Task and Situation Structures for Service Agent Planning

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Abstract

Everyday tasks are characterized by their varieties and variations, and frequently are not clearly specified to service agents. This paper presents a comprehensive approach to enable a service agent to deal with everyday tasks in open, uncontrolled environments. We introduce a generic structure for representing tasks, and another structure for representing situations. Based on the two newly introduced structures, we present a methodology of situation handling that avoids hard-coding domain rules while improving the scalability of real-world task planning systems.

1 Introduction

Classical task planning is to develop a series of actions that transform the world from an initial state to a state that includes the goals of the task \cite{Ghallab, Nau, and Traverso 2016}. It also assumes that a complete task plan is generated before executing the plan \cite{Fikes and Nilsson 1971, Aernoutiques et al. 1998}. However, in the real world, people often do not know the exact details of every future state at the planning time. Also, the world state can be changed by exogenous events at execution time. So, plan people at different levels of abstractions, leaving long-range plan details out at the planning time. Hierarchical planning was introduced to reflect this intuitive planning practice \cite{Tate 1977, Sacerdoti 1974, Yang 1990, Nau et al. 2003}. In Hierarchical Task Network (HTN) planning, refinement rules, called methods, break down a task into sub-tasks. These planning techniques are predominantly rule-driven.

Scholnick and Friedman \cite{Scholnick and Friedman 1993} studied several use cases of task planning. They used “Tower of Hanoi” \cite{Havur et al. 2013} to exemplify “problem-solving tasks” and used “errand planning task” to exemplify “everyday tasks.” They compared and contrasted similarities and differences, and found that the nature of errand planning is quite different from solving Tower of Hanoi. For instance, although errand planning is not as computationally demanding, its planning environment is much more variable. Errand plans rarely play out in a perfectly predictable environment. Goals for errands are often not hard-and-fast or even not well defined. Many more factors influence the execution of a task plan. The rule-based approach that works well with problem-solving tasks finds many difficulties in everyday tasks. \cite{Ghallab, Nau, and Traverso 2014} have also contrasted the differences between planning in the highly abstracted model and executing in a complex real-world environment. The factotum robot in \cite{Ghallab, Nau, and Traverso 2014} is a use case similar to the use case of “errand planning.” The intricacies in planning in such use cases post significant challenges to the traditional state search approaches.

We study a service agent that interacts with human clients for assigned tasks. In this scenario, the agent faces seemingly unlimited kinds of tasks plus their variations, and task plans. The agent may need to repair a plan if the plan fails or need to respond to a “situation.”

Many researchers have addressed the plan repair problem. For example, ASPEN \cite{Rabideau et al. 1999, Chien et al. 2000} has a plan repair mechanism developed for Mars rovers. The plan repair unit keeps monitoring conflicts and applies repair methods when conflicts are detected. ASPEN has a total of ten repair methods. The Reifinement Acting Engine (RAE) \cite{Ghallab, Nau, and Traverso 2016} \cite{Patra et al. 2019} takes an acting-oriented approach that makes online planning a part of an action. It keeps searching for an acting method from a comprehensive refinement method library based on the states of the world, qualified conditions, and the task. Goal Driven Anatomy (GDA) \cite{Ghallab, Nau, and Traverso 2014} was proposed that has a four-phase process of anomaly detection and goal modification/generation process in response to environmental changes or imperfect predictions. It continuously monitors any anomaly and generates new goals that the planner will use to revise the existing plan or create new plans. All these approaches are relying on hand-crafted rules, which are primarily domain dependant.

We define a Situation as “an unexpected event or a demand that the agent needs to respond” in this paper. There are various Situations that could happen. They are unpredictable, and it is hard to enumerate all of them. Those rare Situations are often referred to as “corner cases” or “edge cases”. Take robotaxi as an example. Assuming that a vehicle picks up a customer and sends the customer from location A to location B. Many Situations can happen during the trip. At the pick-up location, the vehicle agent and the customer may not find each other, or the vehicle could not access the pre-arranged spot. During the trip, the customer may complain about the smell or spill in the car, or the customer needs to divert for an urgent errand. We are particu-
larly interested in the use case of “errand planning” in this research. Here are two hypothetical Situation examples:

**The story of “Window Leak”**

[It starts raining. Passenger Annie saw water seep into the cabin. The window is not fully closed.]

ANNIE: The water is getting in.

VEHICLE: Is there something that blocked the window glass?

ANNIE: Yes, looks like it is jammed

VEHICLE: Do you want to go to this pharmacy?.

JOE: No, I’d like to go to the one we just passed. [Joe only wants to go to the pharmacy he just passed by.]

VEHICLE: How about these?

[The vehicle agent checks the window, one of them is open. The agent sends a command to the control unit to close the window. However, the window is not closed. The agent realizes that the window is in a malfunction. The agent recalls a case that the window that could not get closed because the window glass was blocked by a twig.]

VEHICLE: Is there something that blocked the window glass?

ANNIE: Yes, looks like it is jammed

[The agent rolls down the window a little bit and the rider cleaned a foreign object that jammed the window. The vehicle agent rolls up the window again and the window is closed this time.]

**The story of “pharmacy”**

[Passenger Joe went on a business trip. He rides in a vehicle towards the hotel. He passed by a pharmacy and realized that he can pick up a prescription there.]

JOE: Could you stop by that pharmacy?

VEHICLE: How long should I wait?

JOE: Maybe 10 to 15 minutes.

VEHICLE: I will wait for you at the front door of the store in 10 minutes.

[The vehicle turns around and drives to the pharmacy. The vehicle offboards Joe at the pharmacy. 10 minutes later, the vehicle will be back to resume the trip to the hotel.]

Situations like these that could be solved relatively easily by a human driver become challenges to an AI agent. Not only **Situations** are numerous, but also the difference in the context of **Situations** compounds variations. The solution space is impossible to be exhaustively defined. It is infeasible to hard-code all the rules to solve them. This paper illustrates a comprehensive design and practice that aims to provide the following solutions:

1. It creates text-based, generic structures and syntax for Tasks and Situations of all variations.
2. It embeds domain knowledge in executed cases to avoid the necessity of hard-coded or static domain rules.
3. It offers a design that tolerates imperfections in the model (goals, conditions, states, actions, effects) and data. It uses context as additional attributes into guiding the search for solutions.

In the following sections, we first introduce a generic **Task** structure we created. We then present a generic **Situation** structure and **situation handling** process and methodology. After that, we illustrate how the two example **Situation** cases could be implemented with the situation handling process while leveraging our task and situation structures.

## 2 Task Structure

Our connotation of a **Task** is more than its goal conditions. We include the whole history of how this **Task** is accomplished into the **Task** with a motivation of reusing the **Task**. There are many kinds of **Tasks** for a service agent, big or small (big **Tasks** can be divided into small **Tasks**). We created a generic **Task** structure that suits all **Tasks**.

**First**, we define tasks and sub-tasks recursively. They share the same **Task** structure. **Second**, the **Task** structure encapsulates all parameter details in the **Task** and the task plan. This approach follows the theory of case-based reasoning (CBR) and case-based planning (Aha 1996, Hammond 2012). A **Task** is a record of history, an episode of a story. The **Task** structure is implemented with a syntax that is intuitive to engineers (using json format). **Third**, it introduces context as an attribute of a **Task**. Context plays an essential role in planning (Scholnick and Friedman 1993, Leake and Jalali 2014), especially for a service agent. Instead of pattern-matching-based solution search, which fits the Tower of Hanoi use case, it is more beneficial to use similarity-based retrieval for a often imprecisely defined problem space like the errand planning use case. Context is an additional attribute to influence the similarity calculation.

### 2.1 Task Structure

The **Task** structure is illustrated in Table 1. It follows the concept of classic planning with a few attributes that may be worth explaining:

| Attribute         | Explanation                                                                 |
|-------------------|-----------------------------------------------------------------------------|
| Task_name         | string name of a **Task** class                                              |
| Parent_task       | null if no parent                                                           |
| Sub-tasks         | a list of sub-tasks, empty if leaf                                          |
| Action            | the action of the **Task**                                                  |
| Specs             | detail specs for the action                                                 |
| Conditions        | preconditions for this **Task**                                             |
| Effects           | effects after the **Task** is performed                                      |
| Context           | a list of contexts of this **Task**                                         |
| Goals             | goals to be verified                                                        |
| Est Time          | estimated execution time                                                    |


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1. “json is a lightweight data-interchange format.” For details, please check: https://www.json.org/json-en.html
**Sut_tasks**: A list of sub-tasks. Each sub-task takes the same structure of a *Task*.

**Action** is the abstract form of a *Task*. An *Action* has the action (verb), and a few parameters of this action (like a predicate). For example, *Action*: “Robot-r move block-A from location-1 to location-2”. The Action “move” takes three arguments: object-to-be-moved, start-location, and end-location, plus the actor, recorded under a schema attribute. The *Task* of “move”, however, has more information such as **Conditions, Goals**, etc.

**Specs** contains the details of parameters that are used in the action. For example, if location-1, a label, is used as the origin location in a trip domain application, then the location object (with details such as GPS coordinates, type of location, etc.) is included in the **Specs**.

**Conditions** may have different types: “hard” conditions have to be satisfied before the *Task* could be performed; “fail-skip” conditions are conditions that, if failed, the *Task* could be skipped. Other types of conditions could be defined such that when such a condition fails during *Task* execution, it generates a context.

**Context** contains any context information relevant to this *Task*. For example, if the *Task* is to go to the San Francisco airport, going “by bus” or going by “driving a personal car” is context information of this *Task*.

This schema is implemented in json. We have **serialize** and **deserialize** functions in Python that transform data to objects or objects to data when needed. So, we can encode objects in data in a naturally understandable form.

We have built a system for illustration and discussion of *Task* structure, assuming a robo driver serving a customer, called Virtual Service Agent (VSA).

### 2.2 Execution of *Tasks*

In VSA, task planning is an integral part of the task execution process. Before a *Task* is executed, it develops its sub-tasks. When a *Task* develops its sub-tasks, VSA does not apply a method as HTN planning does. Instead, VSA takes a variational approach: it copies an existing *Task* with sub-tasks instantiated and replaces the Spec and Contexts from the new *Task*. The existing *Task* could be from a template or a previously executed *Task*. In the current implementation, when a *Task* is created, it takes the initial status of **unplanned**. After the planning stage, when a *Task* develops its sub-tasks, the *Task* changes its status to **planned**. A *Task* may be of other status: **executing, finished, failed, aborted**, etc.). In the next stage, if there are sub-tasks, each sub-task is iterated and its **execution** function is recursively called the same way as the parent *Task*. If there are no sub-tasks, the action is executed, which usually is sending the *Task* to another agent (the actor) for execution.

During execution, when a *Task* develops its sub-tasks, the “specs” in the sub-tasks will be mapped from the parent *Task’s “specs”*. The bindings of parameters from the parent to children are through a mapping attribute in the *Task* structure (not shown in Table[1]). The following is an example of a mapping:

```

```

```json
{
  "spec.origin": "parent.specs.origin",
  "spec.destination": "parent.specs.destination"
}
```

It means that the origin in the *specs* of this *Task* is assigned the same as the origin of the parent *Task* specs. The destination in the *specs* of this *Task* is also assigned the same as the destination of the parent *Task* specs.

If there is an exception detected during the plan execution, the exception is handled based on the error message. Some of the exceptions will be considered as **Situations** and **Situations** will be handled by the agent. If the *Task* could not be executed, (for example, if the conditions are not satisfied, and a **Situation** could not be handled successfully), the *Task* status will be changed to **failed**. The **failed** status will propagate to its parent *Tasks*, all the way up. Every executed *Task* is saved to the *Task* case library to retain a rich *Task* repository.

This *Task* structure naturally supports replay and simulation. Each executed *Task* is archived in the case library, and we can replay it in the future. On the other hand, we can simulate a *Task* plan similar to replay. It is imperative to have a simulation system in a case-based planning system [Hammond[2012]]. Once an old plan is modified, it is not guaranteed to succeed. A robust simulation will detect failures so that flaws in the modified plan can be repaired. The simulation acts as a validation. The details of validation will be explained later in Section[4] Situation Handling Process.

### 2.3 Implementation

Figure[1] shows the implementation of our VSA (Virtual Service Agent) System. In the graphical user interface, each window represents an agent. Within an agent window, there is an action panel at the top and a message panel at the bottom. The top left window is the VSA panel, where we can monitor the *Task* plan as it is executing. The lower left window is the Map Agent that simulates the vehicle driving through a trip. Among other agents, we have a Dialogue Agent that communicates using natural language with the rider, a Weather Agent that retrieves live weather information, a Mobile Agent that emulates the communication to the rider through a mobile device, a Vehicle Agent that controls the vehicle mechanics and sensors, the Service Center that is the dispatch system that sends trip tasks to the vehicle.

Figure[1] is an example of the *Task* hierarchy of a *Trip Task*. Each line prints the action of the *Task*. We implement it to resemble a *Trip Task* handled by a vehicle sending a customer, Tildaswanson, a fictitious name, from location Meyers Rd to location Dequindre Rd. The *Trip Task* is received from a trip assignment platform (the Service Center). A *Trip Task* has four top-level sub-tasks: A Drive *Task* that drives from where the vehicle is to the pickup location Meyers Rd; at Meyers Rd, the Agent performs the Onboard *Task*; it then performs a Drive *Task* that drives from Meyers Rd to Dequindre Rd; after arriving Dequindre Rd, it performs the Offboard *Task*. The sub-task Onboard *Task*, for example, has its sub-tasks: connect-passenger, load-luggage, etc. The load-luggage *Task* is further developed into sub-tasks: open-trunk, wait-for-load-luggage, close-trunk. Cer-
tainly, whether having the load-luggage Task depends on if the customer has luggage that needs to be put in the trunk. This information is captured in the context information of the parent Task. Instead of using rules like “if has-luggage then . . .” in the refinement method as you would expect in an HTN planning system, VSA uses Task attributes, including contexts, as indices to search for a previous similar Task as a template to develop the sub-tasks.

### 3 Situation Structure

In an open or semi-open world, a service agent faces multifarious Situations. Exhaustively define Situations in ad hoc fashion does not scale. Here, we present a generic Situation structure that is capable of describing all Situations and situation handling without domain specific data types and code. Situation types and situation handling knowledge are not hard-coded, but recorded in text format (json strings) and is in data.

In a nutshell, a Situation will be handled using a Remedy to repair the plan. However, a Situation (class) may be handled with different Remedies, depending on the context. A Situation has a Context attribute that is used to differentiate variations of a specific Situation class. It follows the case-based reasoning methodology such that situation handling cases can be reused. There is also a Logics field in the Situation structure. It is intended to embed problem-solving knowledge in text-based data so that the knowledge is not hard-coded.

Table 2 is the Situation structure. Here are the fields:

| Attribute | Explanation |
|-----------|-------------|
| Name:     | name of this Situation  |
| Time:     | time this Situation occurred |
| Task:     | Task during which the Situation is logged |
| Context:  | contexts while this Situation happened |
| Remedy:   | a list of remedy actions to take |
| Logics:   | how to set the Context and the Remedy |
| Goals:    | new goals the repaired plan should satisfy |

- The Time field is self-explanatory.
- Task is the Task that was executing when the Situation was logged or the Task during which the Situation is handled. There might be multiple Tasks the agent is performing when the Situation is logged, in the case of parallel Task processing. In this case, the most relevant Task is used. For example, if the vehicle is driving and the vehicle is playing music, a car_window_broken Situation will reference the driving Task.
- Context is a list of context attributes under which this Situation occurs. For example, “it is raining” could be a context attribute of a “car_window_broken” Situation. The severity of the window glass broken could be another context attribute of this Situation.
- Goals are a list of new goals that need to be satisfied if the Situation is handled successfully.

Table 2: Situation Structure

| Attribute | Explanation |
|-----------|-------------|
| Name:     | name of this Situation  |
| Time:     | time this Situation occurred |
| Task:     | Task during which the Situation is logged |
| Context:  | contexts while this Situation happened |
| Remedy:   | a list of remedy actions to take |
| Logics:   | how to set the Context and the Remedy |
| Goals:    | new goals the repaired plan should satisfy |
The above information is received when a Situation is detected or received (from another agent), we call it the Situation header.

- **Logics** is used to help determine the contexts that are most relevant to this Situation. The context knowledge may be used for situation handling. For example, in the car-window-broken Situation, the Logics will request a sensor agent to find which window is broken, the severity of the damage, a weather agent the current weather condition. In the implementation, Logics are a list of functions that feed into the Context. The following is an example of Logics. It is in the form of a (python) dictionary:

```

| Attribute     | Explanation                              |
|---------------|------------------------------------------|
| Operation     | add/delete/modify                        |
| Reference     | a list defines references of attributes   |
| Mapping       | functions that fills spec with_task       |
| With_task     | new task that will be added or modified   |
```

Table 3 shows details of a remedy action structure. In the remedy action structure:

- Operation: an example operation will be something like: “add after the drive_task”; or “modify this_task”. It contains both an operation (add/modify/delete) and the target information (“after the drive_task” / “after this_task”, etc.). We adopt this natural syntax. It can be easily parsed with a set of vocabulary.

- References: A list of reference definitions that connect attributes with objects in the program. Through “references”, the keys in the mapping are referenced to the actual object in the program. In the following example:

```

"logics": {
  "window_broken": "vda.checking_window",
  "weather": "weather.current_weather",
  "wetness": "chat.wetness"
}
```

In this example, the keys are attributes that will appear in the context. The values are the functions. The first function is a function of the “vda” agent, which has sensors to tell if a window is malfunction or broken. The second function is a function of a weather agent. It returns the current weather condition. The third function initiates a Chat conversation, getting how much of the concern of the wetness in the cabin from the passenger in the vehicle. The return of the function is a free-formed text string. These attributes are added to the Context information of this Situation. The functions could be more sophisticated, and examples of them are outside of the scope of this paper.

- **Remedy** is a list of remedy actions used to alter the task plan so that the Situation is resolved. A remedy action (or in short: remedy) is simply adding/deleting/modifying a Task.

```

"drive_task": "executing task",
"context": "situation context"
```

"drive_task" that is used in the mapping is referenced to the “executing task” (the “Task” in Table 2). “context” that is used in the mapping is referenced to the Context in the Situation (Table 2).

- **Mapping**: how the Specs of the new Task (the “with_task” in Table 3) is to be set.

The following is an example of the mapping:

```

"mapping": {
  "specs.origin": "drive_task.specs.origin",
  "specs.dest": "context.current_location",
  "specs.actor": "drive_task.actor",
  "action.origin": "drive_task.specs.origin",
  "action.dest": "context.current_location",
  "estimated_time": "drive_task.actual_duration"
}
```

In each mapping item, the left side of “:” (key) is the target of the parameter, the right side of “:” (value) is the source of the parameter. Please notice that “drive_task” and “context” in the source parameters are defined in the “references” described just above.

- With_task: the new Task that is to be added into the task plan.

4 Situation Handling Process

When a Situation is detected, the agent will retrieve the Logics of this Situation (class) from the Situation library. The Logics functions are invoked, and the return values will populate additional Context information of the Situation. The Situation with its Context is then pushed to a Situation Queue.

When the agent executes a Task, it also keeps checking if there is any Situation in the Situation Queue. If there is a Situation in the Queue, the agent will attempt to handle the Situation. The agent will first use the Situation name and Context to retrieve any prior Situation in the Situation library that matches best with the Situation. If a similar Situation is found, the Remedy of the old Situation will be used to repair the plan of the new Situation.

Once the Remedy is applied, the modified plan (Figure 2(1)) will be validated using the Validator (Figure 2(2)). In Figure 2(3) the solid lines in the modified plan are the Tasks that have been executed. The dashed lines are the Tasks that have not been executed. The validation is to validate the unexecuted Tasks. The validation is through a simulation process. It starts with the current State. The agent simulates each Task by checking the conditions first, and then it executes the Task in the simulation mode and it applies the effects of the Task to the States, and then it checks if the goals of the Task are met.

If the goals are met to the end, the modified plan is validated. Otherwise, there are two options: one is to find another similar Situation case in the Situation library to repair the plan and validate the repaired plan again. Another is to call in human assistance as in the process described below.

What if there is a Situation that VSA does not know beforehand? What if there is no prior Situation that is similar
null
The above information feeds into the Context of the Situation. VSA finds a similar Situation from its Situation library that has the following remedy:

```
"add close-window task"
"add confirm-problem-solved task"
```

The “close-window” task is sent to the vehicle, and the vehicle sends a “close-window” command.

The “confirm-problem-solved” Task will trigger a dialog using the Dialog Agent. It returns the confirmation and related response in the form of context.

Unfortunately, assuming, the confirmation is negative. The water is still pulling in. A new “window-fail-to-close” Situation is created because the “close-window” Task was confirmed as failed by the rider in the “confirm-problem-solved” Task.

The Logics under “window-fail-to-close” Situation is:

```
"logics": {
  "close_window": "vda.close_wdw_status",
  "window_malfunc": "vda.wdw_malfunc_detect",
  "window_broken": "vda.broken_wdw_detect"
}
```

In the above Logics, the “close_window” context is already filled from the previous situation handling process. Therefore, the context is carried over.

Assuming we have the following contexts (in addition to all other contexts we have had) after applying the Logics:

```
"context": {
  "close_window": true,
  "window_malfunc": false,
  "window_broken": false
}
```

A similar Situation was found that has Remedy:

```
"add confirm-passenger task: window-is-jammed"
```

The answer populates the Context. Assume that the Context is: "window-is-jammed": true.

A new similar Situation “window-is-jammed” is found and the remedy is:

```
"add open-window task"
"add request passenger task: remove foreign object"
"add close-window task"
"add confirm-problem-solved task"
```

Assuming the final confirmation is positive, and the Situation is resolved. The newly logged Situation and the history will be saved to the Situation library and Task library. In case the final confirmation is negative, and the Agent could not find a relevant Situation. In that case, VSA may send the Situation to SHUI, and human intervention will be called to resolve the Situation.

**Example 2: The story of “Pharmacy”**

Here is what happens in VSA for our next example:

The Dialogue Agent posts a "POI_dropoff" Situation (POI - point-of-interest) on the Situation Queue.

When VSA receives the "POI_dropoff" Situation on the Situation Queue, it attempts to handle the Situation.

The Situation Header looks like this:

```
Situation Name: POI_dropoff
Task: Drive_task
Context: {
  current_location: location....
  stop_location: location...
  stop_type: "stop_by",
  wait_time: 15
}
```

The situation handling finds a previous “POI_dropoff” Situation in the database. The Context of the retrieved old Situation has “stop_type” of “final destination”, which means the passenger would choose the “poi-stop” as her final destination, she would not continue her original journey. The final destination of the trip was changed to the “stop_location” of the Situation, defined in the Context. The retrieved Situation has three remedy actions in the Remedy:

```
["abort at drive_task"....],
["add after current_drive_task"....],
["modify at next_offboard_task"....]
```

1. aborts the current drive_task;
2. adds a drive task to the new stop_location;
3. modifies the offboard_task so that the offboard location is the new stop_location.

The final destination of the trip was changed to the “stop_location”, defined in the Context.

The new “POI_dropoff” Situation, however, is different such that the passenger will continue his journey to his original destination. This is defined in the goal of the Situation.

When the Remedy of the retrieved Situation was adapted to the new “POI_dropoff” Situation, it encounters an exception in the validation (Figure 2). Because the goals of the new situation are different. One of the new goals is that the final destination is the same as the original destination, instead of the stop-location. This exception is captured in the validation and VSA will send the Situation to SHUI. A new Remedy is created manually and is sent back (Figure 2). To VSA. The new Remedy has six remedy actions:

```
["abort at drive_task"....],
["add after current_drive_task"....],
["modify at next_offboard_task"....],
["add after current_wait_task"....]
```

1. aborts the current drive_task;
2. adds a drive task (stop_drive) to drive to the "stop_location";
3. adds an offboard task at the "stop_location";
4. adds a wait task after the offboard task;
5. adds an onboard task after the wait_task;
6. adds a drive task after the onboard task that drives to the final destination.

Applying this Remedy, the new plan passes validation. Figure 5 shows the repaired plan. You may zoom in Figure 5 to see the details. In the upper left VSA panel, the red shows the Situation, the yellow shows the Task that the Situation was handled; the bright green is the executing Task.
(corresponds to remedy action 2); the next four white Tasks correspond to remedy action 3-6. After the Situation is handled, the new Situation with the revised Remedy is saved to the Situation library so that next time, similar Situations will be handled without human intervention.

6 Conclusions

A service agent deals with problems similar to everyday tasks. In such a domain, tasks have more variations; the environment is more dynamic; and goals are often negotiable or even not well defined. In such a domain, situations are multifarious as well and often fortuitous. Furthermore, context plays an important role in how a plan is developed and how a situation should be handled. In such a domain, the bottleneck lies in knowledge acquisition and representation, not in computation efficiency.

This paper presents a comprehensive approach that addresses the nature of such a problem domain. Here we highlight some of the unique features and contributions covered in this paper:

1. Proposed a single, unified task representation structure that fits all tasks and a single situation representation structure that fits all situations for an open world domain. Explicitly called out that task, subtask, and actions are analogous, depending only on an abstraction perspective;

2. Proposed structure and syntax for Tasks and Situations so that domain rules can be completely embedded in task and situation cases;

3. Proposed to use context as an important attribute to reflect variations in Tasks and Situations.

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