Control Transition Interfaces in Level 3 Automated Vehicles
Four Preliminary Design Patterns

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***Abstract*—Automated driving technology is rapidly progressing, which causes increasingly complex in-vehicle systems and similarly complex in-vehicle interaction contexts in need of appropriate solutions. One such context is initiating or confirming control transitions between manual and automated modes in semiautomated level 3 vehicles, which is a particularly challenging context due to the combination of potentially inattentive drivers who need to take back control in emergency situations. In this paper, we present some of the results from a review analysis of academic and industry publications as four preliminary patterns for transition designs in level 3 vehicles.**

***Keywords*–Automated vehicles; SAE level 3; Design patterns; Control transitions; Interface design.**

I. Introduction

Recent years have seen a rapid development and constant increase of automated systems in vehicles. High automation in vehicles is not merely a by-product of advances in automation design but is pursued as a primary goal with the intent to reduce accidents and casualties by reducing the human element and, thus, human error. Currently, the vehicle industry is right in the middle on the road from fully manual to fully automated operation. This so-called *transition phase* bears a number of particular challenges to overcome, caused by a necessity for both human and automated system to interact and conduct parts of the dynamic driving task.

One particularly challenging context is that of SAE (Society of Automotive Engineers) level 3 [1]. At this level of automation, also called "conditional automation" the vehicle can execute all aspects of a dynamic driving tasks while the driver is still required to intervene and take back control, either if he/she chooses to do so or if the system is unable to handle a certain situation and requests a driver intervention. While a level 3 vehicle is driving in an automated mode, the driver is only required to be *receptive* to system output relevant to a request to take back control. The monitoring of the driving environment, which includes assessment of the driving situation, is also performed by the vehicle.

This combination of factors can lead to extended response times in case of emergency transition requests. In such an emergency, the vehicle might decide to transition control back to the driver, either due to difficult traffic conditions or system failure. The driver, however, can not be expected to be ready to take control in the same way a driver of a manual vehicle would, as environment monitoring up to that point was handled by the vehicle. Thus, the driver is likely to require additional time to react to the transition request and then assess the driving situation – time, which he/she might not have in an emergency situation. Some have expressed a desire to skip this level altogether and shorten the transition phase as much as possible [2]. It is doubtful, however, that this skip will be as effective or short as intended and not extended by, e.g., unforeseen technical difficulties or setbacks in development, which are known to happen frequently in virtually any area of research and development. It is sensible to try and provide effective transition interface solutions for this transition phase, long or short as it may be, as these solutions will increase driver safety during that phase.

In order to provide a guide for level 3 transition design, we conducted a review of available literature from academia and industry, with the aim of identifying holes and potentials in automotive design and research. The results of this review are reported in Mirnig et al. 2017 [3]. While analyzing the results of this review, we also identified a number of consistencies among interface designs, which could serve as a further useful basis for designing automated vehicle interfaces. We decided to compile these consistencies in the form of preliminary design patterns. In this paper, we present the first four of these patterns. After this introduction, in Section II, we briefly outline related work regarding design patterns and vehicle automation levels. The patterns themselves are presented in Section III. We discuss these patterns in Section IV and provide a conclusion and future outlook in Section V.

II. Related work

In the following, we provide an overview of automation levels in Subsection II-A and design patterns in Subsection II-B

A. Levels of Vehicle Automation

The extent to which a vehicle is capable of automated operation is usually expressed via *levels of automation*. The three most common definitions for automation levels come from SAE International, the National Highway Traffic Safety Administration (NHTSA), and the German Federal Highway Research Institute (Bundesanstalt fur Straenwesen BASt). While having differences in level of detail and focus on vehicle functions, all three standards describe automation as incremental steps from a basic, nonautomated, to a fully automated level. On an international level, the SAE standard is the most widely used one, to the point where the NHTSA abandoned their automation level definitions and decided to

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adopt the SAE's at the end of 2016 [4]. For the sake of consistency and clarity, we will also use these levels in this paper.

According to the SAE J3016 standard, vehicle automation ranges from across six levels: level 0 (no driving automation), level 1 (driver assistance), level 2 (partial driving automation), level 3 (conditional driving automation), level 4 (high driving automation, and level 5 (full driving automation). Level 3 is defined as "The sustained and ODD-specific (ODD=Operational Design Domain) performance by an ADS (Automated Driving System) of the entire DDT (Dynamic Driving Task) with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately," and represents a critical breakpoint between levels 2 and 3. On level 2, monitoring of the environment is still on the part of the driver, which means that a transition of control from automated driving mode to an unprepared driver does not occur under normal circumstances. On level 4, fallback performance, i.e., handling of the driving task in case of driver's inability to take control or system failure, is to be handled by the vehicle. This means that from level 4 onwards, transition requests from the vehicle are never mandatory to be responded to. Level 3 combines environment monitoring by the vehicle with mandatory fallback performance by the human driver, which is the cause for the likely scenario of control transition to an unprepared driver, making level 3 a particularly challenging design space.

B. Design Patterns

Christopher Alexander is considered by many as the "founder" of contemporary pattern approaches. He initially developed the concept of patterns for architecture, his home domain. According to him, constructing a building consists of a string of solutions to individual and context-dependent problems. It is these problems and their solutions that make up the conceptual building blocks. In his classic work on patterns [5] [6], he described both the basic pattern approach and developed a collection of patterns for the construction of buildings.

His ideas were later adopted by other disciplines as a problem solution documentation method. One of the most well-known of these adaptations is the work of Gamma et al. [7], who provided a pattern structure and pattern collection for software engineering. Human-Computer Interaction, of which automotive interface design is a subdomain [8], has also adopted patterns as a method to document working interface design solutions as *design patterns*. Patterns, which describe working solutions to reoccurring problems, have a counterpart in the so-called *antipatterns*. Antipatterns describe solutions that might look like they should work at first but do not in practice [9]. There is also a third type of patterns, called *dark patterns*, which describe solutions intended to deceive or trick users. Since the focus of these patterns is on the intention behind a solution and less on the implementation and its reproducibility, they can be seen as outside of the "classic" pattern spectrum inhabited by patterns and antipatterns [10].

Pattern writing is an iterative process, which starts with the initial *pattern mining* [11] [12]. Pattern mining is the act of looking for repeated, working solutions within a pool of available data and deciding, whether or the solution is worth making into a pattern. Once a solution has been mined, the actual writing begins. This writing usually follows a standard pattern template or structure, which ensures that the problem and its surrounding context are captured in enough detail to make the solution reproducible, and allow easier sorting and referencing of a pattern in a later pattern collection. According to the minimal pattern structure described in [10], a successful pattern should at least always contain a means of reference, a description of the problem, a description of the context the problem occurs in, the solution in detail, and at least one (although ideally more than one) example. Initial (and intermediate after the first cycle) pattern versions are then iterated by other pattern authors or domain experts, either on a one-to-one basis or in the form of writer's workshops. Once the patterns have reached a high enough level of quality and equally sufficient number, they are published as a pattern collection, either in print or in an online repository.

III. Control Transition Interface Patterns

This work is based on a literature review conducted for the purpose of identifying holes and/or weaknesses in current control transition interaction designs. The review was based on a total number of 469 scientific publications (via IEEE Xplore, ScienceDirect, and the ACM Digital Library) and 200 industry patents (via Depatisnet and Google Patents). After initial analysis regarding the presence of actual interface implementation descriptions, the papers were reduced down to 35 academic papers and 22 industry patents, which were analysed in detail. The full analysis procedure and results can be found in Mirnig et al. 2017 [3]

In this paper, we focus on some of the design regularities that were found as an additional result of the analysis. We use the minimal pattern structure described in [10] for the pattern format. Each pattern consists, thus, of a unique **name**, a **problem** statement, a **context** description, a **solution** description, and several **examples**. The set of patterns presented are preliminary patterns, which have not undergone a full iteration cycle. Thus, future extensions will require iteration and further validation of the current patterns as well. The pattern content is mostly based on the literature reviewed in Mirnig et al. 2017 [3]. Explicit references are made when other sources are cited or concrete examples are provided in the corresponding Subsection of each pattern.

A. Pattern 1: Interaction Method to respond to or initiate transition requests

Problem: Control transitions require adequate means for the human driver to either initiate a request for the vehicle to drive in autonomous mode or respond to a request by the vehicle to take control. Since control transitions represent a fundamental change in driving task performance and delegation, such controls should not be easily confused with other controls and be difficult to activate by accident.

Context: In accordance with the taxonomy proposed by McCall et al. [13], control transitions can occur in five different configurations: scheduled, non-scheduled system initiated, non-scheduled user initiated, non-scheduled system initiated emergency, and non-scheduled user initiated emergency. Scheduled transitions allow longer preparation times for both driver and vehicle (depending on the transition direction).

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Nonscheduled transitions, especially in emergency situations, require quick, efficient and error-free input and should, thus, be the focus when designing transition controls.

Solution: Since a transition means either assuming or relinquishing control, it can be assumed that the driver will be physically connected to the standard physical vehicle controls (steering wheel and pedals) at some point during the transition by necessity. Thus, a sensible position for both initiation and confirmation of transitions is near the physical vehicle controls. Since actuating controls on or near the steering wheel does not inhibit using the wheel's primary control means (turning), proximity to the wheel should be preferred over the pedals. Physical transition controls (switches, knobs, levers, etc.) should, therefore, be placed close to the steering wheel to enable faster execution of driving maneuvers after the transition while (in case of driver to vehicle transitions) simultaneously guiding the driver's attention towards the primary vehicle controls and the road ahead.

Examples: There are numerous implementations for physical transition controls close to the steering wheel. Cullinane et al. [14] describe a button to press on the left side of the steering wheel. Boehringer et al. [15] and Gazit [16] specify actuation of the steering wheel as a transition initiation from vehicle to driver. Coelingh [17] describes actuation of either steering wheel or pedals as transition initiation. Note that such direct approaches increase the likelihood of accidental transitions initiations if no additional confirmatory steps are present. The Tesla S (see Figure 1, which is used, e.g., in a study setup by Dikmen et al. [18], uses the cruise control lever (pull twice towards the driver) for control transitions initiated by the driver.

Figure 1. Tesla S cruise control lever [19]

B. Pattern 2: Consistent Visual Metaphor to Signal Transition Requests

Problem: Due to the novelty of automated vehicles, there are few to no common visual concepts that a driver would naturally associate with a control transition. Thus, it is difficult to use appropriate visual indicators that evoke familiarity in the driver and are unambiguous in their meaning.

Context: There is a multitude of indicators in the cockpit the driver needs to monitor and/or be receptive to. While Advanced Driver Assistance Systems (ADAS) of levels 1 and 2 usually have their own indicators to show whether they are active or inactive, level 3 automation constitutes a different degree of autonomy that allows the driver to perform a primary task other than driving. This means that existing ADAS indicators are not, by default, suitable for also displaying control transitions. A suitable visual metaphor must focus on the essential process of resuming or relinquishing the vehicle's controls.

Solution: The primary interaction means when operating a vehicle are the pedals and steering wheel. Of these two, the steering wheel shape is most easily recognizable and, therefore, presents a robust visual metaphor for assuming or relinquishing control. Since the wheel itself represents controllability by a human, a simple way to use this metaphor is displaying a steering wheel when control by the driver is requested and not displaying it when control is to be relinquished.

Examples: In a simulator setup by van den Beukel et al. [20], transition requests are communicated via a steering wheel icon with superimposed hands grasping the wheel (see Figure 2). When no hands and only the steering wheel are displayed, no transition request is taking place. While the display also contains color coded information, the transition requests are only communicated via displaying the steering wheel with hands on or off.

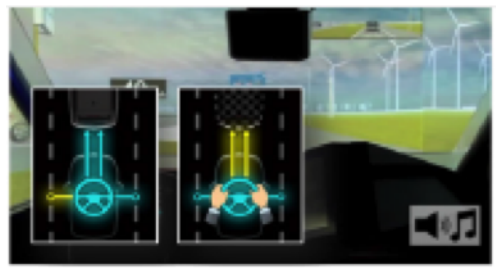

Figure 2. Wheel icon with hands on or off

In a setup by van der Meulen et al. [21], the steering wheel is displayed as a semitransparent icon in the middle of the screen together with a verbal message at the bottom of the screen, whenever a transition is requested by the simulator (see Figure 3). In a real vehicle, displaying an icon in the middle of the screen would require a windshield display or projection, which might not be feasible. In general, the icon is best positioned where the driver's primary visual attention lies while performing driving (manual mode) or nondriving (automated mode) tasks.

Figure 3. Semitransparent steering wheel icon in screen center

The Google patent by Cullinane et al. [14] describes a steering wheel icon with one hand on the wheel (in the same position, where the button to confirm the request is located). The icon is accompanied by a verbal message to push said button when ready to respond to the transition (see Figure 4).

Figure 4. Wheel icon with one hand and verbal message

The Tesla Model S similarly displays transition requests as a verbal message in a box at the bottom of the navigation display with a blue steering wheel icon to the left of the message (see Figure 5).

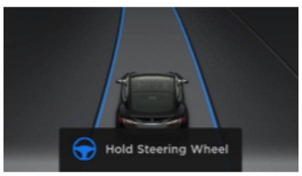

Figure 5. Coloured steering wheel with verbal message

C. Pattern 3: Priority of transitions

Problem: Control transitions can occur in two directions – from driver to vehicle or from vehicle to driver. Depending on which of the two directions is prioritized, different design implications arise for the in-vehicle controls. The problem is deciding which of these (or if neither) should be prioritized and which design implications they entail.

Context: In line with McCall et al. [13], the first distinction to be made is between scheduled and unscheduled transitions. Scheduled transitions put emphasis on planning of the transition, more so on the driver's than the vehicle's side as the initiator. Unscheduled transitions put emphasis on reaction to transition requests, suggesting a focus on the driver as the recipient of the transition request. Depending on whether the nonscheduled transition is an emergency or not, this emphasis might be different.

Solution: *vehicle to driver*: Scheduling a transition from vehicle to driver can depend on traffic or road conditions that the vehicle is not equipped to handle or the vehicle reaching the limits of its operational design domain in any other way. Since the scheduling of these transitions is on the vehicle's side, the driver only needs to be able to respond to such requests in time without necessarily requiring further information or input means. If the scheduled transition is known well ahead in advance, then an additional output with an estimated time indicator would be beneficial. At a basic level, however, an interface design for responding to unscheduled transition requests from driver to vehicle is as also suitable for scheduled ones. Thus, when an interface needs to accommodate scheduled transitions, vehicle-driver transitions should be prioritized during design with designs for unscheduled transitions being usable for scheduled transitions as well.

Driver to vehicle: An effective interface for scheduled transitions from driver to vehicle requires support for the driver to plan the transition ahead of time. This would ideally occur in a navigational interface, where the driver can not only input the planned route but also points (e.g., motorway exits), where they intend to assume or relinquish control. A minimal solution would leave the planning to the driver with no possibility to input the actual transition request ahead of time, which would have to be made manually once the planned point is reached. Such an implementation would be functionally identical to an implementation for unscheduled driver-vehicle transitions, where no planning/scheduling support is needed. Thus, when designing, first priority should be put on a working solution for unscheduled driver-vehicle solutions with possible additional support for more effective scheduled transitions.

Examples: Most implementations, both from academia and industry, focus on transitions from vehicle to driver. Examples for such transitions can be found in Funakawa, Ebina, Hegemann, Forster et al., and Melcher. Examples for implementations focusing on transitions from driver to vehicle can be found in Cullinane [14], Goldman-Shenhar [22], and Albert [23].

D. Pattern 4: Visual Driving Mode Indicators

Problem: In a semiautomated vehicle, the vehicle and driver essentially share the controls. In order to reduce the possibility of involuntary transition of control in either direction, it should at all times be clear who is in control and who is not.

Context: Demonstrators and simulator implementations are often limited in their temporal dimension, mostly focusing on the period briefly before and after the transition but not on a full journey in a vehicle. When the context is extended to a full journey from anywhere to ten minutes to several hours with more than one control transition in-between, an additional complicating factor arises: It might not at all times be clear who is in control of the vehicle. This phenomenon is particularly pronounced in shared or partial control scenarios, where e.g., activated adaptive cruise control can be indistinguishable from full automation. If, in such a scenario, the driver were to falsely assume that both horizontal and lateral automation are engaged, when in reality they are not, and actuates the steering wheel, the vehicle could leave its lane and cause an accident. Generally speaking, the longer a journey is and the more transition occur, the more likely it is that such a *mode confusion* might occur.

Solution: Beyond appropriate output to signal transition requests, a permanent indicator of the current driving mode is required. The driving mode indicator needs to be displayed permanently, so that its information can be accessed on demand. This permanency requirement means that one of the best ways to signal the current driving mode is via a visual indicator, which is less distracting than an auditory or haptic solution. It is not necessary for it to be in the driver's direct field of view while driving and can also be located in the middle console, on a side display, or anywhere else that is either in front or to the side of the driver, so that it can be reached with a quick glance.

The driving mode indicator needs to be expressive enough to meet the functionalities of the vehicle's automation, i.e., if there is only a binary distinction between fully manual or fully automated control, then the interface only needs to be able to display two different modes. If there are several mixed or shared modes, then the display must be able to clearly distinguish between these. Indicators that are effective and easy to implement are icons or color coding (or a combination thereof). In case of a binary system, showing the driving mode via a single icon as being displayed or not displayed is an acceptable solution. Visual indicators can be accompanied by text messages, although should ideally not consist of text only, as this takes longer to process cognitively.

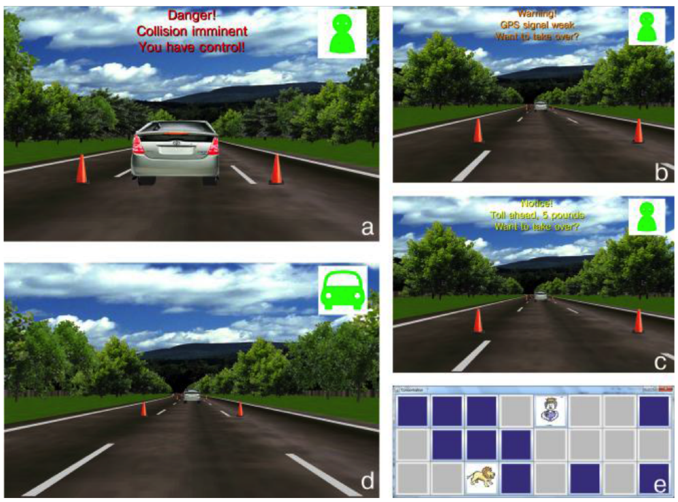

Figure 6. Color coded icon in upper right corner

Examples: Politis et al. [24] have implemented an icon-based driving mode indicator, which displays the current driving mode in the upper right corner (see Figure 6, a-d. The image displayed in e shows the secondary task tablet game and is not part of the mode indicator). In this setup, the transition requests are separate from the driving mode indicators and are displayed in the top center as color coded text messages.

Figure 7. Vehicle being shown as either on or off autodrive lane

The patent by Cullinane et al. [14] divides vehicle lanes into regular/manual and autodrive lanes. The current driving mode is indicated via constantly displaying the lane the vehicle is on and indicating, whether that lane is an autodrive lane or not. This is done via color coding the lanes and an additional text message at the top of the lane indicator (see Figure 7).

IV. Discussion

In the following, we discuss some interesting aspects and limitations of the presented patterns. One concerns the status of the solutions presented and whether or not they could be extended to or with antipatterns, the other the constant improvements in automation technology and associated difficulties of documenting working solutions in an endurable format.

A. Patterns and Antipatterns

All four of the solutions presented in this paper are presented as regular patterns, i.e., *working* solutions. However, while patterns 2 and 4 are clearly presenting working solutions without visible drawbacks, pattern 1 contains a certain antipattern potential. In the case of pattern 1, it is true that most implementations focus on physical input for good reasons and that a dual button setup is one of the more effective solutions to design a safe physical transition interface. The problem, however, lies in the premise of the superiority of physical controls for transition interfaces. As argued in our prior work [3], this is not necessarily the case and might, in fact, be one of the contributing factors to the often perceived impossibility of designing safe and effective control transitions for level 3. Thus, pattern 1 will require further research regarding the suitability of different interaction modes, which could eventually change the part about physical input into an antipattern, if it should turn out that physical input is one of the less suitable modes. Regardless, in its current form as a regular pattern, it properly represents the status quo in driver interaction design.

Pattern 3 is, in itself, presenting working solutions but might be best accompanied by an antipattern in the future. Beyond the priorities based on scheduled versus unscheduled transitions described in pattern 3, there is a strong trend towards putting emphasis and focus on designing vehicle-driver transitions, with driver-vehicle transitions often being an afterthought, if implemented at all. Similar to pattern 1, this limits the exploratory potential in interaction design and might be another contributing factor to the difficulty of designing for level 3 systems. If the design focus is only on in-time notifications for driver-vehicle transitions, this leaves out more nuanced approaches that could, e.g., allow the driver to plan transitions ahead of time and decide (perhaps even before beginning to drive), when to relinquish and assume control and plan their cognitive attention accordingly. Thus, exclusive focus on vehicle-driver transitions might be an antipattern, which is not reflected in the current iteration of pattern 3

B. A Rapidly Evolving Environment

The automotive industry is currently seeing rapid technical developments, which is especially pronounced regarding automated vehicle research and development. It becomes, thus, difficult to consider anything an established or proven solution that goes beyond automation level 2 (which includes advanced driving assistance systems such as adaptive cruise control or lane keeping assistance). Furthermore, even scoping the available technologies themselves is difficult in a comprehensive manner, as automation technologies of levels 3 and above are frequently limited to concept vehicles or industry showcases, which are open to a limited audience within an equally limited timeframe.

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Thus, it is difficult to provide time-tested and proven solutions not only for the automotive domain in general but for automated driving technologies in particular. As the reviews and resulting patterns could show, it is still possible to extract commonalities and bring them into a pattern format even in this rapidly evolving subdomain. But it should be expected that such patterns will be outdated faster than patterns from other domains and that the pool of working solutions to draw from will be smaller. This does not mean that a pattern approach is to be considered impossible or unsuitable for interaction design in automated vehicles but the resulting patterns are likely more limited than they would be in a more static domain.

V. Conclusion and Future Work

In this paper, we presented commonalities of control transition interaction designs in level 3 automated vehicles, which had emerged in the process of a literature review and analysis of academic and industry implementations. These commonalities concerned (a) interaction modes to activate transitions or respond to transition requests, (b) a suitable visual metaphor for control transitions, (c) priority of transition direction depending on transition types, and (d) visual indicators to display driving modes. These results were presented in the form of four patterns, with the intention to make the information contained therein easier to access and (re-)apply. The patterns presented are initial versions, which have not yet undergone a full iterative cycle.

Future work will need to focus on refine and iterate the presented patterns further as well as extend the amount of patterns, as there are far more commonalities to be found in existing transition design implementations than what is covered by the patterns presented above. Maintaining an up to date pattern collection in the rapidly evolving automated driving domain will require a joint effort from within the automotive community and this initial pattern set shall serve as a functional basis for the automotive community to collect design best practices for interaction design in automated vehicles.

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