Design of Context-aware Systems for vehicles using complex system paradigms

Andry Rakotonirainy

Centre for Accident Research and Road Safety - Queensland (CARRS-Q)
Queensland University of Technology
Australia
r.andry@qut.edu.au

Abstract. This paper argues that the driving task exhibits the properties of complex systems. Driving behavior emerges from the intricate and complex interactions between the driver, the vehicle and the environment. An emerging driving behavior could not necessary be linearly predicted. However a context-aware system could assist the driver in augmenting the probability of undertaking safe behavior. Unlike existing context aware systems which isolate one characteristic such as road or driver workload and concentrate on it in exclusion of the others factors, this seminal research proposes a context awareness design which considers the driver, vehicle and environment as a whole. We focus on the principles that underlie the system in order to model it with the view of understanding, predicting and improving driver behavior. This approach places context-aware design within a wider framework that takes into account information related to the driver, environment and vehicle. It recommends approaches for building safety critical context-aware systems. Such an approach aids in the design of safe in-vehicle context-aware systems.

1 Introduction

Pervasive computing technology such as sensors, actuators, wireless networks and processors are commonly used to assist humans to perform tasks. Context-awareness systems have become a growing area of study for pervasive and ubiquitous research communities. Unfortunately context-aware systems have not been thoroughly used to assist driving tasks. Intelligent Transport System (ITS) and Advanced Driver Assistance Systems (ADAS) are growing research fields that use new technology aiming at improving road safety. Context-aware, ITS and ADAS research exhibit striking similarities. Unfortunately, ITS and ADAS research are too often conducted without interactions with the pervasive/ubiquitous research communities.

Almost 95% of the accidents on the road are attributed to the human errors as a casual factors. In almost three-quarters of the cases human behavior is solely to blame. On European roads, 40.000 persons are killed and 1.7 Million are injured every year [13]. Drivers represent the highest safety risk. Computing assistance can improve situational awareness and reduce driver errors. Although context-aware systems have great potential to save lives and prevent injuries on the road, they have not been integrated to safety critical applications such as cars yet. Concretely, context-aware systems can improve the driver's handling of a car by augmenting the awareness of the cars' state (e.g. following distance), the environment (e.g. road conditions) and the physiological and psychological state of the driver (e.g. available attention level). ITS (Intelligent Transport Systems) could potentially reduce road crashes by up to 40% [23].

Driving is a complex behavior influenced by a wide range of factors in space and time. Factors include goals, distraction, errors, expectancies, workload, attention, traffic, vehicle safety features, automaticity, fatigue, memory, capabilities, training and experience. We conceptually consider driving behavior as a complex system in which the environment, driver and vehicle are influencing factors. Factors influencing the driving task exceed our ability to design, comprehend and control. The emerging property of such a system is the driver's behavior (what the driver actually do on the road). Emergence is a well known property inherent to complex systems [11].

Context aware systems aim to improve the safety of driving behavior. However, the inclusion of a context aware system in a complex system such as driving does not warrant safe behavior regardless of how well designed the context aware system is. This is mainly due to the fact that the emerging property of a complex system such as driver behaviour cannot be easily predicted.

Our design methodology consists of considering context aware systems as another component of a complex system. The context aware system influence the driver behaviors' outcomes toward a safe behavior. The evaluation of the emerging driving behavior uses Bayesian networks. Bayesian networks observe the whole complex system as opposed to focusing on individual components or the interactions between them. To our knowledge, merging concepts from context awareness, complex systems and driving behavior models in the view of improving driver behavior has never been attempted.

Section 2 is a reminder of the definition of context and context aware systems. Section 3 describes the role of context aware systems in vehicles. Section 4 briefly describes existing driver behavior models. Section 5 shows how driving behavior is modelized as a complex system. Section 6 briefly described how the benefits of a context aware system could be evaluated using complex system paradigms and Bayesian networks.

2 Context and context-aware systems

Context is any measurable and relevant information that can be used to characterize the situation of an entity (e.g. driver) [3]. Context is highly dynamic in space and time. Context could be considered as a "setting" in which interactions unfold [4]. The setting has the dual role of creating and constraining interactions.

Context-aware systems use Information Communication Technologies (ICT) to provide a greater awareness of relevant information about the physical worlds in order to assist the information recipient in the decision making process.

Drivers operate in highly dynamic environments or contexts. Existing context-aware systems use context such as task at hand, location, user preferences and device capabilities [6, 25, 2, 9] to deliver relevant information to the user. The relevance of the information is relative to a particular circumstance or context. An example would be the context of a technical conversation in which terms have particular meanings that are different to the common meanings used in the language [14].

3 Role of context aware systems in driving

Intelligent Speed Adaptation (ISA) is a simple form of in-vehicle context aware system. ISA limits the speed of the vehicle according to the surrounding context. The relevant context is reduced to the posted speed limit. It is widely recognized that ISA potentially provides one of the most effective intervention for reducing excessive speed.

In-vehicle context aware systems aim at taking into account more contextual information related to the driving task in order to produce adapted or customized actions. Driving is a complex, continuous, multitask processing that involves driver's cognition, perception and motor movements. Driving tasks are classified in two categories both of which can be assisted by a context-aware system:

- Primary task: Tasks restricted to longitudinal/lateral vehicle control and vigilance.
- Secondary task: Other tasks that do not require continual performance.

Monitoring a car requires dynamic allocation of attention to perform tasks. Drivers' attention oscillates between the primary and secondary driving tasks.

Drivers' safety, cognitive and motor workloads introduce new complex factors in the design of context-aware systems. Augmenting drivers situational awareness can have various effects such as:

- making the driver aware of critical safety information well ahead and give the driver enough time to react safely.
- overwhelming the driver with irrelevant information. Information can be inaccurate or missing and confuse the driver.
- distracting the driver from the main critical driving task.

Context-aware systems often assume that users have the cognitive abilities to acquire the produced context-aware information. Such assumptions may be valid in desktop environments but are fundamentally inadequate and potentially un-safe in driving conditions. Conveyed awareness information requires driver's attention in order to register it. Registering information cognitively is not an effortless task.

Drivers' psychomotor resources are dynamically allocated to different driving sub-tasks due to constant interruptions. The allocation and the intensity of attention is determined by the demands or stimuli (cues) from the environment (inside and outside the car) and the psycho-physiological capabilities of the driver. Certain information such as warning about the imminence of a crash requires the full attention from the driver. The warning is expected to be followed by driver's motor reaction. Other type of cues such as in-coming E-mails do not necessary need immediate attention.

Human Computer Interaction (HCI) research has studied the ways people interact with computing devices. Several theories and models have been put forward to analyze human-computer interactions [26, 18, 17, 19, 22]. Psychologists have studied models of attention in human computer interactions [10, 16] and in driving conditions [8]. Despite such considerable works, the design of most context-aware systems have not taken into account the human attention required to register the information to be delivered from a context aware system. To our knowledge, none has explicitly integrated context-awareness and human attention design in automotive environments.

4 Driver behaviour models

Driving behavior models explain and predict the behavior of drivers. Existing models are largely subjective and based on self-report scales [24]. They strongly emphasize the driver's cognitive state and have incorporated important behavioral concepts such as motivation, task capability [5], belief (theory of planned behavior) [1] or risk assessment. However, motivational models such as risk compensation [28], risk threshold [20] or risk avoidance remain highly subjective concepts. The cited work simplifies the driving task by focusing on the cognitive aspect of driving. They do not explicitly take take into account other important factors or context related to the driver (e.g attention), environment and vehicle. Such simplification is useful for a designer who is an expert in a particular discipline such as traffic psychology who wants to define a model that brings all psychology related facts together to explain driving behavior. However the validity of such a simplified approach is debatable when the broader context related to environment, driver and vehicle which are very dynamic, vague, not all known and complex in space and time, are required to explain a behavior.

Recently, statistical models have been used to predict driving manoeuvres and behaviors. They use Bayesian or HMM (Hidden Markov model) [21] [12]. However these statistical models are based on information related to vehicle and do not fully integrate information related to the environment and the driver.

5 Modeling driving as a complex system

We aim to build a driver behavior model which reflects real world driving. We consider driving behavior as an emergent property of a complex system featuring subsystems representing the driver, the environment, the vehicle and the in-vehicle context aware system.

5.1 Complex system

A complex system is a system in which the number of states that can be anticipated or understood can not be accurately identified or enumerated. A complex system consists of dependent components or sub-systems. Components exhibit inter-relationships and interdependence. Some behaviors or patterns emerge from a complex system as a result of the patterns of relationship between its components. The emerging behavior cannot be identified or deduced by observing individual components of the system. Complex systems research seek to understand *(i)* how a large number of factors of different types are combined and *(ii)* how components influence each other to collectively produce an aggregated phenomenon (emergence). Complex systems try to understand the nature of emerging behavior and the conditions which will help it to occur. Emerging patterns arise from the intricate inter-twining or inter-connectivity of elements within a system and between a system and its environment [15]. Mathematically speaking, the emerging phenomena cannot be regarded as the behavior of some average of individual components. Emergence is rarely a simple, linear cause and effect relationship between the elements of a complex system. An event may cause a large effect/deviation on the future behavior the system (e.g butterfly effect), or no effect at all.

Relationships between components have a history and contain feedback loops. The effects of a component actions are fed back to the component and this, in turn, affects the way the component behaves in the future. For example relationships between the driver and vehicle build specific patterns of vehicle handling which changes with feedback, experience and history. The feedback could be negative (damping) or positive (amplifying). Feedback are key ingredients of complex systems. Feedback and behavior form a history which is an important component of a complex system such as driver behavior.

Complex systems are open systems with boundaries that are difficult to determine. Information is dynamically and constantly being imported and exported across the system boundaries. The boundaries are often determined by the observer's needs rather than any intrinsic property of the system itself. Driving behavior exhibits such open properties. That is, the complete set of factors influencing the behavior cannot be bounded.

5.2 Complex systems and occupational safety

The previous section models driving task as a complex system featuring three interacting boundless sub-systems labeled as environment, driver and vehicle. Several separate theories related to each sub systems has been written to explain crash and crash risks. Unfortunately each individual theory is restricted in scope.

At another level of analysis, drivers cognitive state could be influenced by occupational safety. Factors such as safety management, social stressors, anxiety has been shown to have an influence on accident rate [7]. Nonlinear dynamical theory (cusp model) has been used to correlate crash rate and occupational safety parameters [7]. Non linear and complex system theories offer several computational concepts for modeling and predicting occupational accidents in trasporation [7].

6 Approach to improve driver behavior

This section shows how we use Bayesian network to observe and predict safe driving behavior.

6.1 Observing individual behavior with Bayesian network

An accurate prediction of driver behavior requires an understanding of a large number of conditions (contexts) which cannot be quantified with individual observational measures, such as recording ocular movement, traffic flow, or cognitive activities. Furthermore, such an accurate prediction is impossible in a complex system such as driving behavior.

However, the probability of a certain behavior to occur, for a given period of time can be obtained by applying probability theory. We use Bayesian networks to evaluate the probability of a certain behavior to occur. A Bayesian network is a graphical representation of the underlying probabilistic relationships of a complex system. A Bayesian network learns and progressively increase the prediction level of confidence. It is based on solid mathematical foundations.

Our approach consists of gathering relevant contextual information related to the driver, the vehicle and the environment in the real driving condition with sensor technology. Such information is fused and analyzed to contextualize an action as described in Figure 1. These contextualized actions are represented in a Bayesian Conditional Probability Table (CPT).

The study of a set of individual driving behaviors as a complex system could reveal common characteristics among different drivers and will allow a greater understanding of this complexity.

The observation is a learning process that can improve the prediction capability. We have pointed out the prevalence of uncertainty in a driving environment. Thus we use Bayesian learning as a form of uncertain reasoning from observations. Bayesian learning simply calculates the probability of the occurrence of an event, given an observation, and makes predictions on that basis.

6.2 How context-aware systems improve driver behavior

The ability of context awareness systems to improve driving behavior relies on the understanding of the whole driving task, not individual components of the system. However we need to build the context-aware system which can sense contextual information about the driver, environment and vehicle. The context aware system assists the drivers in the decision making process in which they *(i)* assess the situation, *(ii)* identify available options, *(iii)* determine the costs and benefits of each and *(iv)* select the option with the lowest costs and highest benefits [27].

The description of a method for building a context-aware system is out of the scope of this paper. It is a middleware exercise, details of the architecture could be found in [9] and shown in Figure 1. Figure 1 shows that a driving situation is created by the context aware system. The context aware system gathers information using different types of sensor technology. It also gathers psychological information from questionnaire filled by the driver. The context aware system feeds the information into a bayesian network from which we can evaluate future behavior.

The evaluation of the context-aware system is fundamentally different from traditional approaches which mainly consists of performance and usability evaluation. Our method for evaluation consists of using the Bayesian network to observe and understand the driving situation as a whole. Different configurations of the context aware system will be trialled until the whole complex system exhibits a higher probability of stable safe behavior. A good context aware configuration would be a system that provides the high probability of safe behavior. The definition of what is a safe driving behavior is an on-going research. However we take the assumption that a safe behavior is a behavior when the number of errors is minimal.

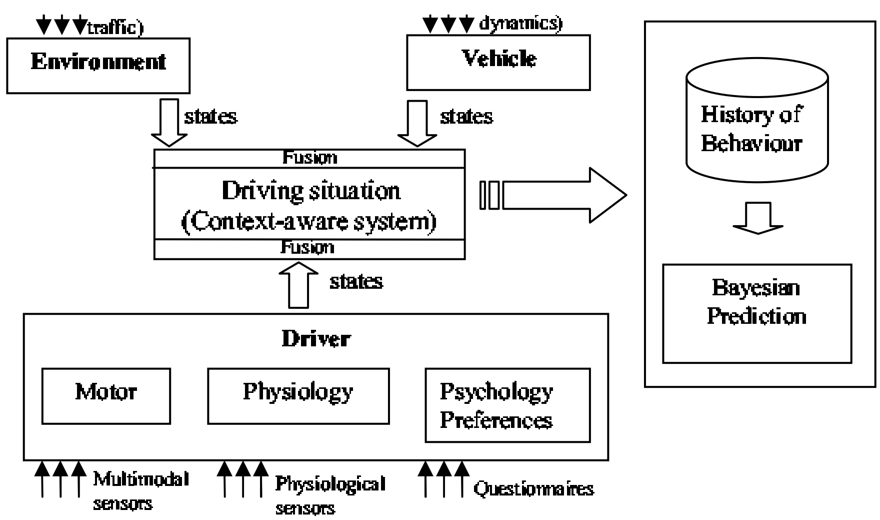

Fig. 1. Observing driver behaviour

7 Conclusion

Driving task is a highly complex behavior influenced by a large number of factors. The use context aware systems in cars aims at improving driver behavior. However the evaluation of the benefits brought by context-aware systems is difficult due to the complexity of driving task. This conceptual paper uses complex system paradigms to configure the design of a context aware system and evaluates its benefits.

References

1. I Ajzen, *From intentions to actions: A theory of planned behaviour*, ch. Action control. From cognition to behaviour, pp. 11–40, Springer Verlag, 1985.
2. Keith Cheverst, Nigel Davies, Keith Mitchell, and Adrian Friday, *Experiences of developing and deploying a context-aware tourist guide: the GUIDE project*, Proc. of MOBICOM'2000, Boston, ACM Press., 2000, pp. 20–31.
3. Anind Dey and Gregory Abowd, *Towards a better understanding of context and context-awareness*, Conference on Human Factors in Computing Systems (CHI 2000): Workshop on the What, Who, Where, When and How of Context-Awareness (The Hague), April 2000.
4. Paul Dourish, *Where the action is: The foundation of embodied interaction*, The MIT Press, 2001.
5. Ray Fuller, *Towards a general theory of driver behaviour*, Accident Analysis and Prevention **37** (2005), no. 3, 461–472.
6. David Garlan, Dan Siewiorek, Asim Smailagic, and Peter Steenkiste, *Project Aura: Toward distraction-free pervasive computing*, IEEE Pervasive computing (2002), 22–31.
7. Stephen J. Guastello, *Catastrophe modellinh of the accident process: evaluation of an accident reduction program using the occupational hazards survey*, Accident Analisys and Prevention **21** (1989), no. 1, 61–77.
8. Jonathan M. Hankey, Thomas A. Dingus, Richard J. Hanowski, Walter W. Wierwille, and Christina Andrews, *In-vehicle information systems behavioural model and design support: Final report*, Final Report FHWA-RD-00-135, U.S Departement of Transportation, Federal Highway administration, 2000.
9. Karen Henricksen, Jadwiga Indulska, and Andry Rakotonirainy, *Modeling context information in pervasive computing systems*, 1st International Conference on Pervasive Computing (Zurich, Switzerland), Springer, August 26-28 2002, pp. 167–180.
10. E. Horvitz, C. M. Kadie, T. Paek, and D. Hovel., *Models of attention in computing and communications: From principles to applications*, Communications of the ACM **46** (2003), no. 3, 52–59.
11. S Kauffman, *At home in the universe: The serach for the laws of self organisation and complexity*, Oxford University Press, 1995.
12. T Kumagai, Y Sakaguchi, M Okuwa, and M Akamatsu, *Prediction of driving behaviour through probabilistic inference*, 8th Int Conf Engineering Applications of Neural Neutworks (EANN"03) (Malaga Spain), 2003.
13. Erkki Liikanen, *Research on integrated safety systems for improving road safety in Europe*, Tech. report, European Commission - Information Society, September 2002.

14. John McCarthy, *Notes on formalizing contexts*, Proceedings of the Thirteenth International Joint Conference on Artificial Intelligence (San Mateo, California) (Ruzena Bajcsy, ed.), Morgan Kaufmann, 1993, pp. 555–560.
15. Eve Mitleton-Kelly, *Complex systems and evolutionary perspectives on organisations: the application of complexity theory to organisations*, Pergamon, 2003.
16. Card Moran, Thomas P. Morgan, and Allen Newell, *The psychology of human-computer interaction*, Lawrence Erlbaum Associates, 1983.
17. Brad Myers, Jim Hollan, Isabel Cruz, Steve Bryson, Dick Bulterman, Tiziana Catarci, Wayne Citrin, Ephraim Glinert, Jonathan Grudin, and Yannis Ioannidis, *Strategic directions in human-computer interaction*, ACM Computing Surveys (CSUR) **28** (1996), no. 4, 794–809.
18. J Nielsen, *Usability engineering*, Academic Press, 1993.
19. Donald A. Norman, *The invisible computer*, MIT Press, Cambridge, Massachusetts, 1998.
20. R. Ntnen and H. Summala, *Road user behaviour and traffic accidents*, Elsevier, New York, 1976.
21. Nuria Oliver and Alex P. Pentland, *Graphical models for driver behavior recognition in a smartcar*, IEEE Intl. Conference on Intelligent Vehicles 2000 Detroit (Michigan), October 2000.
22. Sharon Oviatt, Phil Cohen Lizhong Wu, Lisbeth Duncan John Vergo, Bernhard Suhm, Josh Bersand Thomas Holzman, Terry Winograd, James Landay, and Jim Larsonand David Ferro, *Designing the user interface for multimodal speech and pen-based gesture applications:state-of-the-art systems and future research directions*, Human-Computer Interaction, 2000.
23. M Peden, R Scurfield, D Sleet, D Mohan, A Hyder, E Jarawan, and C Mathers, *World report on road traffic injury prevention*, Tech. report, World Health organization, 2004.
24. Thomas A. Ranney, *Models of driving behaviour: A review of their evolution*, Accident Analysis and Prevention **26** (1994), no. 6, 733–750.
25. Daniel Salber, Anind K. Dey, and Gregory D. Abowd, *The context toolkit: Aiding the development of context-enabled applications*, Proceeding of the CHI 99 conference on Human factors in computing systems : the CHI is the limit, 1999, pp. 434–441.
26. Ben Schneiderman, *Direct manupulation: A step beyond programming language*, IEEE Comput **16** (1983), no. 8, 57–69.
27. Barry Strauch, *Investigating human error: Incidents, accidents and complex systems*, Ashgate Publishing Limited, 2002.
28. G Wilde, *The theory of risk homeostasis: implications for safety and health*, Risk Analysis **2** (1982), no. 4, 209–225.