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Driver's Functions Definition in System of Systems Surrounding Automated Vehicles

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Abstract : This paper addresses the definition of the driver's functions for an automated vehicle of level 3, as defined by the Society of Automotive Engineers. By combining the constituent systems surrounding the automated vehicles in specific use cases, their interactions could be refined in a stepwise approach. This approach enables traceability of interactions between drivers, automated driving systems, and other constituent systems.

Key Words : System of Systems; Systems Engineering; Automated Vehicle; System Modeling Language

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1. Introduction

Automated vehicles are expected to improve transport safety by their use of automated driving systems that interact with the surroundings, including other vehicles, transportation system, pedestrians, and even the drivers of the vehicles themselves. During the process of introducing them to the society, the Society of Automotive Engineers (SAE) has established a multilevel definition of automated driving systems (ADSs) (2014). There is a level called "conditional automation" (level 3), at which drivers are expected to take control of the vehicle when required by the ADS.

The driver of the automated vehicle at level 3 is involved in driving, when the ADS requires. Hence, if the driver's functions are not clarified, it might be difficult to realize the safety transportation system with automated vehicles. In particular, it is necessary to clarify "whether the human must be in command at all time" under the automation (Toshiyuki Inagaki, 2006). When the automated vehicles are introduced to roads, it is necessary to assure the safety of the whole transportation system including the driver.

System of systems (SoS) is a system including systems which are "heterogeneous and independently operable on their own, but are networked together for a common goal." (Jamshidi Mohammad, 2011). Automated vehicles and the surrounding systems are independent systems and some of them are located in the different place from where the automated vehicle is. They must also work together to improve the safety of roads. Especially, a driver of the automated vehicle is also a system relating to them, since he/she has a role to take over the control from the ADS as required by it. The SoS architecture of the automated vehicle and the surrounding systems including the driver, was built in our research to obtain the holistic view to analyze and design the ADS. The interactions between the driver and the ADS in the SoS were verified using Communicating Sequential Processes (CSP) in our previous study (Satoko Kinoshita et al., 2015).

In this paper, the functions of the driver of an automated vehicle are defined by combining constituent systems of the SoS surrounding the automated vehicle under the results of context analysis of the SoS architecture. In this approach, the relationships defined in the context analysis, can be kept during analyzing the detailed driver's functions. Our stepwise approach ensures the traceability of the interactions between the driver, the ADS, and other constituents of the system. Furthermore, it is possible to derive them with necessary and simpler relationships in the SoS by focusing on only closely related constituent systems to the driver. First, we show the results of context analysis of the SoS architecture. Second, the use case analysis with combining constituent systems are described.

2. Background

2.1 Automated Vehicles

SAE International (2014) divides automated vehicles into two broad categories: those in which the human driver monitors the environment and those in which the ADS monitors the environment. This paper uses the level 3 definition of "Conditional Automation," which requires the driver to take control of the automated vehicle in the event that the ADS can no longer execute its automated functions. Although the ADS is required to monitor the surrounding environment during driving, in certain emergency situations the safety of the system is compromised if the driver is drowsy or inattentive and cannot take control instantly. Hence, the behavior of the driver is part of the specification of a level 3 ADS.

A European project named "HAVEit" (Highly Automated Vehicles for Intelligent Transport) was established to set a long-term vision for highly automated vehicles (HAVE IT Website). Moreover, HAVEit, which focuses on automated vehicles of level 3, introduced the "minimum risk state (MRS)" for emergency situations. For example, if the driver of an automated vehicle fails to take control when the ADS attempts to transfer it, the ADS calculates the safest course of action to avoid accidents. Then, a minimum risk maneuver is triggered in which the state of the ADS transitions to a MRS, under which the vehicle stops at the nearest safe place. Note that the MRS was proposed as an approach to improve safety; however, if the rate of transitioning to a MRS can be reduced, automated vehicles can be made even safer.

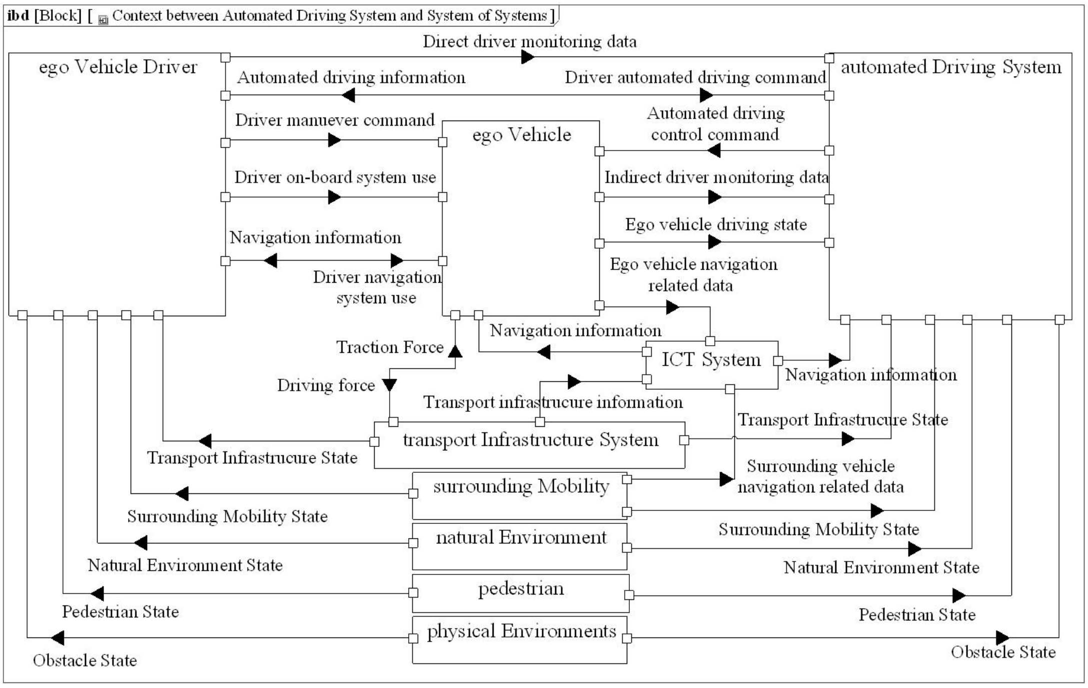
2.2 Road Environments

If the road transport system was completely automated, the elimination of human errors might greatly improve road safety. In fact, in USA, driver errors are responsible for 94% of car accidents (U.S. Department of Transportation National Highway Traffic Safety Administration, 2015). However, for a transitional period, it must be assumed that roads will carry both non-automated and automated vehicles. Thus, automated vehicles will not always be interacting with other vehicles using an ADS. Under these circumstances, the driver of the automated vehicle might be required to interact with the surroundings to improve the safety.

2.3 Application of Systems Engineering to a SoS

A SoS is defined as a system integrated with other systems that are heterogeneous and operate independently of one another (Jamshidi Mohammad, 2011). Special terms are used to characterize a SoS, including "Autonomy," "Belonging," "Connectivity," "Diversity," and "Emergence" (Boardman John, 2006). The ADS, the driver of the automated vehicle, the surrounding mobility, such as surrounding vehicles and motorcycles, and the environment interact with each other to constitute the complete transportation system. Those systems are independent, and their interactions define the overall safety of the system. Therefore, we define a SoS as one that recognizes the automated vehicle, the ADS, the driver, the surrounding mobility, the pedestrians, the ICT systems, natural environment and physical environment as constituent systems.

Lane and Bohn (2013) proposed the use of System Modeling Language (SysML) (Balmelli Laurent, 2007, and Friedenthal Sanford, 2014) to support SoS Engineering (SoSE). First, the constituent systems are defined in a context diagram. Next, the capabilities of the SoS are defined using use cases, which are clarified using sequence diagrams. These sequence diagrams



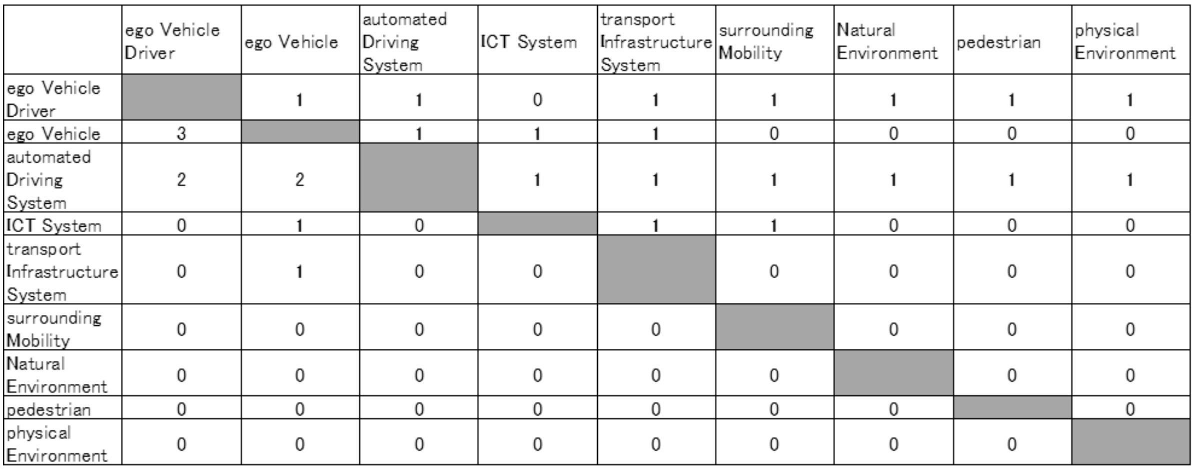
[Figure 1] The result of context analysis of the SoS Architecture

are in turn used to describe operational scenarios that explain the interactions between the constituent systems. An earlier study (Lane Jo Ann, 2013) refers a guidebook by the Department of Defense (DoD) on the application of systems engineering processes to SoSE (DoD, 2008). However, in this paper, we focused on the “understanding systems and their relationships” aspect of SoSE. We demonstrate the steps and present detailed use cases by combining the constituent systems based on the relationships between them after first describing the context diagram of the SoS. The most important point of our approach is to keep the relationships defined in the context diagram.

3. Context Analysis of the SoS Architecture

This section describes the context analysis of the SoS surrounding the automated vehicle. The purpose of analyzing the context of the SoS architecture was to identify safety improvements associated with the introduction of automated vehicles. Automated vehicles need to collect information from the surrounding environment; moreover, the surrounding environment influences the ADS’s driving behavior. Therefore, the interaction between the ADS and the environment is crucial. For the context analysis, we refer to results of HAVEit, accident cases in current roads. We have also done experiment to analyze the interaction between the driver and the automated vehicle. However, this paper only focuses on showing the results.

The characteristics of the current transportation system were first analyzed to clarify the context of the SoS. The constituent systems necessary for the successful introduction of automated vehicles were considered. These



	ego Vehicle Driver	ego Vehicle	automated Driving System	ICT System	transport Infrastructure System	surrounding Mobility	Natural Environment	pedestrian	physical Environment
ego Vehicle Driver		1	1	0	1	1	1	1	1
ego Vehicle	3		1	1	1	0	0	0	0
automated Driving System	2	2		1	1	1	1	1	1
ICT System	0	1	0		1	1	0	0	0
transport Infrastructure System	0	1	0	0		0	0	0	0
surrounding Mobility	0	0	0	0	0		0	0	0
Natural Environment	0	0	0	0	0	0		0	0
pedestrian	0	0	0	0	0	0	0		0
physical Environment	0	0	0	0	0	0	0	0	

[Figure 2] A matrix describing dependency relationships between each constituent system

were the ego vehicle, the ego vehicle driver, the ADS, the transport system infrastructure system, the surrounding mobility, the natural environment, the pedestrians, and the physical environment. The term ego vehicle indicates the automated vehicle that forms the central subject of this paper. The ego vehicle driver indicates the driver of the ego vehicle and “the driver” indicates “ego vehicle driver”.

The use cases of the SoS were described using sequence diagrams to define the interfaces between the constituent systems. Because our focus was on safety, the use cases were as described in HAVEit, comprising use cases that included some element of risk. Analysis of the use case scenarios with sequence diagrams derived the interfaces. Figure 1 shows the constituent systems and the interfaces between them on an internal block diagram using the all results of use case analysis. The relationships among constituent systems should be kept up to analysis and design of the constituent systems.

The dependency relationships shown in Figure 1 were arranged in a matrix (Figure 2), in which the constituent systems made up the rows and columns. If an element in the row received items from the corresponding column in Figure 1, the cell showed the number of items, e.g., the ego vehicle driver in the first row received information from an ego vehicle in the second column. If the ADS was driving the ego vehicle, the ADS received the biggest number of transfers of information from the other constituent systems (Table 1). This number could be checked by the sum of each element

<Table 1> Sum of the number of relationships to receive information

Constituent systems	Sum of the number of relationships to receive information
Ego Vehicle Driver	7
Ego Vehicle	6
Automated Driving System	10
ICT System	3
Transport Infrastructure System	1
Surrounding Mobility	0
Natural Environment	0
Pedestrian	0
Physical Environment	0

of each row. Moreover, in the same matrix, the ego vehicle driver collected many types of information; however, the ADS required the greatest amount of information in order to drive the ego vehicle, and the ego vehicle driver did not need to precisely perceive and recognize the information. In the case that the ADS fails or cannot gather the necessary information, there is a gap between the perceptions of the ADS and those of the driver. Therefore, the driver's functionality while the ADS is running must be sufficient to bridge the perception gap.

4. Functional Analysis for an Ego Vehicle Driver

4.1 Combining Related Constituent Systems

The interactions involving the driver are described in the context defined above. When describing the driver's functions, we must consider the complete SoS, including the influences of the other constituent systems. However, if we attempt to model all the constituent systems in order to derive the driver's functions, the detailed behavior will not be clarified, because some of the interactions are not related to the driver. Only the necessary constituent systems should be considered.

In the SoS related to the automated vehicles, the behavior of the ego vehicle driver and of the ADS define the behavior of the ego vehicle. The ego vehicle is seen as an interface linking the decisions of the driver and the behavior of the other constituent systems. When analyzing the driver's functions, the driver, the ego vehicle, and the ADS should be considered together. Moreover, related constituent systems to the driver are important in deriving the driver's functions, since they influence the driver's decision making. Hence, the specific use cases were defined by combining these systems according to the relationships in Figure 1. These combinations of the constituent systems helps to clarify the context related to the driver within the simpler assumptions than whole ones.

<Table 2> Combinations of constituent systems related to the driver

	Combination of constituent systems
1	driver, ego vehicle, ADS, transport infrastructure system
2	driver, ego vehicle, ADS, surrounding mobility
3	driver, ego vehicle, ADS, natural environment
4	driver, ego vehicle, ADS, pedestrian
5	driver, ego vehicle, ADS, physical environment

In Figure 1 and Figure 2, the ego vehicle driver receives each state of the transport infrastructure system, the surrounding mobility, the natural environment, pedestrians, and the physical environment in addition to the ego vehicle and ADS. Table 2 shows the combinations of constituent systems to consider the use cases related to the driver. The use cases assumed according to the combinations and relationships among constituent systems defined in Figure 1. For instance, a use case protecting the safety of pedestrians was defined for the first combination in Table 2. Note that the ego vehicle driver, the ego vehicle, the ADS, and the pedestrian were considered as systems related to each other for this case. In this use case, a pedestrian attempted to cross the road while the ego vehicle was moving forward. Successful patterns were analyzed using use cases resulted in the combinations of Table 2.

This paper deals with simple use cases consisted of selected constituent systems as the first step of our approach. However, those simple use cases can be basis for analysis of multiple and mixed constituent systems. For example, when more pedestrians are added in the use case, protecting the safety of pedestrians, the new pedestrians influences the basic use case by following patterns; before the basic use case happens, in the middle of it, and after it. Same interactions are repeated in the additional part, when considering only successful situations. As Wickens mentioned (1984), there are attentional resources distributed to perception, decision, response execution, and working memory. Driver's processing capability should be considered in a case of failure, because the driver might not have enough space on their brain to perceive, make the decision, and select response with complex environment such as with several pedestrians. If the attentional resources are completely used with some processes, the driver cannot precisely behave to avoid risks. The failure is not discussed in this paper. On the other hand, this basic use case can be extended to add other constituent systems in successful situations, such as a pedestrian and physical environment.

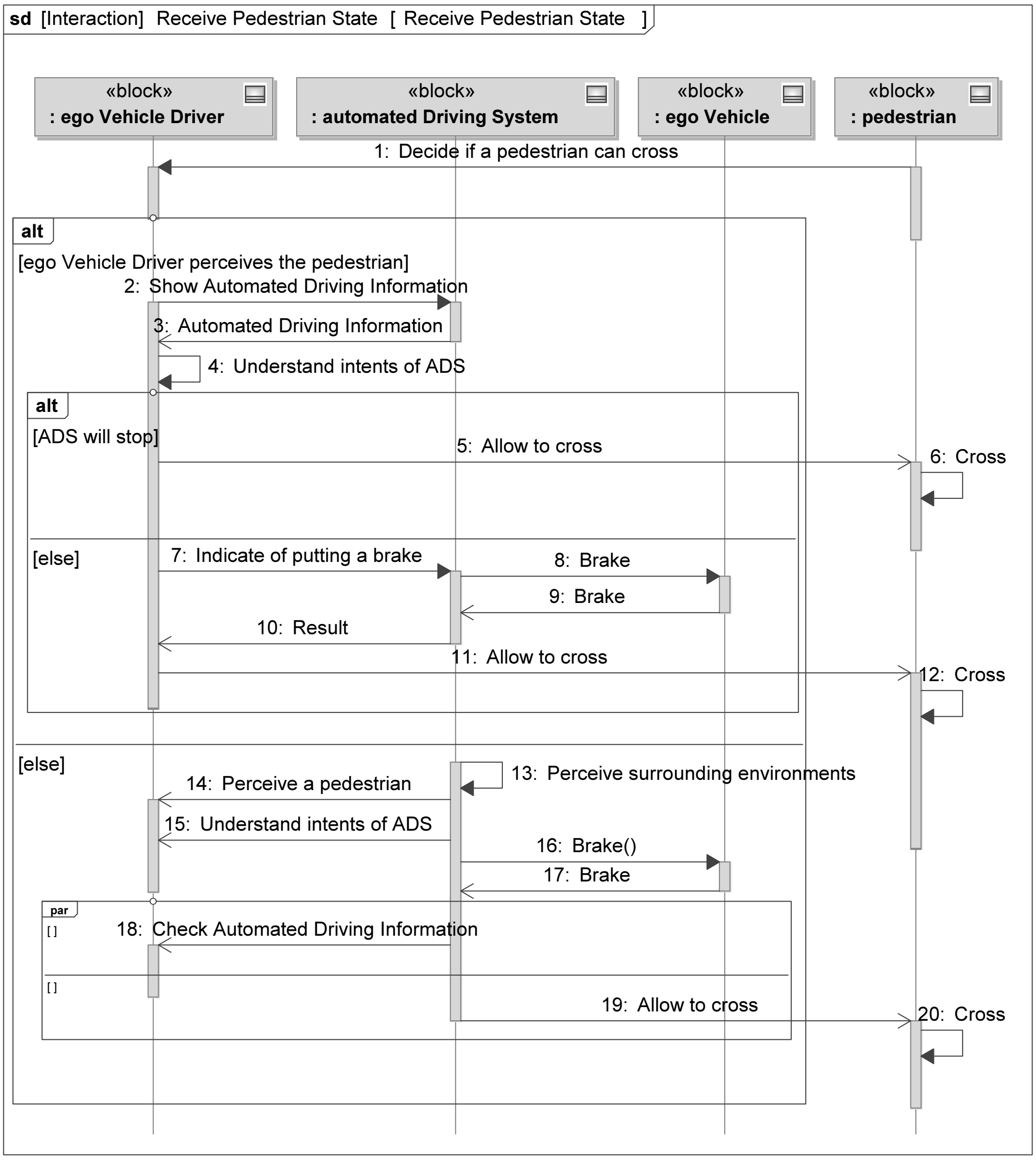
4.2 Use Case Analysis

Use cases are described by sequence diagrams. Constituent systems related to the use case are placed on the lifelines of the diagram to analyze interaction between them. The arrows define messages to call functions of the target lifeline. Figure 3 demonstrates the use case on the safety of pedestrians. The purpose of this use case was to describe how the driver should react by perceiving the pedestrian's state while the ADS was running.

In Figure 3, first, the pedestrian confirmed his/her intention to cross the road before crossing. When a pedestrian attempts to cross a road, he/she cannot sometimes understand the intentions of the driver about the next actions only by observing the behavior of the vehicle. In this situation, the pedestrian attempts to observe the driver in order to recognize the next decision of the driver about control. The, The message "Decide if a pedestrian can cross" indicates that he/she asks to driver to show their agreement with crossing the road.

Second, two cases were used to explain how the driver could perceive the pedestrian and make a decision. When the driver perceived the pedestrian before the ADS, the driver needed to understand the intent of the ADS from its driving information to predict what would happen on the road over the next few minutes. The driver then signaled the pedestrian to indicate that he/she could cross if the driver was clear that the ADS would stop the ego vehicle. If the driver understood that the ADS would not stop the ego vehicle, the driver would command the ADS to stop it, and then the driver would signal the pedestrian. If the ADS perceived the pedestrian before the driver, it let the driver understand its intentions in order to guard against the risk of a collision with the pedestrian. Then, the ADS would signal the pedestrian.

In each use case analysis following the combinations in Table 2, the driver needed sufficient information to understand the intent of the ADS. In the pedestrian case of Figure 3, the driver needed to understand the intentions



[Figure 3] A Sequence diagram for analysis of a use case

of the ADS with relation to the pedestrian. If the ADS showed only its current and next actions without the driver's understanding, the driver could not predict the outcome. This is dangerous if the ADS then transitions driving authority to the human operator. The functions of the driver must include "understanding the intent of the ADS." On the other hand, the driver may not be attentive on driving and may not understand the environment as soon as necessary. Thus, to support the function, the ADS must make the surrounding environment apparent to the driver. In addition, the driver should properly receive the information from the ADS.

If the driver perceives the pedestrian before the ADS, the driver must communicate the intentions of the pedestrian to the ADS before

<Table 3> Driver's functions

Receiving the pedestrian state	
1	Telling the intent of the pedestrian to the ADS
2	Telling the intent of the ADS to the pedestrian
Receiving the driving information	
1	Understanding the intent of the ADS
2	Receiving surrounding information from ADS

signaling the pedestrian to cross. This demonstrates that the communication between the two humans, i.e., the driver and the pedestrian, might exclude the ADS because the pedestrian will not always be aware that the vehicle is being driven by the ADS. It happens under the situation that the automated vehicle does not have any functions to show the current driving mode to the pedestrians. In this case, the driver must sometimes act as the interface between the ADS and pedestrian to show the intent of the ADS. Although the driver is not the main operator of the ego vehicle while the ADS is running, he/she is sometimes required to act as a second brain to reduce risk. Since human behavior is unpredictable, the driver should understand that the environment including humans, such as pedestrians and drivers of surrounding mobility, includes the difficult situation for the ADS to understand.

From the relationships defined in Figure 1, the functions of the driver included "receiving the pedestrian state" and "receiving the driving information." Based on the analysis of the use cases, we were able to decompose these into more detailed functions (Table 3). Deriving the use cases from interactions defined in the context and analysis allowed traceability from abstract interactions to detailed interactions. The functions derived using our approach are refinements of functions defined at the context level.

Through this analysis, the undefined relationships in Figure 1 could be identified. Both the driver and the ADS provided information to the pedestrian as well as received it. As a systems engineering processes, the system model about the context of the SoS at the upper level should be modified to reflect the results of these detailed analysis.

5. Conclusions

This paper defined the driver's functions by combining closely related constituent systems for specific use cases of the SoS surrounding an automated vehicle. The approach clarified the interactions between the constituent systems in the target use cases. The functions derived by our stepwise approach were refinements of functions at the context level. Because the relationships defined on the context diagram were kept when deriving the functions, traceability of the driver's functions was maintained by this approach. The more specific focus of the function analysis allowed the relationships that were missed in the context analysis to be discovered.

This paper discussed about the successful situation. As the next step, the basic use cases defined here will be expanded to analyze emergency situations, such that an automobile suddenly changes the direction to move to the next lane. In addition, we will explore use cases related to other constituent systems to derive their detailed functions and to take real situations into consideration in future studies.

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