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A Legal System to Modify Autonomous Vehicle Designs in Transnational Contexts

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Abstract. Autonomous vehicles, one of the signature technologies of the rapid development of artificial intelligence, have brought about a rapid change in the relevant legal norms and legal mandates. This change makes it more challenging for manufacturers and designers of autonomous vehicles to ensure the legal compliance of their product designs in a more dynamic way. Therefore, rather than approaching the issue from the perspective of judges or the cars themselves, we propose a legal reasoning system applicable to the adjustment of autonomous vehicle design options from the designer's perspective, building on a series of previous studies. Focusing on the circulation of autonomous vehicles between different countries, the system attempts to help designers accomplish the adjustment of design solutions between different legal systems instead of designing new prototypes.

Keywords. legal ontology, conceptual change, reformation, autonomous driving,

1. Introduction

A design-centered approach to regulation is gaining prominence in the EU AI ACT and is thought to enable designers and engineers to influence the role of law in electronic systems to an unprecedented degree [1]. Therefore, compared to existing research on legal ontologies and expert systems that focus on judge's perspective [2] and regulation formalization [3], we aim at designing intelligent systems that will help non-legal-expert-engineers to reason about the legal implications of their designs. Moreover, we would like to address the dynamic character of the task of legal compliance that has not sufficiently been sufficiently discussed in existing research. This dynamism is reflected both in the updating of legal content and in the fact that legal norms change depending on the region, context, object, and other elements. Both AI technologies and related laws are in a constant state of development and contribute to the continuous updating of each other.

To facilitate legal compliance at the design stage, we map legal ontologies and design solutions to an argumentation framework that we developed in previous research

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[4,5,6]. With legal knowledge of symbolic representations, the argumentation framework detects and deals with conflicting parts through inconsistent reasoning to obtain a repaired design proposal. In addition, this system can express the logical processes by which legal distinctions bring about design incompatibilities as well as the reasonableness of modification proposals, and thus has a degree of explainability. It is necessary to point out that the resulting design proposal contains methods to adjust the behaviors of the car, and how to implement these behaviors in engineering needs to be planned by the engineers. We hope that our approach will allow designers to obtain feedback directly related to the design of vehicle behavior, rather than legal knowledge requiring reinterpretation.

For ease of presentation, we take a realistic scenario in autonomous vehicle designs as an example, i.e. adapting a design to different regional regulations. Compared with other basic laws, traffic regulations are characterized by greater clarity and precision, and are therefore more suitable to be dealt with by a logical system of formal expression [7].

We firstly reviewed a range of relevant literature. Legal ontologies, the classic tools for storing and reasoning about legal information, contain many ontologies that express abstract legal knowledge [8,9]. However, these ontologies focus on abstract legal concepts and relationships, lacking the function of giving detection and guidance to the behavior of individuals. There are also some ontologies that portray legal information concretely to specific domains [10]or regions [11]. But most of them are based on the idea that legal rules are regarded as a fixed knowledge base, which makes it difficult to detect and deal with conflicts in a dynamic legal context. Moreover, the OWL1 and OWL2 languages based on Description Logic [12], are not capable of understanding inconsistency and reasoning containing conflicts.

Given that the focus of this study is around detecting and modifying conflicts at a small cost, we deal with the difficulties posed by the dynamics of the legal context for the adaptation of AI design proposals by introducing structured argumentation.In [13], deductive argumentation has been used to express information about the ontology and to perform inconsistent reasoning. There have also been studies using structured argumentation for ontology repair [14]. However, these studies are not centered on legal tasks and do not pay particular attention to the dynamics. Therefore, we have used structured argumentation in past research to explore the adjustment of AI product design in the face of uncertain and inconsistent legal environments [4,5], and how to characterize the dynamic process of obtaining legal interpretations in legal reasoning [6].

Considering the underlying logic, our approach is related to the dynamics of structured argumentation frameworks. In addition, our work primarily operates within the structured argumentation framework, which necessitates accounting for changes in the knowledge base. As mentioned in previous works [15,4,5], our argumentation theory is mainly inspired by the ASPIC$^+$ framework [16,17]. It's worth noting that research in this subarea remains relatively scarce.

2. Example for LeSAC in Transnational Context

The argumentation-based reasoning legal support system for autonomous vehicles proposed in our previous papers is named LeSAC. In order to demonstrate more clearly this system's process of designing program adjustment assistance among transnational legal systems, we use an example to serve as a clue throughout the paper.

Selected rules from UK	**Selected rules from China**
Rule 1: Cars should keep to the left	Cars should keep to the right (**inconsistent**)
Rule 2: Driver should call police	Driver should call police (**same**)
Rule 3: Driver should record and secure scene	Driver should record and secure scene (**same**)
Rule 4: Driver should try to warn others to avoid	Driver should try to warn others to avoid (**same**)
Rule 5: Driver should move the injured person and vehicle if at further risk of being prone to other accidents	Driver should move the injured person and vehicle if at further risk of being prone to other accidents (**same**)
Rule 6: If someone is injured, first aid is encouraged but not obligatory	If someone is injured, first aid is obligatory (**inconsistent**)
Rule 7: Insurance companies must be notified as soon as possible	The location of the accident must be marked before moving the injured and vehicles (**neither inconsistent nor the same**)
Rule 8: Accident liability and compensation needs to be negotiated with the insurance company as well as the other party	Liability for the accident must be determined by the traffic police (**inconsistent**)

Table 1. Selected rules

Example 1. *Suppose an autonomous vehicle that is legal to drive in the UK is undergoing behavioural design adjustments with the aim of exporting it to China. Engineers are currently adapting the design of the car in the event of a collision with a pedestrian to ensure that the design complies with the driving rules in Chinese traffic law.*

This scenario would involve different rules from multiple laws. In order to better demonstrate the functionality of the system in limited space, we have selected eight rules from the UK Traffic Law that are relevant to this example and eight rules from the Chinese traffic law for comparison, as shown in Table 1. These rules cover the situations that may arise when comparing the traffic laws of two countries: (1) parts identical; (2) parts inconsistent; and (3) parts neither identical nor inconsistent, such as requirements in one country which are not found in the other. We have labelled at the end of each norm the type of adjustment it covers.

We simulated 11 specific autonomous vehicle designs based on the selected UK traffic regulations. We call the autonomous vehicle AC and have labelled which norm it corresponds to after each design in terms of its conclusions about behavioural requirements.

1. AC follows the left side of the road (Rule 1)
2. If the AC strikes a pedestrian, the AC immediately reports it to the police (Rule 2)
3. If the AC strikes a pedestrian, the AC stops moving (Rule 3)
4. If the AC strikes a pedestrian, the AC shall record and preserve the accident (Rule 3)
5. At the scene of an accident, AC sends avoidance messages to other vehicles (Rule 4)
6. At the scene of an accident, AC switches on the accident warning lights (Rule 4)
7. If further risky, the AC moves from the accident location to the side of the road to pull over (Rule 5)
8. If there is conscious and competent adults in the car, ask him if he wants to give first aid (Rule 6[3])
9. If the passenger is willing to provide first aid, give appropriate instructions and basic tools such as bandages (Rule 6)
10. If an accident occurs, AC notifies the insurance company immediately (Rule 7)
11. Provide the other party and the insurance company with the necessary information and wait for a decision on liability and follow-up (Rule 8)

[3] Indeed, the UK's regulation of the duty to rescue is complex and involves multiple laws. However, in order to demonstrate the functionality of the system in the limited space available, we take as our scope what is in the Highway Code, i.e. there is no explicit provision for rescue.

3. Reasoning functions in LeSAC

Based on the argumentation theory we present for legal reasoning and AV design supports [4,5,18], we formalise the example given in §2 in the following example and show the changed part of the sets of norms.

Example 2. *Given two legal ontologies from different countries, let $\mathscr{N}^B$ and $\mathscr{N}^C$ denote norms based on traffic laws of the UK and of China respectively:*

$$\mathscr{N}^B = \left\{ \begin{array}{l} r_1 : Driver(x) \Rightarrow KeepToLeft(x); \\ r_2 : Driver(x), CauseAccident(x) \Rightarrow CallPolice(x); \\ r_3 : Driver(x), CauseAccident(x) \Rightarrow Record(x) \wedge SecureScene(x); \\ r_4 : Driver(x), CauseAccident(x) \Rightarrow WarnOthers(x); \\ r_5 : Driver(x), CauseAccident(x), Injured(y), FurtherRisk(y) \Rightarrow move(x,y); \\ r_6 : Driver(x), CauseAccident(x), Injured(y) \Rightarrow \neg obligatoryFirstAid(x,y); \\ r_7 : Driver(x), CauseAccident(x) \Rightarrow NoticeInsuranceCompany(x); \\ r_8 : CauseAccident(x), InsuranceCompany(y) \Rightarrow negotiateLiability(x,y); \end{array} \right\}$$

$$\mathscr{N}^C = \{r_{2-5}\} \cup \left\{ \begin{array}{l} r'_1 : Driver(x) \Rightarrow KeepToRight(x); \\ r'_6 : Driver(x), CauseAccident(x), Injured(y) \Rightarrow obligatoryFirstAid(x,y); \\ r'_7 : Driver(x), CauseAccident(x), Injured(y) \Rightarrow MarkLocation(x); \\ r'_8 : CauseAccident(x), Police(y) \Rightarrow DetermineLiability(y); \end{array} \right\}$$

Due to space limitations, we only introduce definitions that are indispensable for illustrating our approach. Extended from the argumentation system we built for legal reasoning in previous related papers [4,5,18], first, we define a LeSAC for updating.

Definition 1 (LeSAC)**.** *Let $\Delta = (T,A)$ and $\Delta' = (T',A')$ be two legal ontologies for AV, in which Δ is the original ontology and Δ' is a new ontology. LeSAC $= (\mathscr{L}, \mathscr{R}^T, n, \mathscr{K}^A)$ is an argumentation theory instantiated by Δ and Δ', where:*

- *$\mathscr{L}$ is a formal language based on description logic and closed under negation ($\neg$), where $\psi = -\varphi$ means $\psi = \neg\varphi$ or $\varphi = \neg\psi$;*
- *$\mathscr{R}^T = \mathscr{R}_s \cup \mathscr{N} \cup \mathscr{N}'$ is a set of rules corresponding to T and T' (a mapping table can be found in [15,18]), where $\mathscr{R}_s$ is a set of strict inference rules of the form $\varphi_1, \ldots, \varphi_n \rightarrow \varphi$, and $\mathscr{N} \cup \mathscr{N}'$ is a set of legal norms of the form $\varphi_1, \ldots, \varphi_n \Rightarrow \varphi$ ($\varphi_i, \varphi \in \mathscr{L}$); let $\mathscr{R}_s \cap (\mathscr{N} \cup \mathscr{N}') = \emptyset$;*
- *n is a naming function s.t. (such that) $n : \mathscr{N} \rightarrow \mathscr{L}$.*
- *$\mathscr{K}^A$ is a knowledge base based on A and A'.*

Arguments can be constructed by rules from the knowledge base. Let $\mathscr{A}$ denote all the arguments constructed based on a LeSAC and $\triangleleft_{Dem}$ denote a set comparison based on the *Democratic* approach [19]. The preferences between arguments can be lifted by the priority ordering on the set of norms. Considering the aim of this paper, it is reasonable to assume that norms in the new norm set (such as the norms in $\mathscr{N}^C$ of Example 2) take precedence over norms in the previous norm set (such as the norms in $\mathscr{N}^B$ of Example 2). For any argument $\alpha \in \mathscr{A}$, let $\texttt{LastNorms}(\alpha) = \emptyset$ if $\texttt{Rules}(\alpha) \cap \mathscr{N} = \emptyset$, or $\texttt{LastNorms}(\alpha) = \{\texttt{Conc}(\alpha_1), \ldots, \texttt{Conc}(\alpha_n) \Rightarrow \psi\}$ if $\alpha = \alpha_1, \ldots, \alpha_n \Rightarrow \psi$, otherwise, $\texttt{LastNorms}(\alpha) = \texttt{LastNorms}(\alpha_1) \cup \ldots \cup \texttt{LastNorms}(\alpha_n)$.

The preference ordering $\prec$ on $\mathscr{A}$ is defined as follows.

Definition 2 (Argument ordering)**.** *Let* $<$ *be a preodering on* $\mathscr{N} \cup \mathscr{N}'$ *s.t.* $\mathscr{N}'$ *is the new set of norms, for every* $r \in \mathscr{N}$ *and* $r' \in \mathscr{N}'$*, if* $r \neq r'$*, then* $r < r'$*. For all* α*,* β *constructed based on a LeSAC ,* $\beta \prec \alpha$ *iff* $\texttt{LastNorms}(\beta) \lhd_{Dem} \texttt{LastNorms}(\alpha)$*, i.e.: 1)* $\texttt{LastNorms}(\alpha) = \emptyset$ *and* $\texttt{LastNorms}(\beta) \neq \emptyset$*; or 2)* $\forall r \in \texttt{LastNorms}(\beta)$*,* $\exists r' \in \texttt{LastNorms}(\alpha)$ *s.t.* $r < r'$*.*

The above definition in fact sets out the direction of ontology revision, i.e., from the design proposal of the originating country to the target country. In case of conflict between the behavioural guidance of the legal norms of the two countries, the norms of the target country have a higher priority. After merging the sets of rules and knowledge bases obtained from the two legal ontologies, inconsistent legal norms may lead to conflicts between arguments, and the defeat relation is determined by preferences between arguments, defined as follows.

Definition 3 (Attacks and defeats)**.** *Let* α*,* β*,* β' *be arguments constructed based on a LeSAC ,* α ***attacks*** β *on* β'*, iff: 1)* $\beta' \in \texttt{Sub}(\beta)$ *of the form* $\beta''_1, \ldots, \beta''_n \Rightarrow \varphi$ *and* $\texttt{Conc}(\alpha) = -\varphi$*; or 2)* $\beta' = \varphi$ *and* $\varphi \in \texttt{Prem}(\beta) \cap \mathscr{K}$*, such that* $\texttt{Conc}(\alpha) = -\varphi$*.*

Then α ***defeats*** β*, iff* α *attacks* β *on* β' *and* $\alpha \nprec \beta'$*.*

Considering Example 2, after combining the norms based on traffic laws of two countries, we can get the following affected arguments (and their subarguments).

Example 3 (Example 2 continued)**.**

1. Arguments lead to conflicts:

$A_1 : Driver(AV)$ $\quad A_2 : A_1 \Rightarrow KeepToLeft(AV)$ $\quad A_3 : A_1 \Rightarrow KeepToRight(AV)$

$A : A_2 \rightarrow \neg KeepToRight(AV)$ $\quad A' : A_3 \rightarrow \neg KeepToLeft(AV)$

$B_1 : CauseAccident(AV)$ $\quad B_2 : Injury(PD)$

$B : A_1, B_1, B_2 \Rightarrow \neg obligatoryFirstAid(AV, PD)$ $\quad B' : A_1, B_1, B_2 \Rightarrow obligatoryFirstAid(AV, PD)$

$C_1 : InsuranceCompany(IC)$ $\quad C_2 : Police(PL)$

$C_3 : B_1, C_1 \Rightarrow negotiateLiability(AV, IC)$ $\quad C_4 : B_1, C_1 \Rightarrow DetermineLiability(PL)$

$C : C_3 \Rightarrow \neg DetermineLiability(PL)$ $\quad C' : C_4 \Rightarrow \neg negotiateLiability(AV, IC)$

2. Argument be added by updating: $D : A_1, B_1, B_2 \Rightarrow MarkLocation(AV)$

3. Argument can be deleted by updating: $E : A_1, B_1 \Rightarrow NoticeInsuranceCompany(AV)$

By Definition 3, argument A attacks A' on A_3, while A' attacks and defeats A on A_2 due to $r_1 < r'_1$; B and B' attacks each other, and B' defeats B due to $r_6 < r'_6$; similarly, C attacks C' on C_4, while C' attacks and defeats C on C_3 due to $r_8 < r'_8$.

After argument evaluation based on *abstract argumentation frameworks* and argumentation semantics [20], conclusions of sceptically justified arguments including "$KeepToRight(AV)$", "$obligatoryFirstAid(AV, PD)$", "$DetermineLiability(PL)$" and "$MarkLocation(AV)$". These key conclusions suggest that the corresponding design for the AV should be given, while the unaffected original design should be retained. Considering the labelled designs correspond to the norms shown in §2, designs 1, 8, 9 and 11 should be removed (or adjusted), and design 10 becomes unnecessary. Meanwhile, designs according to the abovementioned conclusions of justified arguments should be supplemented.

4. Conclusion

This paper combines legal ontology and argumentation theory to build a system that helps designers make dynamic adjustments to their design proposals in a transnational context. As can be seen from the case study, the system is able to detect the parts of the design requiring adjustment and suggests options for adjustment based on different types of problems. In the future, we will explore the correspondence between engineering features in design and the behavioural guidance of legal norms in an attempt to propose systems with a higher degree of automation.

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