that the IVIS understood a particular command.

In a conversation, participants collaborate to ensure that what has been said has been heard and understood by all before the conversation continues (Clark and Schaeffer 1987). Collaboration consists of two phases, the presentation phase and the acceptance phase. In face-to-face conversations, the acceptance phase can occur in three different ways (Clark and Schaeffer 1987):

(1) The partner presupposes the acceptance of the contributor's presentation by going on to the next contribution.
(2) The partner asserts acceptance of the contributor's presentation, allowing the contributor to retake the floor.
(3) The partner requests the contributor's help in dealing with a possible mishearing or misunderstanding of the contributor's presentation.

Once the presentation has been accepted, the conversation continues. Collaboration with a computer using VRT can be more complex. The presentation phase alone can encounter difficulties, depending on how much the computer will understand and how the computer will try to relay information back to the user. The acceptance phase can also pose problems. Back-channel responses allow face-to-face conversations to receive positive grounding feedback without disrupting the flow of conversation. Computers, on the other hand, are currently unable to present such back-channel responses, leaving the user only two other options of acceptance, assume that everything was understood or request clarification from the computer. Problems arise when the computer understands the drivers' syntactically correct commands, but the meaning is lost and the grounding criterion is not met. At this point, the user must identify the communication breakdown and then repair the dialogue, often with substantial time and effort.

In general, contributors to a conversation follow the principle of least collaborative effort when establishing a grounding criterion. The speaker and addressees try to minimize the effort in establishing common ground needed for communication. Finding common ground in a conversation is essential to communication. Doing so efficiently, with the least amount of effort, is not always accomplished due to reasons of time pressure, construct complexity and ignorance (Clark and Wilkes-Gibbs 1990). Collaborating with computers adds complexity because the user is often unsure if the collaborative effort is mutual. Most frequently, it is not mutual and the responsibility lies with the user to determine if the conversation content is being understood (Brennan 1998). Although grounding may require computers with more processing power than those available today, conversations with future IVIS devices could be structured to greatly reduce the driver's effort and help the driver remain grounded in the driving context.

Grounding techniques change according to the purpose and the medium of the communication (Clark and Brennan 1991). If the information is of great consequence, people often use verbatim displays, such as offering the information in chunks and directly spelling the information in grounding the utterance. On the other hand, conversations of little importance are often grounded referentially by offering alternative descriptions and by gesturing without paying much attention to whether the details are truly understood. Differences in medium, such as face-to-face, telephone, email, video teleconferencing, text messaging and electronic chat rooms influence the viability of various grounding techniques (Clark and Brennan 1991, Brennan 1998). Of course, all of these types of communication assume that a human will eventually be the recipient of the communication. Changing the recipient to a computer adds another layer of complexity. Table 1 shows the design criteria necessary for designing IVIS functions using the principles of collaborative grounding and how back-channel cues can assist in establishing the grounding criterion during driver–IVIS interactions. Lack of consideration for these criteria could undermine user acceptance of IVIS and exacerbate safety issues associated with driver distraction.

3.2. *Integration of in-vehicle information system function using back-channel information*

Figure 2 shows that the types of links between functions are different for each of the three approaches to IVIS design. The most common approach to integration is a relatively simple physical integration by locating different IVIS functions in one single location or interface (Lee and Kantowitz 2005). This might involve an interface with a complex menu structure that incorporates many different IVIS functions into one centralized control area. The BMW iDrive is a clear example of

Table 1. In-vehicle information systems (IVIS) design criteria for collaborative grounding.

Design criteria	Implications of back-channel cues
Simple start-up sequences Time and effort involved in beginning a new interaction with either the driver or computer should be minimized.	Back-channel responses from the driver, such as length and duration of interaction pauses, can be used to determine the driver's attention state and the method of interaction IVIS should employ. IVIS can use back-channel cues to gently alert the driver to non-critical tasks such as new email and a new phone call.
Communication pauses To support the driver in effectively allocating attention to the roadway, the IVIS should allow the user to pause during an interaction without losing the computer's attention.	When events in the driving environment cause the driver to pause interaction with the IVIS, it should provide a mechanism for reminding the user of his or her place in the interaction. Back-channel cues can be used to provide the driver with information about the context of the IVIS interaction when it is appropriate to do so.
Attention coordination The shared context should be used not only to assist drivers in completing IVIS tasks, but also to appropriately divide their attention between the roadway and IVIS.	Using the shared context to determine where the driver's attention currently is, back-channel cues can be used as pre-attentive cues to direct a driver's attention to a different locus of attention, such as the roadway.

Information coordination IVIS should be able to coordinate information from the environment, including the history of IVIS interactions, to better develop a shared context that lends itself to establishing the grounding criterion.	Because computers cannot 'see' what the user sees, the user must expend more effort formulating their utterance to determine the most descriptive words or phrases needed to complete the task. Using the shared context provided by the roadway environment and the interaction history, IVIS will be better able to understand the driver's goal and assist the driver in completing the task. Back-channel cues can be a vital part of the shared context, adding relevancy to information gleaned from direct communication.
Degree of uncertainty The degree to which the computer' feels it has understood what was said should be conveyed to the user.	Back channel cues such as the change in intonation can reflect the computer's level of uncertainty about the discourse. This can alert the driver to potential mistakes that the computer might make, facilitating an easier transition to error recovery. These cues can also encourage the driver to modify how commands are given in order to avoid potential errors. Communicating uncertainty can also guide more appropriate reliance on collision-warning information and vehicle control systems.
Error recovery Users must be able to initiate self-repairs when speaking to the computer. Waiting for the computer to not understand (in the case of a grammatical error) or continue with the interaction (in the case of a mis-saying) can cause frustration and wastes time and effort.	Back-channel cues from the computer can make it immediately evident that it has not understood what was said. The driver can then initiate a self-repair and correct the error, eliminating cumbersome 'I do not understand . . .' sequences, or worse, an unrecognized error resulting in the failure of task completion. Similarly, the computer should be able to recognize back-channel cues from the driver indicating that the last utterance was not understood or heard.

physical integration, where 700 functions are channelled through a single controller and display. Despite the common interface, there is limited sharing of information between the different systems that are operated by this one controller. IVIS systems that are designed using the interference mitigation approach typically employ a physical integration of the different IVIS functions. Physical integration can appear to simplify the IVIS but can undermine driver safety by requiring frequent eye glances away from the road to confirm selections. For this reason, the design strategy of interference mitigation may not be effective.

As described by Lee and Kantowitz (2005), functional integration considers the information required by each function and the information produced by each function to support communication between the driver, the IVIS and the roadway. The identification of information flows between inputs and outputs can either be accomplished by the designers of the system or discovered by the users. Discovering links between systems that are unsupported by the technology requires the drivers to 'finish the design' themselves, which can place high demands on the driver. They must take action to provide the links between IVIS functions in order to ensure that these systems function properly. This action does not come without consequences. Drivers who must complete these information links themselves may experience increased cognitive load, distraction from the roadway, frustration and dissatisfaction with the system (Lee and Kantowitz 2005). Functional integration reduces distraction by limiting unnecessary data entry, minimizing temporal conflict of alerts and helping drivers defer IVIS interactions when driving demands are high. Functional integration is also critical because it identifies information that should be shared through back-channel cues. The workload management and attention-grounding approaches to IVIS design consider functional integration to minimize distraction.

Functional integration of IVIS functions supports direct communication by linking the driver, roadway and IVIS. Consider the functional integration of a forward collision-avoidance system and mobile phone. Information about the environment is obtained by the collision-avoidance system and can be used to influence the operation of the mobile phone. Information regarding the mobile phone can be used to influence the warning system. Specifically, integration of a forward collision-warning system and a mobile phone makes it possible to dynamically adjust the warning threshold, such that distracted drivers who are talking on a mobile phone would receive a warning earlier than attentive drivers. Likewise, the collision-warning system could also provide information about the evolving traffic situation to inhibit the receipt of new calls. As the traffic situation becomes more demanding, the workload manager could even hang up the phone. The direct communication that arises from functional integration is a key component of workload management.

The attention grounding builds on the idea of functional integration with the use of back-channel cues and grounding. Two important problems plague the example above. First, the sensors and algorithms for collision-warning systems are imperfect and tend to generate many false alarms (Parasuraman *et al.* 1997). Second, abrupt interventions of the workload manager, such as ending a mobile phone call are likely to annoy drivers. The attention-grounding approach can address these issues. First, the attention-grounding approach provides drivers with graded cues that indicate how the evolving context, such as the degree of threat posed by a traffic situation, affects the likelihood of receiving a collision warning. Such information could be displayed with back-channel cues that could inform the driver without becoming the focus of the driver's attention. This concept is similar to the likelihood alarm concept (Sorkin *et al.* 1988). Second, information regarding the evolving collision situation could be used to adjust the intonation and pacing of the IVIS voice to subtly guide the driver's attention to the road. Such subtle cues may be substantially less annoying than the more direct approach of a workload manager. Although the workload management approach supports functional integration, it supports integration only through direct communication. The shared context created by back-channel communication can extend the benefits of functional integration, particularly when IVIS technology is not completely reliable.

3.3. *Description of distraction*

Each of the three approaches assesses and responds to the potential of IVIS functions to distract drivers and undermine driving safety. With interference mitigation, distraction assessment focuses on identifying functions that might physically distract drivers by causing them to look away from the road or take their hands off the steering wheel. This has been termed structural distraction and guidelines have been developed that minimize the number and duration of glances required. VRT has been touted as an effective means to mitigate this interference. While it might be successful in mitigating structural distraction, the implementation of VRT requires the additional consideration of cognitive distraction associated with the mental operations of generating and interpreting speech communication.

Most researchers currently address cognitive distraction as mental workload that is governed by a single, limited resource. According to this approach, distraction occurs when the joint demands of driving and using the IVIS exceed the driver's limited attentional resources (see figure 3). The driver's attention to the IVIS is indicated by the dotted bar and to the roadway is indicated by the shaded bar. Distraction would occur if the total height of this bar were to exceed the line labelled 'Attentional Resource Capacity'. A more sophisticated approach uses the multiple-resource theory (Wickens 1992). Three dimensions define the attentional resources: stages (early vs. late processes); modalities (auditory vs. visual encoding); and processing codes (spatial vs. verbal). According to this approach, distraction occurs when driving and using the IVIS exceeds any one of the resources. Avoiding competition for the same resource can minimize distraction. For example, driving demands associated with monitoring lane position (visual perception, spatial encoding and manual control) would be less likely to exceed the driver's capacity

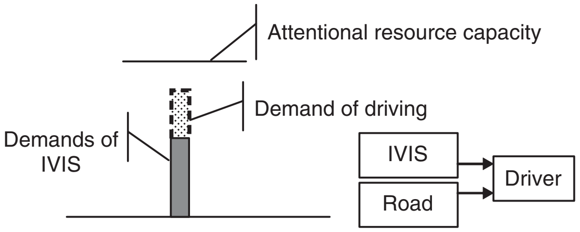

Figure 3. Limited resource theory of workload and distraction. IVIS = in-vehicle information system.

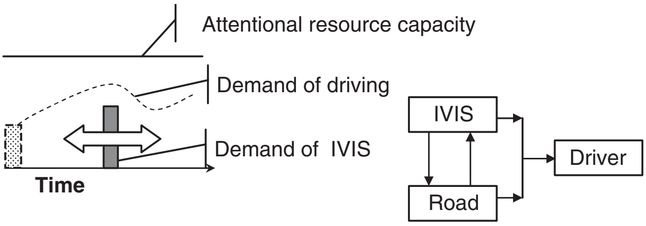

Figure 4. Workload management and the time-dependent element of distraction. IVIS = in-vehicle information system.

if email information was presented by voice (auditory perception, verbal encoding and verbal control) rather than as text on a liquid crystal display panel. IVIS Design Evaluation and Model of Attention Demand (DEMAnD) is a prototype software application intended to assist designers in creating and evaluating IVIS functions. This software uses the multiple-resource theory to help predict driving performance decrements as drivers use various IVIS functions (Hankey *et al.* 2000). As shown by the schematic in figure 3, the interference mitigation approach treats the driver as a passive recipient of the workload imposed by static roadway and IVIS demands.

By relying on fixed elements of the IVIS design to mitigate IVIS interference with driving, the interference mitigation approach neglects the changing states of the driver, the IVIS functions and the roadway. An approach to interface design that neglects the dynamics of the cognitive demands on the driver will likely fail. The workload management approach to distraction considers the changing demands of the driving task and use of the IVIS over time. This approach suggests that at times the driving task is relatively easy and the driver could devote more cognitive resources to the IVIS. At other times, driving demands are higher and interacting with the IVIS could overload the driver. Specifically, a straight motorway during the day with little traffic places relatively modest demands on the driver and dialling a mobile phone might be feasible. Dialling a mobile phone on an icy exit ramp may exceed the capacity of most drivers. These fluctuating demands are shown in figure 4.

According to the workload management approach, the system actively adjusts functionality by estimating the demands of the current roadway and IVIS states. Figure 4 shows the function of the workload manager as it shifts the shaded bar in time so that the combined demands of the IVIS and the roadway do not overload the driver. When the assessed driver workload is low, the IVIS allows the driver to complete activities that are not driving related, such as answering a mobile phone call. Conversely, when the IVIS perceives the driver workload as being high, as in the case of a congested motorway, it might send all incoming phone calls directly to voice mail. IVIS-centred workload management addresses important drawbacks of interference mitigation by considering the changing nature of the driving experience. This is quite important because drivers often fail to consider the driving situation as carefully as they should when they choose to engage in potentially distracting activities. For example, drivers answer mobile phones 1–4 seconds after they begin to ring independent of context (Nowakowski *et al.* 2002). Poor decisions of drivers regarding when to begin an IVIS interaction may have consequences as great as the demand of the IVIS interaction. The workload management approach assumes the driver passively responds to workload demands and fails to consider how to support

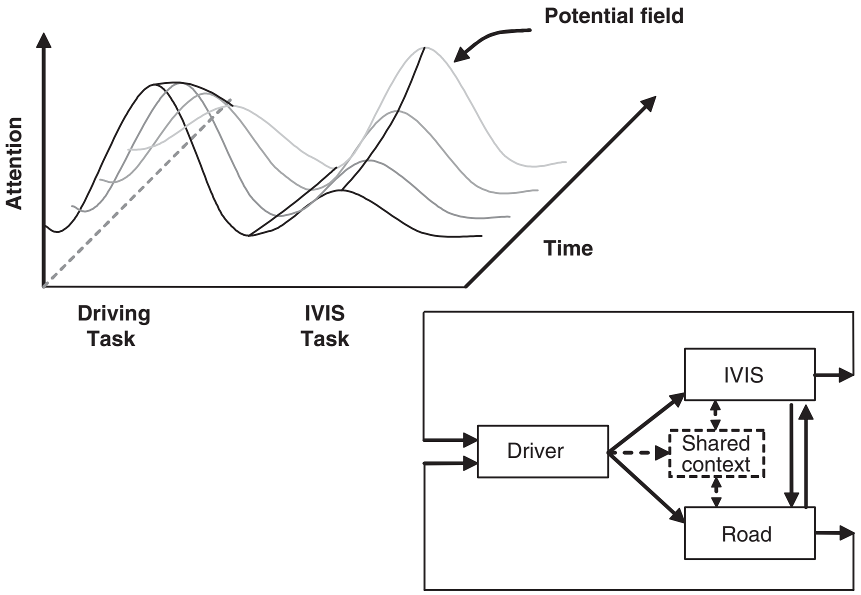

Figure 5. Dynamical systems model of attention with distraction as a breakdown of coordination. IVIS = in-vehicle information system.

drivers in strategically managing their workload. As shown by the schematic in figure 4, the workload management assumes that the drivers' workload must be managed by the IVIS rather than including the driver as an active partner in coordinating the IVIS and roadway interactions.

Perhaps the most important limit of current approach in describing distraction is the failure to consider the dynamic evolution of IVIS and driver interactions. Most approaches to determining driver distraction centre on discrete interactions, without consideration for what has happened before or after. In this situation the workload manager fails to consider the overall task structure and how easy it is for a driver to interrupt either a driving or IVIS activity. With the attention-grounding approach, distraction arises from a failure to coordinate the dynamic interaction of demands of the roadway and IVIS. This approach describes driver distraction as a poor distribution of attention arising out of a poorly coordinated activity and not as a situation exceeding a pool of limited resources.

A dynamic systems perspective seems particularly well suited to describe the dynamic interaction of the driver, roadway and IVIS because it provides a formal description of how the behaviour of interactive systems evolves over time (Kelso 1995, van Gelder and Port 1995, Beer 2001). The potential field in figure 5 is a representation from the dynamic systems perspective that contrasts with the trajectories in figures 3 and 4. The vertical axis represents the potential field that influences the likelihood of attending to the roadway or IVIS, rather than the degree of demand as represented in figures 3 and 4. The distribution of attention depends on this potential field and how it fluctuates over time according to the dynamics of the interaction. According to this representation, attention to the roadway depends on the dynamics associated with shifting between schemas of different activation potentials. The peak at the left of the figure shows that attention is likely to focus on the road, but then, as time passes, attention becomes more likely to focus on the IVIS. This potential field evolves over time as a product of the interaction—extended interactions with the IVIS may shift the potential field in favour of the IVIS. This makes it possible to predict the distraction potential associated with the duration of the IVIS interaction and the dynamics of the driving task. For example, a long IVIS interaction during a low-demand driving situation may cause a withdrawal of attention from the roadway that is as severe as a single high-demand activity, a situation not addressed by the multiple resource theory. Specifically, a long phone conversation may gradually shift the potential field such that drivers become increasingly likely to disregard roadway events.

The schematic representation of the IVIS, roadway and driver in figure 5 shows that the driver actively influences the attentional demands of the roadway and IVIS, rather than being the passive recipient of those demands. The driver, IVIS and roadway jointly influence the behaviour of each other such that it is not effective to talk about driver performance depending on roadway or IVIS demands because the driver state contributes to roadway and IVIS demands (Jagacinski and Flach 2003). For example, errors that drivers make when interacting with the IVIS could increase the IVIS demands and drivers could adopt a slower speed to decrease roadway demands. In that way the dynamic systems perspective provides a formal representation of the coordination described in the turn-taking associated with joint control of conversations. This representation also emphasizes the value of considering design features that support effective coordination and turn-taking in helping the driver actively manage the evolving demands of the IVIS and roadway. Using a dynamic systems perspective to understand how coordination breaks down provides a useful description of driver distraction that is qualitatively different than the limited capacity perspectives shown in figures 3 and 4.

4. Conclusions

The concept of attention grounding has three important elements that contrast with the traditional approaches to IVIS design. First, it considers the need to augment direct communication with back-channel communication. Second, it uses the back-channel communication to coordinate the interaction of IVIS functions. Third, it recognizes the need to go beyond mental workload and consider the dynamics of how drivers distribute their attention. Some particular benefits of the attention grounding framework include:

- Back-channel cues can promote fluid communication with unreliable speech recognition systems.
- Back-channel cues can help identify the driver state and enable IVIS to adapt to the changing demands on drivers.
- Back-channel cues regarding roadway events could support situation awareness and help drivers actively manage their interactions and minimize distraction.
- Back-channel communication can enhance interaction with imperfect technology by indicating the context for appropriate reliance.

- Distraction depends on the dynamics of the IVIS–driver–roadway interaction. Distraction mitigation must consider when and where drivers' deploy their attention, not just the magnitude of attentional resources demanded by the situation.

Without back-channel cues creating a shared context, communication between the roadway, driver and IVIS functions will be disjointed and vulnerable. Imperfect IVIS technology and unpredictable roadway demands are an inherent part of the driving domain and must be considered in IVIS design. The need to support adaptive behaviour by conveying goal-relevant constraints to operators has been clearly articulated by others (Rasmussen *et al*. 1994, Vicente 1999). This paper describes one approach for conveying constraints to promote the smooth coordination in the driving domain. Back-channel communication, and the shared context it supports, facilitates coordination between the driver, IVIS and roadway, creating a safer and more effective IVIS.

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