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The role of context and perception of road rules in the pedestrian crossing decision: a challenge for the autonomous vehicle

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Abstract. Pedestrian behavior is based on both cognitive processes and the construction of social knowledge and representations. The results of various studies we have conducted showed that pedestrian compliance with road rules varied according to crossing regulation, built environment, gender and age. They also addressed the role of rule perception and internalization. Finally, they showed how informal learning, through observation, of road rules can explain the construction of conventional level rules, the application of which is contextual. These different elements demonstrated how knowledge of social norms can be an issue for the autonomous vehicle.

Keywords: Pedestrian · Compliance · Rule perception · Social norms

The decisions we make are not always the most rational and prudent. We all know that we do not comply with all existing health, hygiene and safety rules, even if we are fully aware of them. Knowing the traffic rules is not enough to guarantee their application. To fully understand user behaviors, taking into account cognitive mechanisms is not enough. Pedestrian behavior is also based on the construction of social knowledge and representations of the roles of different users, rules and risks.

In this chapter, we propose to review studies that highlights the role of individual and social factors in pedestrian crossing decisions – and how these factors can challenge the implementation of the autonomous vehicle. Specifically, we begin by presenting the results of various studies we have conducted showing that pedestrian compliance with road rules varies according to crossing regulation, the built environment, gender and age. We then address the role of rule perception and internalization. Finally, we emphasize how informal learning, through observation, of road rules can explain the construction of conventional level rules, with contextual application. We end by discussing how knowledge of social norms can be an issue for the autonomous vehicle.

Situational and individual variations in compliance with the rules

Spatial and temporal compliance

It is a truism to say that user behavior does not always comply with the rules of the road. However, there is a need to better understand the situations in which this lack of compliance occurs and the reasons for it. For example, in a study examining reported and actual behavior of children aged 5-6 years [1], we observed that children are aware of pedestrian rules and report compliance with them, but do not apply the same rules when they are observed on the way home from school with their parents. Knowing a rule does not necessarily mean complying with it. This compliance, which we studied especially among adults, varies in particular according to the physical environment and the perception of road rules.

In a real-life study [2], we observed 400 pedestrians (200 men and 200 women) aged 18 to 55 years at 4 intersections, including 2 without traffic lights. The results showed that spatial conformity (use of the pedestrian crossing) varies according to the configuration of the intersection: pedestrians are more compliant with the use of the pedestrian crossing in the presence of a traffic light than in its absence. Crossing regulation is most often implemented when the infrastructure is complex and/or traffic or pedestrian density is high. The presence of regulation not only acts as a reminder of the injunctive norm, but can be interpreted as a sign of a significant dangerousness of the crossing, leading to increased spatial compliance among pedestrians, whose compliance thus varies according to the road layout.

A subsequent study [3] observed pedestrian behavior at crossings regulated by pedestrian traffic lights by combining in situ observation of the behavior of 422 French adult pedestrians with questionnaires collected after the crossing. The results showed that the size of pedestrian groups and traffic density are associated with safer behaviors, while the presence of vehicles parked near the crossing site are associated with higher risk behaviors. In addition, the driving experience appears to increase safety behaviors and alertness. Pedestrians who report difficulty crossing a road look more towards the traffic light and tend to cross the road in a straight line rather than diagonally. In addition, pedestrians who have already fallen into the street - reported more by older pedestrians - look more closely at other pedestrians before and during the crossing. In terms of temporal compliance (pedestrian green light crossing), pedestrians who cross against the red pedestrian light look less towards the ground and the light, but more towards the traffic before and during the crossing than those who complied with the traffic light. They also run and jaywalk more often. It appears that pedestrians anticipate pedestrian red light violations before they arrive at the intersection to be crossed, depending on traffic conditions and not the color of the pedestrian light, as they look less towards the traffic light before crossing. These behaviors observed before and during the crossing could reveal a deliberate time-reduction objective, where the intentional violation of pedestrian red lights goes hand in hand with the vigilance of incoming traffic before and during the crossing, suggesting an awareness of the risk pedestrians take. The role of two gaze targets (traffic light and incoming traffic) should be further examined as possible indicators of an intention to violate the crossing time rule.

Variation according to gender and age

In addition to these variations in spatial and temporal compliance, it appears that pedestrian behavior also varies by sex. The results of Tom & Granié [2] showed differences between men and women in temporal compliance and in visual research before and during the crossing. Men's visual focuses are mainly on moving vehicles, while women's visual attention is mainly focused on other pedestrians. In addition, these results show that the visual attention of males does not vary with the crossing configuration (with or without pedestrian light) or the crossing phase and remains focused on the dynamic elements of the environment, such as moving vehicles. On the contrary, women, when crossing with traffic lights, mainly look at the pedestrian light before the crossing and at other pedestrians during the crossing. They seem to be more attentive than men do to the static elements of the scene and - in the absence of external regulation to facilitate decision-making - to the social environment rather than the physical environment. The visual centering of female participants on other pedestrians, particularly in the absence of a time rule for crossing, can be interpreted as the result of a stronger social influence and normativity on decision-making among women than among men.

In another in-situ study [4], we observed, using the same observation grid as in Tom & Granié [2], 682 pedestrians (375 women) of two age levels (middle-aged and older adults) at five sites in a major French urban center. The sites all included pedestrian crossings, in mid-block or intersection, regulated or not by traffic and pedestrian lights. The results showed that, in the situation of regulated pedestrian crossings, older people comply with the legal and safety rules more often than middle-aged adults do. They focus on a more diversified number of different visual indicators in preparation for their crossing. Their gazes are more focused on the ground, both before and during the crossing. They also stop more on the sidewalk before crossing, cross when the light is red for traffic, without running. However, the more cautious behavior of older pedestrians is accompanied by less traffic control than among younger adults, who are more likely to violate the pedestrian light rule. Behavioral control and compliance with the rules of caution seem to be accompanied by a delegation of responsibility to the regulatory system in crossing decision-making and a concomitant decrease in traffic condition monitoring.

Variation according to the built environment crossed

This contextual compliance seems to be based, at least among pedestrians, on their perceptions of the crossing environment and, more particularly, on the inferences that pedestrians make from certain clues found in the environment about the pedestrian-driver balance of power.

In an exploratory study [5], we analyzed the role of the environment, understood in a broader definition including the built environment, on pedestrians' perception of the situation. We used a focus group methodology with two groups of five and six pedestrians. We had them discuss the walking pleasantness and facility of crossing 20

environments, photographed in order to give a 180° view of the road scenes. The results showed that two types of crossing environments are positively rated by the pedestrians interviewed. Some pedestrians prefer environments that are complex for the driver to deal with (wide sidewalks, lack of parking, markings and pedestrian crossings, context animated by the presence of coffee houses and shops), i.e., environments containing ambiguity and uncertainty [6], requiring increased attention of the drivers towards pedestrians. On the contrary, other pedestrians prefer environments that organize and simplify pedestrian use (presence of pedestrian crossings, well-delimited sidewalks, clear visibility, in a rather calm context, and with moderate traffic). In these environments, legibility and predictability are important, both for the driver and for the pedestrian - thus facilitating decision-making, thanks to the presence of a highly regulated space.

In a second part of the same research project, we set up an experimental study [7] whose objective was to identify the variations produced in decisions to cross, depending on different types of urban environments. This experiment also aimed to identify the environmental characteristics that pedestrians take into account and the inferences they develop and use to explain their decision to cross a road. A series of photographs presenting five different types of environments (i.e., city center, inner suburbs, public housing in the outskirts, commercial zone in the outskirts and countryside) were presented to 77 participants divided into three age groups (pre-adolescents, young and middle-aged adults). Their decision to cross or not to cross, their perception of pleasantness and safety, and the elements they considered when making a decision were collected for each environment presented. The quantitative results showed that pedestrians' perception of the pleasantness and safety of public spaces, in terms of walking, varies widely across urban environments. In addition, the decision to cross varies significantly depending on the environment. Pedestrians were much more likely to make the decision to cross the street in the city center than in the other sites presented. The qualitative analysis of the interviews showed that the presence and function of buildings, the quality of sidewalks and the presence of marked parking spaces are key factors in explaining their decision to cross, allowing them to deduce pedestrian and traffic density and vehicle speed.

In these studies too, it is clear that the rules are used flexibly by pedestrians, depending on the context, and especially on the situation in which the pedestrian and the driver find themselves. This reveals how the pedestrian, a member of a dominated and vulnerable group in the road space, finds himself in need of inferring information about the drivers, a dominant group in terms of density, potential nuisance to the pedestrian and urban development. Thus, pedestrians place great emphasis on environmental analysis, looking for clues to understand their place in the environment in the balance of power with the driver, and driver's current and predictable behavior.

We found further evidence of this estimation of power balance in the study of perceptions of crossing environments among pre-adolescents [8]. Three hundred and forty-two secondary school students aged 11 to 16 were asked about their perceptions of the level of pleasantness, safety and convenience of five crossing environments near secondary schools (i.e., the three schools from which the participants came, one from another French region and one from Quebec, Canada). Each environment was represented through five photographs, reproducing a 180° vision from the crossing

point. Analysis of the comments showed that the most highly positively rated aspects of the presented environments concern the aesthetic appeal of residential housing, the impression of space emerging from the width of the lanes, as well as the large number of pedestrian crossings and recent road markings.

On the contrary, the relative anarchy of parking also gives pre-adolescents the feeling that pedestrians are not taken into account and respected by drivers. Vehicle parking and the type of built environment therefore seem to be important indicators, allowing both high school students and adult pedestrians to infer the current and future behavior of drivers [7]. Similarly, the presence of traffic lights can be negatively perceived by some pre-adolescents who perceive them as an indicator of traffic density (lights are only used when there is a need to regulate vehicle flows) and therefore of more complex and dangerous crossings. On the contrary, according to other pre-adolescents, the presence of traffic lights makes crossing easier, because it allows a delegation of decision-making to the environment, lowering the feeling of danger. This protective effect of traffic lights had already been pointed out in pre-adolescents who are not very confident about independent travel [9] and observations of senior pedestrians seem to show that the regulation of pedestrian-driver interactions by the layout is also sought when perceptual-cognitive abilities decline [3, 4].

Thus, one of the five environments presented is denigrated by all pre-adolescents, including those who frequent it on a daily basis. Participants explained this negative perception by the absence of sidewalks and the degradation of ground markings, including pedestrian crossings, which is perceived as the symbol that pedestrians are not taken into account in the environment. Inversely, the environments perceived positively by pre-adolescents have in common the strong presence of recent road markings, which, like the width of the pavements, not only mark and differentiate everyone's spaces [5] but also reinforce the real but also symbolic visibility of pedestrians.

The role of rule perception

Compliance with traffic rules is not only subject to the local context at the time of decision-making. It also varies according to the perception of road rules themselves. Thus, perception of danger and risk associated with pedestrian behavior, normative beliefs and reported behaviors differ according to whether or not the danger to oneself is intentional.

Differences between errors, transgressions and lapses

As part of a research on the influence of educational practices on risky behavior, we interviewed 258 adult parents (104 males and 154 females), aged 25 to 54 years old, about their perception of danger, self-risk, normative beliefs and reported behaviors in response to injury-risk pedestrian behavior, using the Road User Behavior Perception

Scales (EPCUR) [10]. EPCUR is composed of four subscales, each randomly presenting 16 pedestrian behaviors. This list of behaviors, based on Elliott and Baughan's tool [11] and previous research on pedestrians [10], differentiate between non-hazardous transgressions (for example, "crossing at a red pedestrian light in a street without a car") and dangerous behaviors without transgression (for example, "crossing while forgetting to look"). The first subscale (Declared Behavior Scale) measures the frequency with which the individual reports manifesting each behavior. In the second subscale (Hazard Perception Scale), the individual must assess the level of danger they perceive about each situation. In the third subscale (Risk Perception Scale), the individual must intuitively assess his or her own probability of having an accident if he or she engages in the above-mentioned behavior. The fourth subscale (Normative Belief Scale) measures individual cognitive norms about the acceptability of behavior [12, 13]. The individual must estimate the level of severity of the transgression he or she attributes to each of the behaviors presented.

Analyses of the responses at these different scales showed that individuals differentiate two groups of behaviors for each scale: (1) self-endangerment behaviors, including lack of visual information taking, (2) offence and risk taking behaviors, including absence of temporal or spatial conformity (lights or pedestrian crossings) and errors during pedestrian-vehicle interaction. These analyses of the EPCUR scales thus revealed that pedestrian behavior, whether in terms of perception of danger and risk, normative beliefs or declared behavior, is differentiated by adults on a single dimension: intentionality or not of the endangerment. Moreover, it appears that intentional behaviors include both offences against legal rules and diagnostic errors, concerning the estimation of intervehicular time and the influence of other pedestrians. This lack of differentiation among pedestrians between infringements and errors as shown in this study raises questions that we addressed to other studies. Using the theoretical framework used by Reason in the construction of the Driver Behavior Questionnaire [14] and the scales of aggressive [15] and positive [16] driving behaviors towards other users, we developed the Pedestrian Behavior Scale (PBS)[17, 18].

The 47 items of this scale are based on existing validated versions of the PBQ [19-21], as well as other reported pedestrian behavior scales [10, 11], and differentiate between 5 types of pedestrian behavior: 1/ Violations, defined by a deviation from the legal rules of the highway code concerning pedestrian behavior (10 items); 2/ Errors, defined as decision-making that places the pedestrian in danger, but without violations of the legal rules (11 items); 3/ Inattentions, defined by inappropriate behaviors related to a lack of concentration on the task (8 items); 4/ Civic behaviors, defined by behaviors to calm social interactions (5 items); 5/ Aggressive behaviors, defined by conflicting behaviors with other users (6 items). Following Torquato and Bianchi [20], "filter" items were added (7 items).

Study 1 [17] was conducted with 276 students (175 female and 101 male) aged 26 to 40 years. Factor analyses revealed five axes: "violations or errors during the crossing", "inattention", "violations or errors during travel", "aggressive behavior", and "positive behavior". Study 2 [18] was conducted with 343 participants (217 female and 126 male) aged 15 to 78 years. Here, factor analyses revealed four axes. Factor 1 "transgression" includes legal violations and error items. Factor 2 includes

"inattention" items. Factor 3 is composed of items of "aggressive behaviors" and factor 4 includes items of "positive behaviors".

The main difference between the factor structure of the DBQ and the Pedestrian Behavior Scale (PBS) is that, contrary to the DBQ for drivers, the transgression axis of the PBS includes both offence and error items. However, this result is consistent with Elliott and Baughan's study [11] on the adolescent pedestrian behaviors, whose "unsafe street crossing" dimension is composed of both error and violation behaviors. Similarly, these results can be compared to the previously cited validation study [10], which also differentiated between self-endangerment behaviors (inattention) and intentional risk-taking behaviors (error-transgression). In their perception of pedestrian rules and compliance behavior, it seems that individuals differentiate behavior according to whether or not there is prior intention (present in errors and violations, but not in inattentions) rather than on the basis of objective (consequences of the act for themselves and others) or legal (infringement or not of a traffic rule) criteria.. These risk-taking behaviors (i.e., the deliberate engagement in behaviors in which accidental risk is perceived [22]), are either deviations from legal rules or from informal rules of caution. In other words, French pedestrians do not seem to clearly differentiate legal rules and cautionary rules. In contrast to pedestrians, the studies using the DBQ conducted on drivers (and particularly on French drivers [23]), all showed that drivers differentiate, within intentional risky acts, between behavior that violates legal rules and error behavior. This suggests that legal and social rules are less differentiated among pedestrians than among drivers.

Differences in social value between self-endangerment and risk-taking

This lack of differentiation between transgression and error in pedestrians in favor of a broader differentiation between intentional risk behavior and self-endangerment related to inattention is perceptible from adolescence onwards.

A recent study we conducted analyzed the evolution of relationships with parental and peer behaviors on a sample of 2,473 secondary school students aged 10 to 16 years, equally distributed in terms of gender and age [24]. Secondary school students were asked about their perceptions of the frequency - for themselves, their parents and their peers - of intentional or unintentional risky behaviors as pedestrians. The results showed that secondary school students systematically assess their behavior as being more often risky than they reported for their parents, and less often risky than they reported for their peers, regardless of the type of behavior. However, the results showed differences according to age, gender, but also the type of behavior mentioned. Indeed, regarding intentional risky behaviors (and unlike unintentional risky behaviors), the gap between Self and parents is larger for boys and increases with age, while the gap between Self and peers decreases with age and is greater for girls. This suggests that different logics are involved, for each type of behavior (intentional versus unintentional), depending on the way in which relationships with parental and peer norms are constructed. They also show that there is a gap between actual social behavioral norms and adolescents' perceptions of them. By gradually conforming to peer norms on intentional risk behaviors but not on self-endangerment, adolescents,

particularly boys, seek to confirm themselves as individuals separated from their family group and to confirm themselves as members of their sex group. Our results among adults [10] seemed to confirm that for men: intentional risk-taking was more acceptable than unintentional endangerment. This shows that intentional risky behavior also seems to be a way of social valuing, at least for adolescent boys.

As we will see, this valuation of intentional risky behavior among men may be the consequence of the socialization process experienced by young pedestrians, who are more confronted during their acculturation on the road with the normative behaviors of their social environment than with the legal rules concerning pedestrian behavior.

Socialization to pedestrian rules and behaviors

Informal learning of traffic rules

To better understand the state of skills and forms of behavioral learning in childhood, we used the auto- and allo-confrontation method [25] with nine pre-adolescents aged 11-12 (5 girls and 4 boys) in the first year of secondary school, observed and then questioned about their behavior during their walk from home to school [9]. Our results showed first of all that journeys seem to be affected by a form of routinization based on behavioral and travel habits and a strong knowledge of the specific traffic contexts on the route taken, leading to a strong sense of control of the situation in everyday travel environments. However, children are aware that they cannot use this knowledge in unknown environments, which in turn leads to greater compliance with legal rules when the context changes. In addition, while some important pedestrian skills to handle crossing situations [26] appear to be fairly well mastered by the children in our sample (i.e., crossing site selection, environmental analysis and time gap estimation), compliance with road rules is far from systematic.

Children comply with the rules according to their perception of the constraints they involve, their knowledge of the road environment and their assessment of traffic conditions. Moreover, their observation of offences committed by pedestrians and motorists leads them to put into perspective both the validity of the rules and the need to comply with them. Their expectations of driver behavior are all the more limited because, in accordance with previous studies [27], they perceive drivers as not respecting the rules, particularly those governing their interactions with pedestrians. Thus, the road environment is often seen as hostile, insecure, unpredictable, and vehicle-dominated and the relationship with the driver is not perceived as an interaction but as a relationship of driver domination over pedestrians [28]. In this respect, these results are in line with the results previously presented [7, 8] in which pedestrians' judgments about environments are based mainly on the estimation of the pedestrian/driver balance of power. The 11-year-old pedestrians interviewed thus use their own rules, which are defensive in nature, to the detriment of legal rules. Moreover, this and other studies [29] show that, in this situation as in others, the child acquires knowledge both through direct confrontation with the situation and through observation of the behavior of others.

During this informal learning, the child can reproduce the behaviors that can be observed in experienced adult pedestrians, but not the skills that lead to their

decisions. Traffic knowledge among the young pedestrians interviewed is only based on informal learning of the road space, as part of their usual daily journeys. They identify rules of action, based solely on the behavioral patterns they can observe in other pedestrians, without formal learning of the rules and cognitive skills involved in pedestrian behavior.

Representation of traffic rules and compliance

The studies we have conducted show the contextual variability that children observe in the behavior of others leads them to categorize road rules in the conventional domain, defined in social domain theory as gathering rules of an arbitrary, relative, modifiable and contextual nature [9, 30]. This categorization of traffic rules at the conventional level affects the compliance of individuals, because conventional rules remain external and are not internalized (i.e., integrated into the individual's value system) [31].

In one of the studies mentioned above, conducted with 162 children (83 boys and 79 girls) in the last year of kindergarten (5-6 years) [1], we observed both the knowledge of road rules, their compliance and internalization and their behavior during the accompanied home-school journey. The rule governing the behavior is considered internalized if the individual avoids to commit this behavior even in the absence of any external disapproval [32]. The results revealed that children with higher internalization of traffic rules report more cautious and more controlled behaviors on the street.

However, internalization appears to vary with age. Our results on young adolescents aged 11 to 15 years [33] showed that, like the perception of danger, internalization is an important inhibitor of risky pedestrian behavior. However, the reported risky pedestrian behavior increases during adolescence, while the perception of danger and the level of internalization decrease.

The challenges for the autonomous vehicle

All the studies presented show that pedestrian behavior at the time of crossing is not based on the traffic rules of the Highway Code. They are based on social norms in which the behaviors to be adopted vary according to the situations, gender and age of individuals, with some intentionally transgressive behaviors being valued by certain social groups. These elements of knowledge about social norms are important to take into account in current thinking about autonomous vehicles for several reasons.

First, the individual has access to these social norms regarding travel in road space before learning the legal rules of the Highway Code. The individual can observe these social norms in action early on, during his or her first travel experiences, as a pedestrian but also as a vehicle passenger. It is therefore important to understand their learning, which will guide the perception of risk and the categorization of legal rules and thus the individual's behavior and compliance with legal rules, throughout life.

Secondly, it must be taken into account that these social norms govern the actual functioning of road space, more than legal rules. These social norms (what the subject may define as "normal" behavior to adopt when travelling in an urban environment) are not necessarily in line with legal norms. The more the social norms to which users

refer and comply differ from legal norms, the more difficult their behavior may be to anticipate, if these social norms are not known by the users with whom they interact. Individuals must therefore acquire knowledge both of the social norms to which they must comply, but also of the social norms to which other types of users comply.

Making decisions in road space – whether as pedestrian or driver – requires anticipating the behavior of others according to the role they play in that space (for example, the use of another mode of transport) and the social rules that are linked to that role [35]. Thus, knowledge of legal norms is not sufficient to anticipate correctly the behavior of others, it is also essential to know and understand the different social norms by 1/ identifying them through the behavior patterns of different types of users [29] ; 2/ within the same type of users, differentiating them according to certain criteria of belonging to social groups: women, men, young people, the elderly, motorcyclists, truck drivers, drivers of powerful cars, etc. [9]. These social categorizations will allow a classification of observed behaviors that will facilitate the anticipation of other users' behaviors, depending on the situation, their roles in the urban space, and refined by taking into account their membership of a certain social group [36]. As a result, expectations of others are not based on legal norms, but on the social norms corresponding to their social group and mode of travel. Knowledge of social norms is thus essential to understand and anticipate the behavior of others during interactions between users in the road space. These elements should be considered in the ongoing discussion on the autonomous vehicle in all industrialized countries.

This knowledge can also be taken into account in the necessary discussions on the pedestrian behavior models that will have to be implemented in the autonomous vehicle, so that it correctly anticipates the behavior of the pedestrians with whom it is likely to interact. The research presented in this chapter showed that pedestrian behavior is strongly related to context (presence or not of regulated crossings, built environments of crossing locations) and individual variables (gender, age, but also time pressure). They also show that pedestrians modify their behavior according to the balance of power with the driver, which they consider more or less favorable depending on the situation. The autonomous vehicle must therefore take into account the fact that the pedestrian's behavior towards it may vary according to the spaces crossed but also according to individual characteristics.

They can be taken into account in the discussions on the behavior models that must be implemented in the autonomous vehicle so that its behavior is understandable and predictable by users of the different transport modes. Using social norms in the model of driver behavior would make the behavior of the autonomous vehicle more understandable and easier to anticipate by other drivers but also by pedestrians. For interactions with other vehicles, this consideration of social standards should at least be necessary on a transitional basis, pending a complete homogenization of the fleet of vehicles on the road. It will also be necessary to secure interactions with users of other modes of travel that will remain un-automated. This requires a correct understanding of the content of the social norms used by drivers (which may vary according to culture), interacting with other drivers but also with other types of users. This could be studied through observations in real or virtual situations, but also

through surveys of reported behavior, including gaps between actual behavior and legal rules (i.e., contextualized rules for the use of different modes of transport).

Moreover, since the arrival of the autonomous vehicle is highly publicized, pedestrians may already have built a model of the behavior of the autonomous vehicle, of which they can anticipate a more rational behavior, more compliant with the rules and more attentive to their presence than a vehicle driven by a human. Pedestrians can already attribute a more cautious behavior to the autonomous vehicle than that of other vehicles and adapt their crossing behavior to these beliefs, thinking, for example, that they will always be perceived by the autonomous vehicle, which will not suffer, like humans, from attentional blindness in certain situations. These representations of the autonomous vehicle among pedestrians will have to be studied, as they may ultimately put the pedestrian at risk.

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