# A New Planning Agent Architecture that Efficiently Integrates an Online Planner with External Legal and Ethical Checkers*

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Keywords: Planning, Online Planning, Legal Check, Ethical Check, Norm Check, Agent Architecture.

Abstract: Transferring and using datasets online presents significant legal and ethical challenges, including issues related to privacy, safety, and bias. Careful planning is essential for compliance with the diverse legal frameworks and ethical standards of different countries. In our approach, legal and ethical checkers are implemented as independent modules capable of operating on separate servers if necessary. This structure is logical given the specialized knowledge required to express legal and ethical norms specific to each country. This paper describes the integration of a planning agent that employs an online Hierarchical Task Network (HTN) planner with these legal and ethical checkers. It also introduces, assesses, and compares three different interaction modes between these modules to facilitate efficient online legal and ethical planning. The assessment emphasizes interaction frequency and computation time, with scenarios related to international data transfer and usage demonstrating the effectiveness of the proposed approach. By exploring these interaction modes, the paper aims to provide a robust framework for managing the complexities of adhering to diverse legal and ethical requirements in a global context.



## 1 INTRODUCTION

As data are transferred globally via the Internet for various services, legal and ethical issues concerning privacy, security, and other factors have become central concerns. Numerous laws and ethical guidelines have been established to regulate data transfer and usage. A well-known set of data protection regulations is the European General Data Protection Regulations (GDPR) (European Commission, 2016). Due to the complexity of laws and ethical guidelines, research has focused on automated compliance checks for data transfer norms. The policy representation of the GDPR, in particular, has been studied extensively (Agarwal et al., 2018; Bonatti et al., 2020; Palmirani et al., 2018; Vos et al., 2019).

Planning the transfer and utilization of datasets is crucial because these processes are multi-step in nature. Compliance with legal and ethical guidelines is also essential when constructing data transfer and utilization plans. Several studies have focused on automated planning that considers ethical and/or legal norms directly (Berreby et al., 2018; Hayashi and Satoh, 2022; Hayashi and Satoh, 2023; Lindner et al., 2020; Taheri et al., 2023a). In particular, the studies in (Hayashi and Satoh, 2022; Hayashi and Satoh, 2023) utilized a general-purpose online HTN planner for data transfer planning, adapting it to dynamic situations where rules describing legal and ethical norms were included in the planning agent database.

Due to the complexity of legal and ethical norms, specialized expertise is generally necessary to conduct automated compliance checks across different countries. Unlike previous approaches, we propose the use of a general-purpose online planner paired with independently developed norm checkers. Consequently, our problem setting differs from that of a planner that directly references legal and ethical norms. In particular, we developed a new planning agent architecture that utilizes external legal and ethical checkers, which were implemented as separate modules. Each module shares the same interface but can be implemented differently within the proposed

*This paper is based on our earlier workshop paper (Hayashi et al., 2024).



Hayshi, H., Taheri, Y., Tsushima, K., Bourgne, G., Ganascia, J.-G. and Satoh, K.
A New Planning Agent Architecture that Efficiently Integrates an Online Planner with External Legal and Ethical Checkers.
DOI: 10.5220/0013098300003890

In *Proceedings of the 17th International Conference on Agents and Artificial Intelligence (ICAART 2025) - Volume 1*, pages 263-272
ISBN: 978-989-758-737-5; ISSN: 2184-433X

architecture. When these modules are installed on separate servers, ensuring that they use consistent and up-to-date information is crucial. High efficiency depends on frequent interactions between these modules. Each module operates independently, as the development of each module requires different specializations or domain expertise.

The contributions of this study are as follows: First, we propose a new architecture that integrates an online planning agent with legal and ethical checkers. Next, we demonstrate efficiency improvements by adjusting database locations and introducing the concept of fluent subscription. Finally, the efficiency gains in terms of the number of interactions between modules and their computation times are illustrated through simulations involving multiple scenarios of planning and replanning for data transfer and utilization. Notably, the details regarding the expressiveness and efficiency of each module are beyond the scope of this paper.

The remainder of the paper is organized as follows. Section 2 presents a new architecture that integrates the three modules discussed earlier. Section 3 introduces the three interaction modes between the planning agent and the legal and ethical checkers. Section 4 explains the experimental scenarios, and the results are presented and discussed in Section 5. Finally, Section 6 provides the conclusion of the paper.

## 2 OVERALL ARCHITECTURE

This section introduces the overall architecture[1] surrounding the planning agent, as shown in Figure 1. The architecture includes a planning agent, a legal checker, an ethical checker, and an action executor. The planning agent incorporates an online HTN planner that generates plans based on its beliefs and adapts them in response to changes during plan execution. The agent sends action execution instructions to the action executor and updates its beliefs and plans based on feedback from the executor. The legal checker evaluates each action in a plan against legal norms to determine whether it is legal. The ethical checker selects the most ethical plan by comparing multiple plans based on various ethical norms. The action executor performs the actions and reports the outcomes back to the planning agent. Additionally, the executor can identify unexpected fluctuations in server activity, safety levels, or occupancy levels and report these to the planning agent.

[1]This architecture was first presented at a workshop (Hayashi et al., 2023).

Given a task (①), the planning agent creates a least-costly plan using a best-first search algorithm and sends it to the legal checker (②). The legal checker assesses the plan's legality and reports the results to the planning agent (③). The planning agent then constructs the next least-costly plan and submits it to a legal checker for verification (② in the second iteration). This process (②–③) repeats until a predefined number of legal plans are obtained or no further plans are possible.

Once a set of low-cost legal plans is ready, the planning agent sends them to the ethical checker (④) and requests it to select the most ethical option. The ethical checker evaluates the plans and reports the most ethical one back to the planning agent (⑤). At this stage, the planning agent commits to the plan deemed both legal and most ethical.

The agent proceeds to sequentially execute each action in the plan using the action executor (⑥). Upon receiving an action execution request, the action executor attempts to perform the specified action and/or carry out observations. The results are then reported to the planning agent (⑦), which updates its beliefs and plans based on the execution outcomes and/or observations. If the current plan becomes invalid or less cost-efficient, the action executor reports new observations to the planning agent, triggering a replanning process. Similar to the initial planning phase, the planning agent engages the legal and ethical checkers during replanning (②-⑤).

### 2.1 Planning Agent

The planning agent generates plans using the online forward-chaining total-order HTN planning algorithm of Dynagent (Hayashi et al., 2006). Similar to SHOP (Nau et al., 1999), a standard (offline) HTN planner, it employs task decomposition through a best-first search to identify the least-costly plan. The information used for planning, referred to as belief, encompasses facts, task preconditions, action effects, task costs, and task decomposition rules (known as methods in SHOP).

Due to the simplicity and expressiveness of the planning domain heuristics, SHOP-like total-order HTN planners continue to be utilized and studied for improved computational efficiency (Behnke et al., 2018; Magnaguagno et al., 2021; Schreiber, 2021). Another modern online forward-chaining HTN-like planner employs Monte Carlo tree search techniques (Patra et al., 2019; Patra et al., 2020) to explore extensive search spaces in order to find suitable plans.

The planning agent also monitors and controls plan execution, incrementally modifying alternative

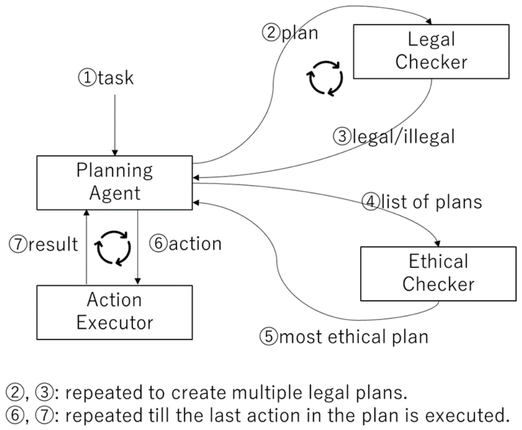



Figure 1: The flow of planning and execution in the proposed architecture.

plans as execution progresses. State changes may affect certain task preconditions within the plans; thus, the planning agent checks these preconditions, removes invalid plans, and incorporates new valid intentions to adapt to a changing environment. Moreover, the plan is adjusted if it becomes invalid or less cost-efficient.

To execute actions within the current plan, the planning agent utilizes the action executor. Each time an action is successfully executed, the belief is updated based on the action's effects. The planning agent first removes the executed action from the head of each plan and then eliminates invalid alternative plans, subsequently adding new valid plans. If an action execution fails, the current plan becomes nonexecutable, and all plans with the failed action at their heads are removed from the alternatives.

As mentioned earlier, the planning agent relies on legal and ethical checkers to filter out illegal plans and to select the most ethical legal plan, respectively.

## 2.2 Legal Checker

Research in legal compliance encompasses various approaches, such as modal (deontic) logics (Governatori et al., 2011; van Riemsdijk et al., 2013), natural language processing (Contissa et al., 2018), and logic programming (Chesani et al., 2018). Several languages have been developed to represent legal rules, such as Proleg (Satoh and et. al., 2011), which extends Prolog with exceptions to better accommodate laws, and Catala (Merigoux et al., 2021), which is designed for representing legal rules including income tax. In this work, we used the logic programming language Prolog in the legal checker for the following reasons: First, the logic of legal norms with exceptions can be effectively expressed as "negation as failure" in Prolog. Additionally, since we implemented other components of the system in Prolog, using it for the legal checker facilitates seamless integration. However, each module could theoretically be implemented in any programming language.

The legal checker verifies whether a given plan from the planning agent is legal. Since a plan consists of a list of actions, the legal checker evaluates each action and considers the plan legal only if all actions within it are deemed legal. In this work, the legal checker assesses whether the proposed actions are compliant with GDPR based on the information provided in the database. This database contains details about data owners' permissions, EU member countries, and relevant nodes within the EU. For instance, if a data owner restricts data transfers outside the EU, the legal checker will classify any plan suggesting such transfers as illegal.

## 2.3 Ethical Checker

The ethical checker is responsible for evaluating and selecting the optimal plan from the valid options. The evaluation mechanism primarily involves an ordering process based on a model with multiple criteria, as first introduced in (Taheri et al., 2023b). The ordering process considers various moral criteria corresponding to distinct ethical dimensions of the problem. Typically, a moral criterion pertains to a specific harm or risk that could affect the individuals involved. Additionally, some optimization criteria for system efficiency may also be incorporated. In our use case, which involves the transfer and processing of personal data, the relevant criteria include technical safety, data sensitivity, processing bias, efficiency, regulatory protection, and data parsimony.

These criteria are organized into a total preorder of superiority. If one criterion is deemed superior to another, it is considered strictly more important, with the inferior criterion serving only to differentiate options that are equivalent according to the superior criterion.

To evaluate the input plans, they are assessed against each criterion (see Section 4 for details on this evaluation process). These measurements are represented on an ordinal scale through preorders, which means that each criterion organizes the plans according to its underlying standard, allowing for potential equivalence among them. The use of an ordinal scale helps avoid inconsistencies and enhances expressiveness in ethical evaluations. Next, the global preorder is obtained by aggregating all these preorders while considering their relative superiority. If the superiority constitutes a total order, this process amounts to combining the different criteria lexicographically. For simplicity, the six criteria are ordered as follows

$$\text{techn. safety} > \text{data sensitivity} > \text{bias} > \text{efficiency} > \text{regul. safety} > \text{data parcimony}$$

The ethical checker manages a superiority relation defined as a total preorder, which encompasses several equivalence classes of criteria ranked in decreasing importance. Within each equivalence class, a compromise is reached through classical voting rules from computational social choice theory, such as Copeland's method (Pacuit, 2024). The resulting preorders are then combined lexicographically. The ethical checker adopts a relativist view, meaning it does not determine which input plans are morally right or wrong. Instead, it selects the best plan among those proposed by identifying the one most aligned with the given ethical context.

# 3 INTERACTION MODES BETWEEN MODULES

This section introduces three interaction modes between the planning agent and the legal and ethical checkers.

As discussed in Section 2, the planning agent interacts with the legal and ethical checkers during both planning and replanning. The planning agent, legal checker, and ethical checker are implemented as separate modules, which can be installed on different servers. This modular design is practical, given that ethical and legal norms vary between countries. To achieve higher efficiency, it is essential to minimize the number of interactions between these modules and decrease computation time while ensuring that the most recent information is reflected in the plans.

The three interaction modes introduced are as follows. 1: *default* mode, 2: *subscription* mode, and 3: *all-subscription* mode. The interaction modes are compared in Section 5 through experiments that evaluate the number of interactions between modules and the required computation time. The following subsections describe each interaction mode in detail.

## 3.1 Default Mode

The default mode represents the most straightforward interaction design and serves as the baseline for comparison. Figure 2a shows interactions in the default mode. In this mode, the common knowledge of fluents describing the changing world is recorded in the planning agent's database as a belief. Legal and ethical checkers query the planning agent regarding the truth value of a fluent whenever they need to evaluate a plan for legal or ethical compliance.

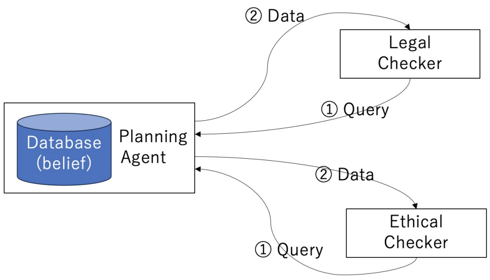
Each time an action is executed or the truth value of a fluent is updated, the planning agent replans and updates multiple plans, the legal checker verifies the legality of each updated plan, and the ethical checker selects the most ethical plan from these updated legal plans.

This default interaction mode ensures that the most recent information is used for planning, replanning, and legal and ethical checks. However, this is inefficient because the planning agent sometimes requests legal and ethical checks unnecessarily. Additionally, legal and ethical checkers frequently query the planning agent for the truth value of a fluent, thereby increasing the number of interactions.

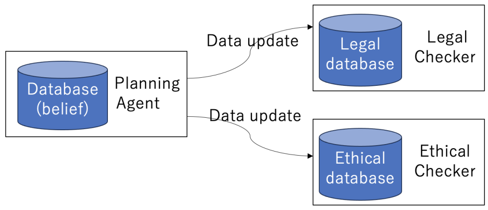
## 3.2 Subscription Mode

The subscription mode is designed to improve interaction efficiency between the planning agent and the legal and ethical checkers. While the default mode is straightforward and easy to implement, it exhibits inefficiencies for two main reasons. First, legal and ethical checkers frequently query the planning agent to verify the truth value of a fluent, which constitutes part of the planning agent's beliefs. This results in a significant increase in the number of interactions between the modules. Second, the planning agent sends requests to the legal and ethical checkers each time an action is executed, increasing unnecessary legal and ethical evaluations, as well as an increased number of interactions and computation time. In the subscription mode, if an action is executed successfully and does not alter the truth values of the fluents impacting legal and ethical norms, it is unnecessary to modify the current plan or consult the legal and ethical checkers.

In the subscription mode, legal and ethical checkers address the first issue by declaring fluents that affect their norm checks as subscribed fluents. Fig-




(a) Default mode.




(b) Subscription mode.

Figure 2: Interaction modes between modules.

ure 2b shows the interactions in subscription mode. The legal (or ethical) checker maintains a separate database of the subscribed fluents. Initially, the planning agent, legal checker, and ethical checker synchronize the truth values of each subscribed fluent in their databases.

To address the second problem, the subscription mode enables the planning agent to omit legal and ethical checks when an action is successfully executed, as long as the action does not alter the truth values of the fluents that impact legal or ethical norms. However, if the execution of the action changes these truth values, the planning agent requests the legal checker to re-evaluate the plans for legality and the ethical checker to select the most ethical legal plan.

In addition, if the truth value of a fluent is updated through observation, the validity of the existing plans may be affected. In such instances, the subscription mode operates similarly to the default mode: the planning agent replans and generates multiple plans, the legal checker verifies the legality of each plan, and the ethical checker identifies the most ethical legal plan.

### 3.3 All-Subscription Mode

The *all-subscription* mode is a specialized case of the subscription mode. In this mode, all fluents are subscribed by the legal and ethical checkers. In this case, it is unnecessary to declare the subscribed fluents.

## 4 USE CASE MODEL

To show the characteristics and efficiency of our proposed approach, we apply it in a data transfer and processing situation. A similar use case model has been used in previous works, such as (Taheri et al., 2023a) and (Hayashi and Satoh, 2022; Hayashi and Satoh, 2023), to illustrate legal and ethical compliance in data manipulations. The model primarily consists of multiple nodes used for transferring and processing data, as illustrated in Figure 3. Each node represents a segment of a corporation located either within or outside the EU. Node 4, indicated by a square, serves as the central node functioning as a cloud server for data processing across various purposes. The other nodes, depicted as circles, are utilized for data storage and transfer. In this use case, users' personal data are stored at the circular nodes. Different sections of the organization may request data processing and receive the corresponding outputs at their designated nodes.

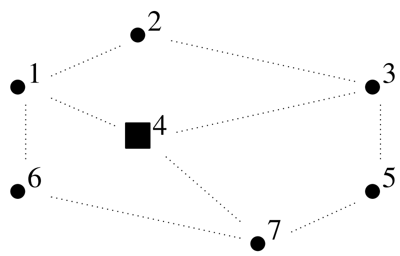



Figure 3: Nodes and connections in the network.

To perform a task, the system locates the data, transfers it to the processing node, and applies the specified process. After processing personal data, the system delivers the output to the requested node. The planner in our architecture generates possible plans to fulfill the given task, i.e., the potential paths for transferring and processing data within the network. Each plan represents a different potential behavior of the system. In this architecture, these behaviors are verified by the legal checker for potential infringements of modeled regulations. The legal checker rules out the illegal plans, and the remaining plans are ordered by the ethical checker based on their alignment with the ethical specification (cf. Section 2.3).

Additional information regarding this use case enables testing of the architecture across various scenarios. Table 1 presents the details of the nodes utilized in this model. The *region* indicates geographical location of each node, categorized as *EU* or *Non-EU*, reflecting our primary focus on GDPR compliance. This regional classification is essential for the legal verification process, as transferring personal data out-

Table 1: The attributes of each node.

| Node | Region | Safety Level | Occupancy Level |
|---|---|---|---|
| 1 | Non EU | medium | normal |
| 2 | EU | medium | normal |
| 3 | EU | medium | busy |
| 4 | EU | high | busy |
| 5 | EU | high | normal |
| 6 | Non EU | low | busy |
| 7 | Non EU | high | normal |

Table 2: The information of available processing.

| Processing | Location | Purpose | Bias Level | Required Categories |
|---|---|---|---|---|
| p1 | node 4 | recom | 2 | [c1,c2,c3,c4] |
| p2 | node 4 | recom | 1 | [c2,c3,c5] |
| p3 | node 4 | recom | 3 | [c1,c3,c6,c7,c8] |

Table 3: The information on personal data.

| Data | Category | Storage Location | Owner | Take-out from EU |
|---|---|---|---|---|
| du11 | c1 | node 1 | u1 | permitted |
| du12 | c2 (sensitive) | node 1 | u1 | permitted |
| du13 | c3 | node 1 | u1 | permitted |
| du14 | c4 | node 1 | u1 | not permitted |
| du15 | c5 (sensitive) | node 1 | u1 | permitted |
| du16 | c6 | node 1 | u1 | permitted |
| du17 | c7 (sensitive) | node 1 | u1 | permitted |
| du18 | c8 | node 1 | u1 | permitted |
| du21 | c1 | node 2 | u2 | permitted |
| du22 | c2 (sensitive) | node 2 | u2 | permitted |
| du23 | c3 | node 2 | u2 | permitted |
| du24 | c4 | node 2 | u2 | permitted |
| du25 | c5 (sensitive) | node 2 | u2 | permitted |
| du26 | c6 | node 2 | u2 | permitted |
| du27 | c7 (sensitive) | node 2 | u2 | permitted |
| du28 | c8 | node 2 | u2 | permitted |

side the legislative zone raises ethical implications for data subjects. It also plays a critical role in the ethical verification process, particularly for assessing *regulatory safety* (the fifth criterion). The *safety level* corresponds to the safety protocols implemented at each node, which can be classified as high, medium, or low. It is crucial to route data through more secure nodes to prevent potential breaches that could compromise user privacy. Thus, safety level is integral to the ethical checking process under *technical safety*, which is the most critical criterion. The *occupancy level* denotes whether a node is busy and is employed to minimize data management time and enhance the overall *efficiency* of the system (the fourth criterion of the ethical checker). This information about occupancy level is utilized by both the ethical checker and the planning agent. Additionally, the costs associated with tasks at busy nodes and data transfer tasks to these nodes are set at 10, representing a tenfold increase over the default task cost of 1.

Table 2 shows the processing available to apply to personal data. It includes information on the *location* of processing that is node four and the *purpose* that is *recommendation* for all processing in this case. The *bias level* shows the extent to which processing can be biased with respect to a particular group. We show this simply by positive integers from which is derived the *bias* criterion of the ethical checking (3rd criterion). Each processing requires certain *categories* of data, which are indicated by a list and the category name, e.g., c1, c2, etc.

Last but not least, Table 3 shows information on personal data. This includes their corresponding *category*, which can be sensitive, the node on which the data are *stored*, the data subject who is the *owner* of the personal data, and permission from the user to take the data out of the EU. Note that the data owner may change permission during execution.

Based on Tables 2 and 3, *data sensitivity* (2nd ethical criterion) is computed by counting the number of sensitive data categories that are moved and processed. In contrast, *data parcimony* (6th ethical criterion) is based on the total number of data units transferred or processed. We demonstrate the functionality of our architecture by testing it in some scenarios in the following section.

### 4.1 Scenario basecase

Scenario basecase is the baseline scenario. In this scenario, the situation does not change along the way. The job given to the planning agent is the following: to load the necessary data, process recommendations, and deliver the results to node 7. As shown in Figure 3, several routes can be considered. First, the planning agent creates a number of plans that have different data and/or use other routes. The legal checker performs the following checks on those plans: node 7 is outside the EU, and du14 is prohibited from being taken out of the EU, so the plans containing du14 (e.g., a plan moving from node 1 to node 7 via node 4 using data [du13, du14, du15]) are rejected. The ethical checker selects the optimal plan among the legal plans. In our experiment, the plan that uses the following route is chosen: node 1 $\rightarrow$ node 4 (recommendation process) $\rightarrow$ node 7, and it does not use du14.

### 4.2 Scenario precondition-replan-1

This scenario demonstrates how the system responds to the physical changes in the operating environment. The objective is to process the personal data of the user $u2$ for recommendation. The data is initially stored in a database at node 2, and the output of the processing is requested at the same node. The initial plan is to transfer the data through node 1 to node 4, apply the processing $p2$, and transfer the output back to node 2 via node 1. As shown in Table 1, node 1 and node 3 have the same values for every attribute except occupancy level, where node 1 is less busy than node 3; therefore, node 1 is selected in the initial plan. During execution, when the data are loaded from the database, the system detects that node 1 is suddenly deactivated. The planner would do a replanning and select node 3 as an intermediate to send data to node 4, apply the processing, and transfer it back via node 3 again.

### 4.3 Scenario precondition-replan-2

This scenario is expanded from precondition-replan-1. After loading the data of $u2$ and replanning at node 2, the system transfers it to node 4 via node 3. After applying the selected processing, suppose that the system recognizes that node 1 has been reactivated. The planner considers the new change by forming a replanning from the current state and chooses node 1 again as the intermediate node to transfer the output back to node 2.

### 4.4 Scenario cost-ethical-replan

This scenario demonstrates how the system responds to the action-execution cost used in planning. As in Scenario precondition-replan-1, the objective is to process the personal data of the user $u2$ for recommendation. The data is initially stored in a database at node 2, and the processing output is requested at node 7. The initial plan is to load the data at node 2, transfer it through node 1 to node 4, process the data, and transfer the output to node 7. Note that the transfer routes via node 3 are avoided because the occupancy level of node 3 is busy. Note also that the ethical checker also considers the occupancy levels of nodes for plan selection. During execution, when the data are loaded from the database, the system realizes that the occupancy levels of node 1 and node 3 change from ordinary to busy and from busy to normal, respectively. The planner would do a replanning and select node 3 as the intermediate to send data to node 4, apply the processing, and transfer the output to node 7.

### 4.5 Scenario ethical-replan

Scenario ethical-replan shows how the system would react to changes that affect the ordering of plans by the ethical checker. The task in this scenario is to use $u1$'s personal data to generate recommendations and deliver the result at node 5. $u1$'s data is stored at node 1. To perform the task, the planner transfers personal data from node 1 to node 4 to run the selected process and chooses an intermediary node between node 3 or 7 to deliver the result to node 5. As node 7 has a higher safety level, the ethical checker initially selects the plan that transfers data through it. However, just after processing the data at node 4, the system realizes that, due to some external incidents, the safety level of node 7 has changed to *low*. The system then initiates a re-evaluation, and the ethical checker selects the path that passes through node 3 because it is safer. In this scenario, the physical constraints are fixed; however, the properties that affect the ordering of the ethical checker and, consequently, the selected plan are changed. The re-evaluation process shows the functionality of our proposed architecture and the ethical checker component in similar situations.

### 4.6 Scenario legal-replan-1

Scenario legal-replan-1 demonstrates how the system responds to the changes affecting decisions by the legal checker. In this scenario, the planner discovers that a user has rewritten permission information in the database during execution. The legal checker re-evaluates the legality and finds that it is not currently allowed. So, the planner re-creates different plans. Specifically, the initial plan selects the dataset [du21,du23,du26,du27,du28] and the route to take the data from node 2 to node 7 via the EU to achieve the goal. However, during execution, just after loading the dataset at node 2, the permission information for du28 was rewritten to prohibit taking the data out of the EU. Because node 7 is outside the EU, it is illegal to move du28 there. So the planner uses another dataset [du22,du23,du25] to achieve the goal.

### 4.7 Scenario legal-replan-2

This scenario is expanded from scenario legal-replan-1. In this scenario, scenario legal-replan-1 is executed, and just after the first replan, the user additionally prohibits another specific piece of data, du25, from being taken out of the EU. This causes a second replan, and finally, the data is selected so that neither du28, which is prohibited in scenario legal-replan-1, nor du25, which is not permitted in this scenario, is used.

### 4.8 Scenario legal-ethical-replan

This scenario occurs in the order of what happens in scenarios ethical-replan and legal-replan-1: As in scenario legal-replan-1, the user is prohibited from transferring specific data outside the EU, prompting a replan. The plan selected after the first replan is to move from node 1 to node 4 to node 7 to node 6, using different data. However, while data is en route to node 7, a change in the security level of node 7 from high to low is detected, prompting an ethical replan. This results in the final selection of the route from node 4 to node 1 to node 6.

## 5 EXPERIMENTS AND DISCUSSIONS

Tables 4 and 5 present the results obtained from the scenarios introduced in Section 4. All executions were performed using SWI-Prolog (threaded, 64 bits, version 9.0.4) on a MacBook Air running MacOS 14.4.1, Apple M2, eight cores, and 24 GB memory. All runs used the same maximum number of plans, 16. Thus, the planner generates a maximum of 16 plans. The database information that is shown in Section 4 is almost the same, but some parameters are modified to represent each scenario. Note that each module can be implemented in any programming language and installed on different servers as long as they can communicate with one another, for example, via remote procedure calls.

In this implementation, SWI-Prolog is used to run three modules on a single computer. Therefore, there is little communication cost between the modules. However, we can distribute these modules to different servers. In this case, the communication cost between modules will be significant. In this experiment, we evaluated the communication cost by counting the number of interactions.

Table 4 presents the total CPU time for planning, replanning, legal checking, and ethical checking. Table 5 indicates the number of interactions between the planning agent and legal/ethical checkers. Table 6 summarises the results.

In comparing the default and all-subscription modes, the computation times were almost equal, but the number of interactions in the all-subscription mode was significantly lower. In the default mode, the legal and ethical checkers are called whenever an action is executed. The all-subscription mode functions similarly as action executions typically alter the truth values of certain fluents subscribed by both checkers.

Furthermore, in the default mode, the legal and ethical checkers have to request the planning agent for the truth value of a fluent. Meanwhile, in all-subscription mode, these checkers consult their databases and do not need to consult the planning agent. This significantly reduces the number of interactions. Considering the communication time required for each interaction, the impact of the all-subscription mode is enormous. Note that although the communication times for interaction are not included in Table 4, it is possible to estimate them by multiplying the number of interactions and the approximated unit communication time.

In the subscription mode, unnecessary legal and ethical checks are minimized. Compared with the all-subscription mode, both the number of interactions and the computation times are lower. This shows the considerable impact of the subscription mode on the system efficiency. Overall, the subscription mode proved to be the most efficient in terms of number of interactions and computation time.

Table 4: Executed results: CPU time (seconds).

| | default | all-subscription | subscription |
|---|---|---|---|
| **basecase** | 1.378223 | 1.373324 | **0.461348** |
| **precondition-replan-1** | 2.384789 | 2.299939 | **1.323991** |
| **precondition-replan-2** | 2.834865 | 2.746833 | **1.602472** |
| **cost-ethical-replan** | 2.311678 | 2.279096 | **1.154411** |
| **ethical-replan** | 2.709023 | 2.680235 | **1.318428** |
| **legal-replan-1** | 3.400821 | 3.655947 | **0.831619** |
| **legal-replan-2** | 86.016189 | 86.042916 | **49.701664** |
| **legal-ethical-replan** | 19.350356 | 19.304388 | **11.013482** |

Table 5: Executed results: the number of interactions.

| | default | all-subscription | subscription |
|---|---|---|---|
| **basecase** | 16916 | 84 | **25** |
| **precondition-replan-1** | 46038 | 121 | **35** |
| **precondition-replan-2** | 50357 | 140 | **51** |
| **cost-ethical-replan** | 24617 | 104 | **35** |
| **ethical-replan** | 32760 | 121 | **43** |
| **legal-replan-1** | 41069 | 157 | **47** |
| **legal-replan-2** | 92655 | 337 | **73** |
| **legal-ethical-replan** | 60612 | 216 | **107** |

Table 6: Summary of experiments in different interaction modes.

| | default | all-subscription | subscription |
|---|---|---|---|
| **Replanning after action** | always | almost always | not often |
| **Average CPU time** | baseline | same as baseline | 48% of baseline |
| **DBs for legal/ethical checkers** | no | yes | yes |
| **Average number of interactions** | baseline | 0.37% of baseline | 0.13% of baseline |

## 6 CONCLUSION

In this paper, we demonstrated how to implement a planning agent that smoothly integrates an online planner, a legal checker, and an ethical checker. Additionally, we compared three interaction modes, finding that the fluent subscription technique effectively reduces the number of interactions and computation times, which is essential for the efficient integration of these modules.

Future work will focus on improving integration methods toward the real-time computation of legal and ethical planning. For example, a more extensive map will yield additional alternative plans. Currently, the planning agent sends a limited number of alternative plans to the ethical checker only from the cost viewpoint. In this case, we might need to send more alternative plans to the ethical checker so that it can select the most ethical plan from various points of view. For this purpose, the planning agent also needs to pick up the alternative plans from various points of view before sending them to the ethical checker. An alternative approach is to call legal and ethical checkers during planning to guide the planner's inferences.

Another future work is to integrate multiple planning agents, legal checkers, and ethical checkers in different countries. This topic of multiagent planning becomes essential as these modules are developed for each country.

## ACKNOWLEDGMENTS

This work was funded by JST AIP Trilateral AI Research (JPMJCR20G4); JST Mirai Program (JPMJMI23B1); JSPS KAKENHI (22H00543 and 21K12144); Agence Nationale de la Recherche (ANR, French Research Agency) project RECOMP (ANR-20-IADJ-0004).

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