Knowledge level support for programming agents to interact in regulated online forums

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Abstract. The Web is populated by multiple and heterogeneous online systems. When aiming at supporting users with tasks on the Web, intelligent agents should be able to access these systems in a seamless and regulated way. Our approach to tackle the accessibility challenge has two facets. First, we introduce a knowledge layer structured along the Multi-Agent Oriented Programming approach to comprehensively describe the system's resources and regulations using ontology. Second, we illustrate the use of this knowledge layer with an agent reasoning and acting in compliance with the system's regulations towards achieving its goals. We use online forum as the domain application to highlight the applicability and usefulness of our approach.

Keywords: Multi-agent systems · Knowledge representation · Regulation · Online forum · Hypermedia

1   Introduction

The World Wide Web is already used by human or artificial agents achieving their goals by browsing and acting on Web resources [9]. Crawlers [3], curators [13] or recommender are examples of such software agents inhabiting the Web. Some of them use AI methods such as, for instance, GPT Assistants and AgentGPT to moderate forum and other interactions in online environments[1]. Some proposals investigate the next step for having communities of agents acting and interacting on the Web [4, 12]. This paper follows this line of research and extends work presented in [10]. It considers the regulation of an online forum application where multiple autonomous agents collect content aligned with their users' interest and participate in discussion on their behalf, by writing and publishing posts.

To support autonomous agents in the automated execution of collective tasks on the Web [7, 8], one of the challenge is to enable those agents to seamlessly access the Web, i.e. to discover, use and act on Web resources including MAS's resources such as description of other agents, interaction protocols or norms and

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[1] https://agent-gpt.net/forum-moderation-with-agentgpt-an-essential-guide/#Exploring_Forum_Moderation_with_AgentGPT

organisations. In this paper, we claim that introducing a knowledge layer structured along the agent, environment, interaction and organisation dimensions of the Multi-Agent Oriented Programming (MAOP) approach [1] is a suitable first step to tackle this challenge and enable the collective execution and regulation of autonomous agents in Web systems. This knowledge layer enables agents (i) to discover both applicative and MAS's resources; (ii) to infer how to interoperate with them; (iii) to extract and integrate data from heterogeneous sources; and (iv) to interpret and reason about this data and behave accordingly.

This paper tackles this challenge with two contributions. First, we introduce a knowledge layer structured along the MAOP approach to comprehensively describe the system's resources and regulations using various ontologies. Second, we demonstrate the use of this knowledge layer with a web-based multi-agent application where we illustrate how an agent reasons and acts in compliance with the system's regulations towards achieving its goals. We show the applicability and usefulness of our approach with the practical use case of agents interacting with the Reddit online forum and the MAOP approach supported by the JaCaMo framework [2]. We demonstrate how agents can dynamically discover and use knowledge about the resources and regulations of this forum to properly interact and use these resources in the online forum.

The remaining of the paper is structured as follows. First, we provide an overview of the background knowledge, i.e. tools and ontologies supporting our approach, i.e., Multi-Agent Oriented Programming and Hypermedia Multi-Agent System ontology (Section 2). Then, we introduce the two facets of our contribution in section 3 and section 4. Finally, in section 5 we conclude the paper.

2   Background

Multi-Agent Oriented Programming (MAOP) plays a significant role in the development of multiagent systems (MAS). The use of MAOP, particularly supported by frameworks like JaCaMo [1], can help programmers to design and deploy intelligent agents that work together and communicate effectively over a distributed environment. MAOP is well know for its capacity to model complex systems along four dimensions: Agent [2], Environment [14], Interaction [17], and Organization [11]. The Agent dimension denotes the agents that are the autonomous software entities capable of perceiving and acting on the environment. They use their beliefs about the environment to decide for actions leading toward the achievement of their goals. The Environment dimension denotes the shared, dynamic and evolving space where agents can interact with each other and with artifacts, i.e. shared non-autonomous resources that can observed and acted on by agents. It can be used to model a variety of physical and virtual settings. The Organization dimension defines coordination and regulation patterns taking place in a MAS. It consists in social structures (roles played by agents in groups), coordinated activities (missions and collective goals undertaken by

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[2] JaCaMo Framework: https://jacamo-lang.github.io/

agents) and norms (obligations, permissions and interdictions of agents while playing roles in groups with respect to missions and goals) governing the behavior of agents within the system. The Interaction dimension defines how agents may interact with other agents and artifacts.

New challenges and opportunities arise when trying to deploy MAS on the Web. The Hypermedia Multi-Agent Systems (Hypermedia MAS) [6, 7, 16] approach was proposed to overcome these challenges and support creating MAS that are not only dynamic and open but also capable of seamlessly interacting with hypermedia entities on the Web. Ciortea et al. [9] aim for a deeper integration of agents into the Web's hypermedia structure, thus transforming the Web into a suitable place for agents to act and interact in tight cooperation with human agents. They see the Web as a comprehensive media through which agents can access the external world. This hypermedia structure gives a consistent way for agents to interact with the world, from physical sensors to digital services. In Hypermedia MAS, agents perceive and act on resources represented and deployed in the hypermedia environment [5], such as websites, APIs, and semantic resources. In [6], agents gain the capacity to interact with physical devices, access Web-based data sources, and perform tasks that were previously beyond their reach.

The representation of resources and regulations in the hypermedia environment can be accomplished in different manners. The Web of Things (WoT) Thing Description (TD)[3] is an ontology for describing the capabilities of IoT devices and services. These representations enable agents to discover physical resources and learn how to interact with them. The Hypermedia MAS Ontology (hMAS ontology)[4] is an ontology for describing the structure and regulations of multi-agent systems. In this work we use these ontologies because the WoT TD ontology is a W3C standard and the hMAS is a comprehensive and modular ontology that allows the representation of MAS developed using the MAOP approach.

3   Knowledge level support for agent programming

In this section, we provide an overview of the various components of our approach. Before, we present a motivating scenario (Section 3.1). We then present the knowledge layer that describes the resources and regulations of the system that agents can use to discover and interact with the system (Section 3.2). Next, we present what agents can use to reason about the knowledge layer and decide what to use to act (Section 3.3). Finally, we describe what agents can use to act in the environment (Section 3.4).

3.1   Online Forum Motivating Scenario

We have chosen a multi-based online forum to exemplify our proposal (cf. Figure 1). In this online forum, agents have the permission to retrieve (`Read`) and

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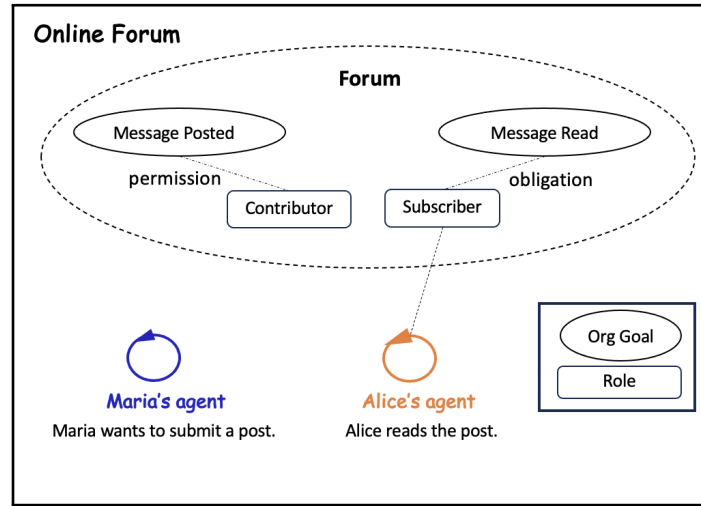[3] https://www.w3.org/TR/wot-thing-description11/
[4] https://ci.mines-stetienne.fr/hmas

Fig. 1. Online forum motivating scenario

the right to post (`Post`) messages depending on the role they adopt. Playing the `contributor` role, agents may submit posts, while playing the `subscriber` role, agents navigate diverse forum threads for reading more details about posts. *Alice* and *Maria* are two users in the `Online Forum`, each with a personal autonomous agent acting on their behalf. *Alice*'s agent has adopted a `subscriber` role in the context of the `Forum` thread. By playing this role, *Alice*'s agent has the permission to achieve the 'Message Read' goal. *Maria* is a new user with the intention of achieving the 'Message Posted' goal. *Maria*'s agent has to choose a suitable role to be permitted to achieve her goal in the system under the governance of the online forum regulation. Her agent reasons using the knowledge layer describing the online forum resources and regulations, and decides to adopt the `contributor` role in the `Forum` thread to be allowed to achieve the 'Message Posted' goal.

In the next sections, we introduce our approach using this small user story of the agent-based interaction and use of online forum.

3.2   Knowledge level support for Discovering

Description of action possibilities in the environment. In a first step, in order to describe the action possibilities in the environment for the agents, we represent the hypermedia environment of the motivating scenario using the hMAS ontology. Action possibilities are represented as *signifiers* in the hMAS ontology. Signifiers describe behaviors that agents can perform to exploit an affordance. Signifier is a perceivable sign or cue that can be interpreted meaningfully by an agent to reveal information about a behavior possibility. Affordance is a behavior possibility that is a relationship between an ability of an agent
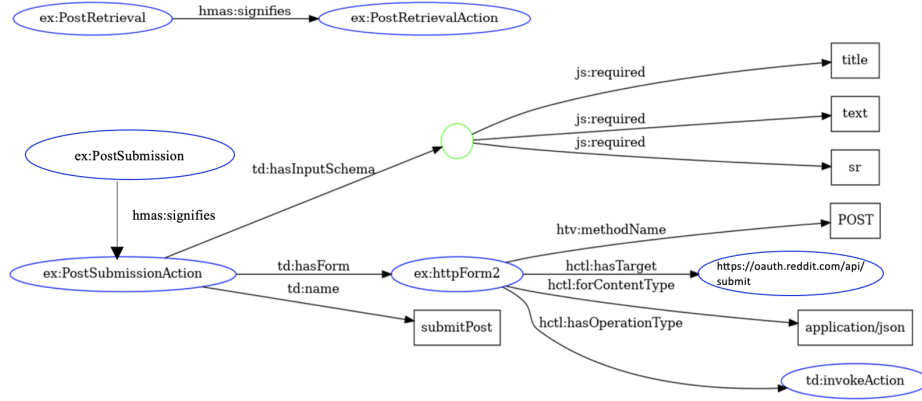
Fig. 2. Representation of signifiers and affordances using the hMAS ontology

and a situation that includes agents and features of the environment[5]. Signifiers are not simple informational resources, but rather constructs available in hypermedia environments that enable situated agents to discover and interpret affordances [15].

In the context of the Reddit online forum, we use two signifiers: `ex:PostSubmission` and `ex:PostRetrieval`. Each one describes a behavior that agents can perform to exploit affordances (see Figure 2), by providing each a description of actions that agents can use to act in the environment. More specifically, the `ex:PostSubmission` signifier `hmas:signifies` the specification of the behavior `ex:PostSubmissionAction`. This action is specified through a *form* defined by the property `td:hasForm` that describes an *HTTP POST* request and an *input* defined by the property `td:hasInputSchema` that defines the input data schema of the `ex:PostSubmissionAction` action. We have a similar description for `ex:PostRetrieval`.

Representing regulation. Going a step further in the building of the knowledge layer to make accessible to the agents a description of the online forum's structure, we use an organization abstraction represented using the hMAS ontology. Within this organization, agents can discover organizational goals (e.g `submitted_RedditPost`), missions (e.g. `submit_RedditPost`), and roles (e.g. `reddit_contributor`) and groups (e.g. `reddit_group`) given the norms that concern them. Organizational goals are the specific objectives that agents are expected to accomplish within the organization. Missions define the set of organizational goals that an agent committed to the mission has to accomplish. Roles define positions of agents in the organization. The organization of the Reddit online forum, depicted in Figure 3, revolves around key entities that create a structured environment for regulating agent interactions.

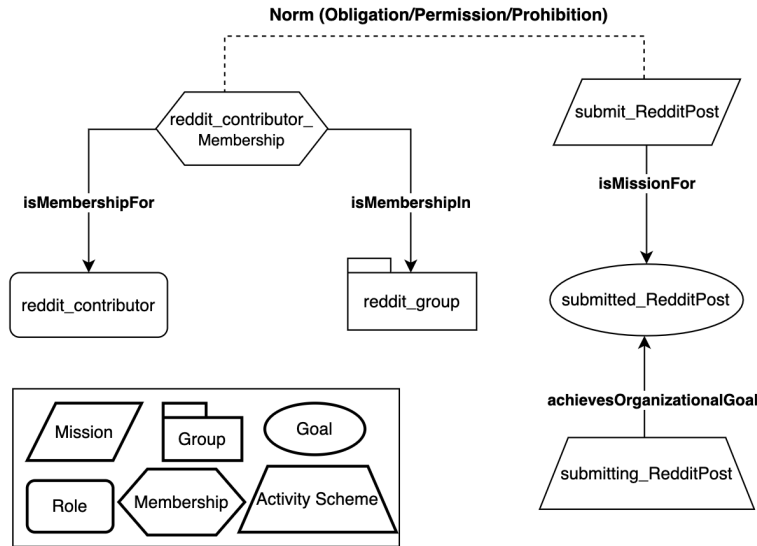[5] Please see more about these definitions at https://ci.mines-stetienne.fr/hmas/core

Fig. 3. Structure of the Reddit organization

At the core is the concept of a `reddit_group`, representing a subreddit where discussions and content sharing take place. Within this online forum, participants can adopt specific roles such as: `subscriber` and `contributor`. Subscribers follow discussions to retrieve existing posts, while contributors actively contribute by submitting new posts to the subreddit.

Let's suppose that, in this organization, *Maria*'s agent has the goal to submit a post to the Reddit online forum, `submitted_redditPost`. To achieve that goal, the agent needs to identify the most suitable mission. *Maria*'s agent initiates the decision-making process by retrieving the goal from her beliefs. She crawls the organization ontology to extract the relevant missions to that goal. Based on the norms and the extracted mission, she infers that she has to adopt the `reddit_contributor` role within the `reddit_group`. When done, the `reddit_contributor_Membership` is created as a new state of the organization. Thus, *Maria*'s agent is allowed to commit to the `submit_RedditPost` mission. She commits to that mission and follows the plan for `submitting_RedditPost` activity scheme outlined to achieve the `submitted_RedditPost` goal.

3.3 Knowledge level support for Agent Reasoning

Previously, Maria's agent had discovered the signifiers. Using the knowledge presented in Figure 4, the agent is able to know that these signifiers can achieve her goal.

Reasoning then on the description of the missions in relation to that goal in the organization, and on the relation with the corresponding mission and role
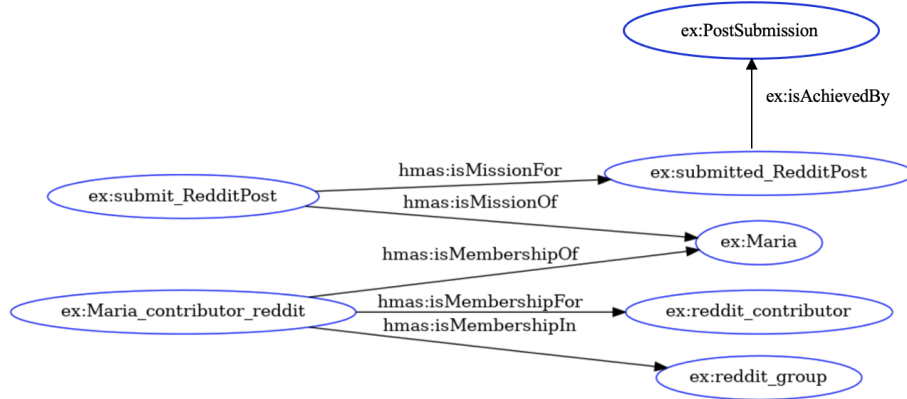
Fig. 4. Result of a role adoption process and the commitment to a mission

coming from norms, Maria's agent is able to select which role to adopt to achieve her goal. Figure 4 shows the new state of the organization after the adoption of the role `reddit_contributor` in the `reddit_group` of the Reddit organization by Maria's agent.

Once Maria's agent has adopted a role, it gets an obligation to commit to the suitable mission and to achieve her goal. Maria's agent being obedient commits to this mission and goal. Figure 4 shows the result in the knowledge graph of the commitment of Maria's agent to the `submit_RedditPost` mission.

3.4   Knowledge level support for Acting

The online forum TD in Listing 1, titled `Online Forum Thing`, does not have physical counterparts and is primarily used to facilitate interactions via agent actions.

```
<#thing> a td:Thing ;
    td:title "Online Forum Thing" ;
    td:hasSecurityConfiguration [ a wotsec:NoSecurityScheme ] ;
    td:hasPropertyAffordance [
        a td:PropertyAffordance , js:ObjectSchema ;
        td:name "retrievePost" ;
        td:title "retrieve post" ;
        td:hasForm [
            htv:methodName "GET" ;
            hctl:hasTarget <retrieve> ;
            hctl:forContentType "application/json" ;
            hctl:hasOperationType td:readProperty ;
        ];
    ] ;
    td:hasActionAffordance [ a td:ActionAffordance ;
```

```
td:name "submitPost";
td:title "submit post";
td:hasForm [
    htv:methodName "POST";
    hctl:hasTarget <submit>;
    hctl:forContentType "application/json";
    hctl:hasOperationType td:invokeAction
  ];
td:hasInputSchema [ a js:ObjectSchema ;
      js:properties [ a js:StringSchema;
        js:propertyName "title"
                      ];
      js:properties [ a js:StringSchema;
                      js:propertyName "text"
                      ];
      js:properties [ a js:StringSchema;
                      js:propertyName "sr"
                      ];
      js:properties [ a js:StringSchema;
                      js:propertyName "kind"
                      ];
      js:properties [ a js:StringSchema;
                      js:propertyName "url"
                      ];
      js:required "title", "text", "sr"
                    ] ;
] .
```

Listing 1. Online forum Thing Description

It defines the security configuration and provides property and action affordances. The `retrievePost` property affordance enables users to retrieve posts. It offers a `GET` method, targeting a retrieve endpoint, and expects data in `application/json` format. This property affordance supports reading operations. The `submitPost` action affordance allows users to submit new posts. It uses a `POST` method, targeting the submit endpoint, and requires input data in `application/json` format. Users must provide certain required inputs that vary from one online forum to another. For instance, in the following example, `title`, `text`, and `sr` information are necessary when invoking this action. In the given context, `sr` refers to the subreddit, which is a specific category or topic within the Reddit online forum. A subreddit is a dedicated section within Reddit where users can share and discuss content related to a particular theme, interest, or subject. This online forum TD instance serves as an abstract representation within the Reddit online forum environment, enabling interactions through the `retrievePost` and `submitPost` affordances.

4   Knowledge level support in action

In the previous section we presented the knowledge level support that agents can use to act in the Web-based environment. In this section, we illustrate how the knowledge level support can be used to regulate agents' interactions within our illustrative Reddit online forum use case. Reddit provides a dynamic and collaborative environment where users, or agents acting on their behalf, can engage in discussions, share content, and contribute to specific topics (i.e., `subreddits`). Figure 5 illustrates the architecture of our multi-agent architecture with the artifacts (Thing Artifact and Linked Data Artifact) used to access the knowledge layer and Web Resources, and the artifacts (JaCaMo Org artifacts) used to monitor and regulate the activities of agents under the governance of normative organisations.
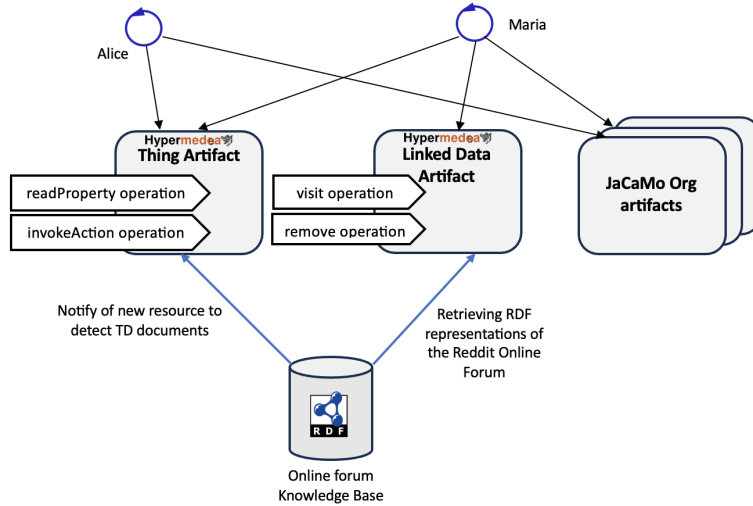

Fig. 5. Reddit use case Multi-Agent Architecture

We have used JaCaMo [1] and Hypermedea [6] to implement this use case. Hypermedea brings to the JaCaMo platform, a set of dedicated artifacts to handle the access to Web resources and knowledge layer. The Hypermedea used artifacts are the *Linked Data* and the *Thing* artifacts. The Linked Data artifact is used to crawl Linked Data from the Web, to store it in a local database, and to query it. It is responsible for retrieving RDF representations of resources. The *Thing* artifact is used to create a proxy for a WoT device, which allows agents to interact with the device in a standardized way. For JaCaMo, the organizational artifacts enable organization and environment integration.

In this use case, we focus on two agents: *Alice* and *Maria*. Both agents are playing roles in the `reddit_group` group Within the Reddit organization's

structure, there are distinct roles such as: the *reddit_subscriber* and the *reddit_contributor*. Each role comes with specific obligations and permissions, expressed by norms, as follows: agents who play the *reddit_subscriber* role are obliged to read posts, and those who play the *reddit_contributor* role are permitted to submit posts to Reddit. This structure creates agents that can violate norms (read posts obligation) and trigger alarms within the JaCaMo organization if obligations or interdictions aren't fulfilled. In our implementation, *Alice* is a dedicated hard-coded obedient agent that we have developed in [10] to retrieve posts from the Reddit online forum. This agent plays the *reddit_subscriber* role. Conversely, *Maria*'s agent chooses a suitable role by reasoning about the online forum structure using the knowledge layer. The reasoning steps that *Maria*'s agent followed to act on the Reddit online forum are illustrated in Fig. 6.
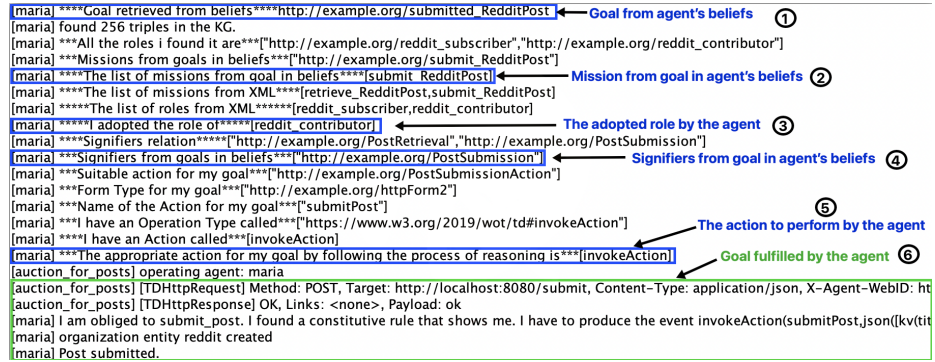

Fig. 6. Maria's agent achieves the goal of submitting a post

- First, she starts the reasoning process by retrieving her goal from her beliefs, specifically `submitted_redditPost`.
- Second, using that goal and the knowledge graph describing the Reddit organization, *Maria*'s agent engages in reasoning to identify the most suitable mission for that goal.
- Third, based on the organization's norms and the goals retrieved from *Maria*'s beliefs, she needs to make decisions about the appropriate roles to adopt. Once *Maria*'s agent adopts a role, she has an obligation to commit to the suitable mission and achieve her goal.
- Fourth, based on the goal extracted from her beliefs, *Maria*'s agent extracts all the signifiers related to that goal (see Section 3.3).
- Fifth, *Maria*'s agent makes decisions about the actions to take within the Reddit online forum.
- Finally, *Maria*'s agent achieves her goal and submit successfully a post in Reddit.

The agent's successful submission of posts to Reddit demonstrates its ability to use a knowledge layer for discovering, reasoning, and acting on any online

forum. In Algorithm 1, we present the reasoning process that outlines the various steps that *Maria*'s agent follows to reason about the knowledge layer and make decisions, such as submitting a post to the subreddit `testingground4bot` on Reddit.

Algorithm 1 Reasoning process

1: Forms ← FindAll(Form, rdf(Action, "https://www.w3.org/2019/wot/td#**hasForm**", Form))
2: Names ← FindAll(Name, rdf(Action, "https://www.w3.org/2019/wot/td#**name**", Name))
3: **for each** Na ∈ Names **do**
4:     **for each** Fr ∈ Forms **do**
5:         Operations ← FindAll(Operation, rdf(Fr,"https://www.w3.org/2019/wot/ hypermedia#**hasOperationType**", Operation))
6:         NL ← [ ]
7:         **for each** U ∈ Operations **do**
8:             NL ← Append(NL,ConstructOperationWithParameter(U, Na, Parameters))
9:         **end for**
10:     **end for**
11: **end for**
12: **return** NL

Maria's agent initiates the reasoning process by finding all actions associated with a relationship defined by the property `td:hasForm` from the W3C TD ontology, that describes how an operation can be performed. The algorithm systematically identifies these actions and their corresponding names. For each action and its related form, the agent explores further to identify the semantic intention of performing the operations described by the form linked through the property `hypermedia:hasOperationType` in compliance with the W3C WoT ontology. Thus, the agent has the name of the action which is `Na=submitPost` and the name of the operation which is `U=invokeAction`. Using the retrieved information, the agent constructs the action *ConstructOperationWithParameter* with the type of the action to take *U*, name of the action *Na*, and a list of required parameters: the title of the post, the text, the subreddit, and the type of the post (i.e., link, self, image, video, videogif). This process enables Maria's agent to reason about the available knowledge and formulate decisions based on the identified actions and the associated operations.

5   Conclusions

In this paper, we demonstrate how a knowledge layer can be used to discover and guide agent interactions in online forums for reasoning. The case study showed the feasibility of using MAOP platform to handle the access to the Reddit

online forum resources for discovering, reasoning and acting by submitting and retrieving posts. The agents start by getting a structured view of the online forum using Hypermedia MAS Core Ontology (hMAS). This includes understanding the relationships between different entities like agents, roles, groups, missions and signifiers. Next, we integrate the Thing Description (TD) to act on the Reddit online forum. By combining hMAS and TD, agents can then reason and act in a way that fits well with the forum's structure. Thus, MAOP approach proves effective in guiding agents to discover, reason and act on online forums.

Acknowledgment

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