Applying COAALAS to *SPiDer*

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Abstract. Artificial Intelligence techniques and tools have been applied to Assistive Technologies (AT) in order to support elder or impeded people on their daily activities. A common application are intelligent pill dispensers and reminders that help the patient comply with his medication. This has become even more important, as patients suffering from multiple pathologies are prescribed cocktails of drugs that require strict compliance in order to achieve a successful treatment. Existing intelligent pill dispensers tend to focus in the user-tool interaction, neglecting user's connection with its social environment and the possibility to monitor patient's behaviour, effectively adapting to a dynamic environment and providing early response to potentially dangerous situations by detecting unexpected or undesired patterns of behaviour. In previous work we have presented COAALAS, an intelligent social and norm-aware device for elder people that is able to autonomously organize, reorganize and interact with the different actors involved in elder-care, either human actors or other devices. In this paper, we present SPiDer an intelligent pill dispenser integrated with the COAALAS architecture.

1. Introduction

Population ageing is becoming a global problem, as older population (aged 60 years or over) is estimated to grow from the current 11% to 22% by 2050 [15]. Moreover, the cost of supporting an elder is greater than the cost of supporting a child in a ratio of five to three [14], most of this cost being caused by higher health expenses. In the coming years this situation (together with other economic factors) will put great pressure on the national healthcare budgets, mainly because therapies for managing chronic diseases (*e.g.*, diabetes, Parkinson, *etc*) are performed away from the institutional care setting, typically at home. This distributed approach to daily care requires that elders be capable of *autonomously* taking several different medications at different time intervals over extended periods of time. This can easily lead to forgetfulness or confusion when following the prescribed treatment, specially when the patient is suffering multiple pathologies that require a treatment with a drugs cocktail. This gets worsened in elders suffering from a cognitive impairment. Since medication compliance is a critical component in the success of any medical treatment, this becomes an important problem to tackle for the patient's well-being and the efficient use of resources.

In this context, Assistive Technologies (AT) have been able to provide successful solutions on the support of daily healthcare for elder people, mainly focused on the interaction between the patient and electronic devices. However, the distributed approach that such kind of healthcare has to follow in the current socio-economical setting (*e.g.*, people mobility, online available services, shared costs, hetereogeneous knowledge sources, distributed responsabilities, *etc*) requires more complex AT designs that go further than the interaction with a tool and are able to focus on the relationship between the users and their social environment: caretakers, relatives, health professionals.

In previous work, we presented the COAALAS project (COmpanion for Ambient Assisted Living on *ALIVE*-Share-*it* platforms) [8], a framework for multi-agent systems that combines organisational and normative theories with Ambient Assisted Living (AAL) technologies. The project aims to create a society of organisational aware devices (typically sensors and actuators) that are able to adapt to a wide range of AAL situations always with the goal of improving people's Quality of Life (QoL). COAALAS models the device network around the user as a society, including the set of behavioural patterns the devices are expected to follow. COAALAS effectively supports smart assistive tools that integrate human actors with the surrounding devices, contributing to the state-of-the-art in semi-autonomous and intelligent devices for elder people by allowing the devices to be both social-and norm-aware.

The mid-term objective of COAALAS is to integrate a wide range of sensors and actuators in a domotic setting, in order to transparently assist the user in their daily activities, while keeping all the participants of the healthcare workflow involved. The first design and implementation of such a sensor/actuator is the social electronic reminder for pills [7], which tackles the supply of the required stock of medicines to a user with difficulties to leave their house, while supervising that he follows the medical treatment prescribed by his doctor, not missing any dose due to forgetfulness or taking it at the wrong time due to confusion. In this paper we will take a step forward in that implementation by integrating COAALAS with another project which includes further physical devices providing additional functionalities.

The focus of our previous published work with respect to COAALAS has been the description of the architecture framework and technical design of the social electronic reminder. In this paper we present proposals existing in the state of the art that have properties common to COAALAS in §2, and the COAALAS architecture in §3. Then we present an approach on how to integrate one of the existing proposals in the COAALAS architecture at §4. Our proposal is then put into context with both our research purposes and the state of the art. Finally, in §5, conclusions are drawn and future work outlined.

2. State of the art

This section presents a short survey on the existing work in the area of Ambient Intelligence (AmI) for supporting independent living, with special emphasis on the works focused on facilitating activities of daily living (ADL). In this paper we specially focus in those activities related with the intake of a prescribed medication in compliance with medical schedules. Special attention is put on COAALAS that has been selected as basis for the work presented in this paper.

2.1. Medication prescription and regimentation

AT can be effectively used for guiding elders with their prescribed treatments, avoiding major problems such as non-compliance with the treatment and adverse drug reaction.

Several devices are available for helping patients manage their daily doses of medication. They range from simple pill containers with multiple compartments that can hold a month's supply to intelligent pill dispensers[10] with an alarm function which can detect when the patient takes the pill, and that can be telematically programmed in case the treatment changes. However, those devices tend to have a static encoding of their functions, and are unable to react to changes in the environment (*e.g.*, they will keep on dispensing the pills even if the patient is on holidays away from home) and autonomously react to potentially dangerous situations (*e.g.*, the dispenser is about to run out of supply for a given pill). Furthermore, to the best of our knowledge none of those devices takes into consideration the important role that third parties may have in the activity. For instance, the prescribing doctor scheduling a visit with the patient when the treatment finishes, a delivery company refilling the dispenser when it is about to run out of medication, or the patient's personal computer displaying reminders when it is time to take a given medication. Nor they reflect the social constraints that apply in the relation between the user and the other actors. For instance, forbidding the delivery company employee from entering the user's home if the doctor considers the user capable of autonomously refilling the dispenser.

2.2. Agent-based healthcare systems

In [3] ECA (Event-Condition-Action) rules are used for Smart Homes that support assisted living for the elderly. A basic interpretation of the ECA rules is that, on detecting certain events, if certain pre-conditions are satisfied, then a given set of actions are to be enacted. By using rule-based systems and other Artificial Intelligence (AI) techniques, devices and hardware-oriented technologies for Smart Homes can be augmented and enriched. With that goal in mind, Augusto *et al* propose connecting the devices to a central monitoring facility that performs all the reasoning. This approach differs from the rest in the sense that devices show a complete lack of intelligence, leaving all the reasoning to a central component, effectively preventing coordination and cooperation among the agents representing the different devices. A similar work [13] proposes using abductive logic programs for the reasoning process. Abductive logic programs provide active behaviour, just like the ECA rules, but they also provide added declarative semantics and a extensive background knowledge available via the logic programming. For instance, this approach allows for easily applying preferences to the reminders issued to the user. Both works present a higher system adaptability, allowing even for a customization that adapts the system to the preferences of the user. However they lack the coordination among different agents that would allow the system to autonomously recover from a failure if one of the agents stops working. A critical property considering the centralized design of the the system.

2.2.1. Robocare

Robocare [4] is a project deployed on a domestic test-bed environment that combines a tracking component for people and robots and a task execution-supervision-monitoring component. The system is composed of several software and hardware agents, each providing a set of services, and an event manager that processes requests to the different services and directs them to the appropriate agents. The system also includes a monitoring agent, with knowledge of the assisted person's usual schedule. In order to coordinate all the agents and monitor user's behaviour heavy computational processes take place, limiting the tested scenarios to non-crowded environments, where only 2-3 persons and only a small portion of the domestic environment are monitored. What is more, the expected schedule is non dynamic and small justified deviations (*e.g.*, relatives visiting the user) are currently detected and corrected.

2.2.2. *Independent LifeStyle Assistant*

The AHRI (Aware Home Research Initiative) [6] is a residential laboratory for interdisciplinary research where several projects have been evaluated. The most relevant one is the ISLA (Independent LifeStyle Assistant) project [9], that passively monitors the behaviours of the inhabitants of the residential laboratory, alerting relatives in case of potentially dangerous situations (*e.g.*, the user falls). The ISLA project presents two main innovations with regards to the Robocare project. First of all, agents autonomously interact within them in order to achieve their goals, without the need of an event manager agent that coordinates them. However, in order to transform context-free perceptions provided by the agents into context-aware perceptions, a centralized coordinating agent is used. Second, agents are able to learn schedules based on the daily tasks performed by the inhabitants. Models are built, reflecting which devices are triggered as a result of the performance of which activities, and alerts are raised whenever an unlikely activity takes place. Therefore, instead of using generic static schedules for the users, the schedules are built dynamically based on user's detected behaviour. However, once a schedule has been learned, the user is not able to deviate from it without raising an alarm.

Evaluation of the ISLA project presents two main conclusions. First, the need for coordination of the agents and centralized control outweighs the benefits of the distribution and independence of components agents architectures provide. Second, partial observability of actions performed by the individuals is a problem, specially when plans are abandoned due to forgetfulness and reminders need to be issued. Individuals do not tend to be in favour of having every of their moves observed.

2.2.3. *MINAmI*

In the scope of the MINAmI project [12] a qualitative study of three ambient intelligence scenarios is reported, being the most relevant one a scenario that deals with monitoring the taking of medication. In the scenario users are given a smart pillbox, with a cap that counts the number of opening and closing events and a clock. The pillbox can communicate with a mobile phone, that displays the timed record of cap openings and closings. If the users forgets to take his medication for a prolonged period of time, the pillbox sends a notification to a care center. During the evaluation of the scenario, users felt it was too intrusive on their privacy, arguing the data should not be reported to their doctors. They considered relying on such devices for the reminders could weaken people's cognitive abilities, and that such a system would not be suitable for users taking a cocktail of medication rather than just a single medicament, as several pillboxes should be provided. The scenario presented seems to be mainly theoretical, lacking an implementation, and does not provide a fully integration of the pillbox with the rest of the devices in the Smart Home (*e.g.*, the system can notify that the user forgot to take his medication even when the rest of the devices are showing that the user has not been at home on the last 3 weeks, for instance, because he is on holidays).

2.2.4. SPiDer

SPiDer focuses in the specific problem elderly face when trying to follow a complex schedule of medications (*i.e.*, the low compliance with complex prescribed medication schedules) and aims to partially solve the aforementioned problems through the use of AT and AI tools [11]. The system developed by *SPiDer* has three main components: the Smart Pill Dispenser (*SPD*) which allows to perform the dispense tasks and the sensing of the environment, the Identification Access Management (*IAM*) which allows to monitor and manage the entrance and exit of the house, and the MAS which integrates both the *SPD* and the *IAM* components and adds new features as communicative tools between the system and the outside world. There is a physical implementation of the *SPD*. *Figure* 1b depicts the physical version of *SPiDer* and *Figure* 1a the architecture of the MAS, which is divided in three platforms containing each of them several agents. Those agents have responsibilities related to the goals of the system which are reached through their cooperation. Allows the dispensing of different kinds of drugs, is adaptable to the ADLs of the patient and successfully involves externals actors such as relatives, doctors and caretakers.

3. COAALAS

COAALAS focuses on scenarios where the elder user, physically or cognitively impaired, has to comply with the medication prescribed by a doctor. Such scenarios can get especially complex due to a high and uncountable number of potentially unexpected circumstances, *e.g.*, the combination of several treatments that impose a temporal order on the doses, lack of user's discipline on taking the medicines during the correct interval, delays on the delivery of the medicines, lack of communication between the user and the doctor, and so on.

In such scenarios, the primary goal of our approach is to provide enough support to enable a change in the users' (including elders, doctors, health professionals among other stakeholders) non-compliant behaviors by engaging them in the drug intake task. With this purpose in mind we introduce the design and proposed implementation of a social-norm aware pill dispenser. The dispenser, based on the concepts developed by COAALAS [8], will support the elderly or disabled people to manage their daily doses of medication while presenting the following three properties. *Social awareness*: The device is connected with other assistive devices and with relevant actors (such as doctors, caretakers and other health professionals, relatives, *etc*) for helping the elder take his daily doses of medication. *Autonomy*: The device can react to changes in the physical or social environment without requiring human intervention. Furthermore, it should be able to react to simple changes in the scenario autonomously (*e.g.*, a change in the scenario implies the pill dispenser is not filled by the patient any more, but by a care giver). *Normative awareness*: The device performs its task while following a set of specified behavioural patterns. However, due to its autonomy, the device has the option of breaking the patterns, provided it considers it will be in the benefit of the society (*e.g.*, if an incoming stock break is detected).

COAALAS builds on the results of two European funded projects: EU-*SHARE-it* [2] and EU-*ALIVE* [1]. By combining several state-of-the-art AI techniques (such as Autonomy, Proactivity, Social Behaviour and Adaptability) COAALAS provides a multi-agent platform able to integrate software agents embedded in the Ambient Assisted Living (AAL) devices and human actors. This allows for making AAL devices intelligent enough to organize, reorganize and interact with other actors. The agents embedded in the devices have an awareness of their social role in the system – their commitments and responsibilities – and are capable of taking over other roles if there are unexpected events or failures. COAALAS creates a society of physically organisational-aware devices able to adapt to a wide range of AAL situations that could have an impact on the user's well-being and keep him actively involved with his entourage.

COAALAS builds on top of the *ALIVE* framework, a multi-level architecture that provides support for *live*, open and flexible service-oriented systems. The *ALIVE* framework presents normative structures that allow for easily expressing both expected behavioural patterns and the actions to be taken when the actors involved in the scenario do not comply with these patterns. For achieving this functionality, *ALIVE* relies on substantive norms that define commitments agreed upon actors and are expected to be enforced by authoritative agents, imposing repair actions and sanctions if the system reaches invalid states (*i.e.*, states that are outside of the expected behavioural patterns). Substantive norms allow the system to be flexible, by giving actors (human or computer-controlled) the choice to cause a violation if this decision is beneficial from an individual or collective perspective.

The organisational level in *ALIVE* contains organizational structures inspired in the *Opera* methodology [5] by using the three following concepts: *Objective* (*i.e.*, daily take the prescribed medication dose), *Role* (*e.g.*, patient, caretaker, doctor, *etc.*) and *Landmark* (*i.e.*, a medication dose has been provided).

ALIVE provides coordination structures that provides actor's patterns of interaction, effectively allowing the system to move between relevant states (*e.g.,* the pill dispenser needs to be refilled, the pill dispenser has been refilled, etc.). The coordination structures are formed by tasks containing both pre and post conditions and the permissions required for executing the tasks (associated to the different roles in the scenario). A set of organizational aware intelligent agents select a role according to their capabilities and start enacting the plans associated to that role as requested. Finally, *ALIVE* also includes a service level that maps actions in the environment to abstract tasks. Non-organizational aware agents in the system register their capabilities (e.g., tasks they can perform) via a white pages system and are coordinated by the organizational aware agents to execute the tasks required for enacting the different plans.

4. Applying COAALAS to *SPiDer*

In §3 we introduced the theoretical principles and main aspects of COAALASİn this section we present an integration of COAALAS with a different working system. To motivate such integration let us first introduce the operational capabilities COAALAS achieves. By doing so we will be able to notice the similarities and differences of both projects, as well as the benefits and disadvantatges of their integration.

The *ALIVE* framework COAALAS provides a flexible multi-level architecture able to model the complex interactions among different actors involved in the AAL tasks, where a set of heterogeneous actors have different responsibilities and offer or consume different services. Thanks to *ALIVE*'s multi-level approach, COAALAS supports introducing changes at a high level (*e.g.*, introducing a new actor, a new objective for the system or a new expected pattern of behaviour) without performing any modification to the lower levels (*i.e.*, reprogramming the agents in the different smart devices) because changes at higher levels automatically trigger changes at the lower levels. COAALAS provides AT devices with a high level layer, easy to use and understand by non-technological experts. By using this layer, devices as *SPiDer* can be easily adapted to introduce a new medication regime or to include a new actor (*e.g.*, patient's relative as a caretaker) in the system.

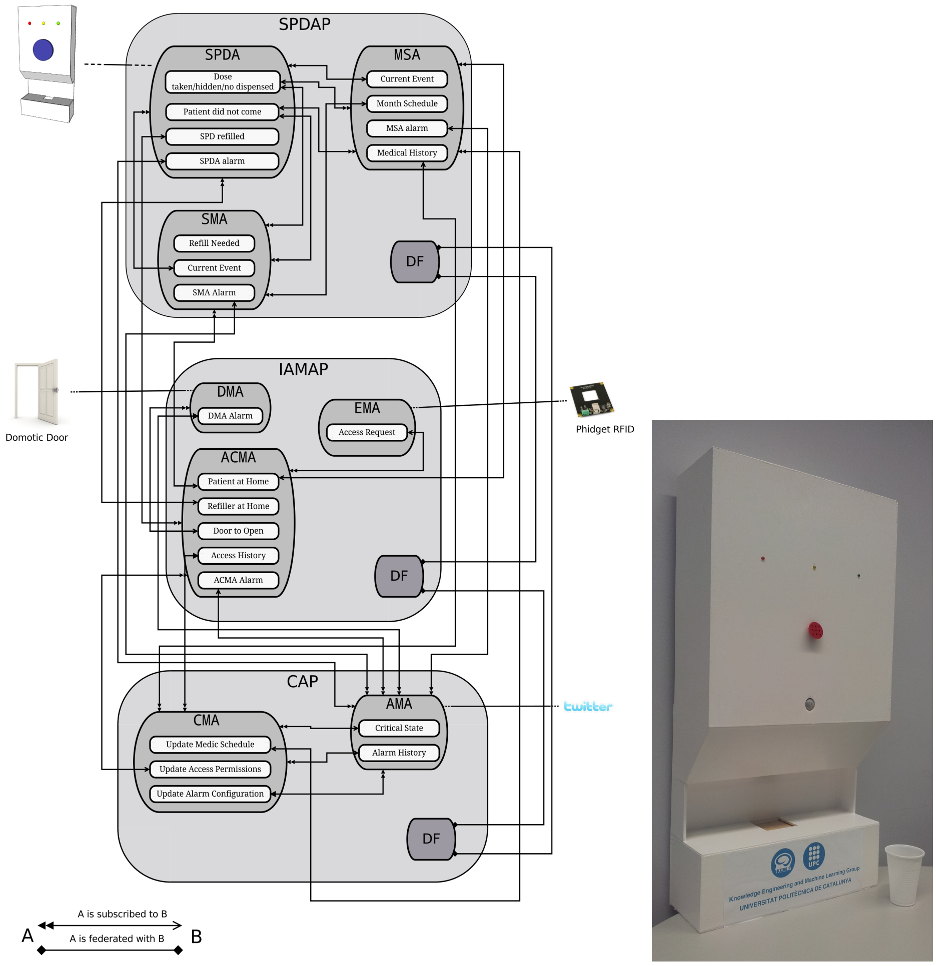
COAALAS also allows for monitoring the different actions performed by the set of actors in order to fulfill the AAL tasks. Deviations from the expected patterns of behaviour can be detected, and sanctions or repair actions applied. Therefore, COAALAS provides support for dealing with unexpected events (*e.g.*, sending a doctor, or an urgent shipment of medications to the patient when the pill dispenser device runs out of pills).

Finally, the *ALIVE* framework provides COAALAS with a set of intelligent agents that support both exception handling and organisational normative awareness capabilities. Exception handling is common in other service-oriented architectures, however, most approaches tend to focus on low-level (*i.e.*, services provided by the actors) exception handling. The *ALIVE* approach enables managing of exceptions at multiple levels ranging from substituting services (*i.e.,* low level exception handling) to looking for alternative ways to achieve a particular goal (*i.e.,* high level exception handling). Regarding organisational normative awareness, making normative agents reason about their tasks before performing them, and discarding the ones that do not comply with the expected patterns of behaviour, adds organisational awareness to the execution of the different tasks.

Based on these operational capabilities, we seek to integrate COAALAS with a working project with the goal of obtaining a unified working system with high-level capabilities. In that regard we have chosen the project *SPiDer* which as we will see next, meets most of COAALAS architectural design decision and therefore supposes a good match. As introduced in §2.2.4, *SPiDer* incorporates a functional MAS in its approach (see Figure 1a). It is organized in three platforms, where each platform is responsible of different part of the full system functionalities.

The first platform, named *Smart Pill Dispenser Agent Platform* ($SPDAP$) is in charge of those tasks intimately related with the dispensing and management of medications. Most of those tasks are performed through the Smart Pill Dispenser (*SPD*) (see a photo of its working prototype in 1b). The SPDAP is composed by three agents: Smart Pill Dispenser Agent ($SPDA$), Medic Scheduler Agent (MSA) and Stock Manager Agent (SMA). The main responsibilities of that platform is to control the drugs supplies of the *SPD*, maintain an updated, dynamic and adaptable schedule and dispense the appropriate doses at the correct time. Thus, in terms of the *ALIVE* framework we can identify three main roles: a) *Drugs supply supervisor*, b) *Scheduler* and, c) *Dispenser*

The second platform, named *Identification Access Management Agent Platform* ($IAMAP$) is in charge of those tasks related with the *SPiDer*'s Identification Access Management module (IAM). It is composed by three agents: Door Manager Agent (DMA), Entrance Manager Agent (EMA) and Access Manager Agent ($ACMA$). The principal responsibilities of this platform is to detect, evaluate and control the accesses to the house of the different stakeholders involved in the system. From the *ALIVE* approach, two roles can be identified: a) *Doorman* and b) *Access Manager*.



(a) Architecture of the *SPiDer* project. Boxes from large to small represent Platforms, Agents and Services

(b) Operational prototype of the SPD

Figure 1. *SPiDer* relevant components

The third platform, which is called *Communication Agent Platform* (CAP) is in charge of the communicative functionalities as to detect or even prevent critical situations due to a lack of compliance with the prescribed medication. It is composed by two agents: Communication Manager Agent (CMA) and Critical Manager Agent ($CrMA$). This platform manages all the communications providing a channel for external actors to actively interact with the system and vice versa. It also detects when a situation is considered critical and actively prevents the effects of such situations by making use of the communication channel to alert outdoors. Hence, regarding to the *ALIVE* perception, two roles are implicit: a) *Communicator* and, b) *Critical Situations Supervisor*

At this point, once successfully identified the roles, we can argue that the integration between *SPiDer* and COAALAS is both coherent and appropriate. To finalize such integration we next have to identify the landmarks and the norms to fulfill the *ALIVE* requirements regarding its organizational layer. Several landmarks could be easily identified (*e.g.*, dose taken, dose hidden, patient out of home, critical situation arises, poor drugs supplies, refiller at home, *etc*), but those require the direct feedback of experts and potential system users. Landmarks will be therefore defined and refined as the system is tested. Finally, with the incorporation of the norms to ensure the adaptability of the system and its well-performance the complete integration *SPiDer*-COAALAS should be accomplished.

5. Conclusions and future work

AT are applied to support people in their daily life. Most approaches focus solely on the direct interaction between users and the assistive tool. AI has the potential to provide innovative mechanisms and methods capable of taking into account more complex interactions. For instance, the important role that third parties may have in user activities, and explicitly reflect the social constraints that apply in the relationship between device and patient. A simple reminder system can be implemented using a smart-phone's calendar and alarm systems. However, it would lack the autonomy, social awareness and normative awareness our proposal provides. A simple alarm system is not able to adapt reminders to user's calendar (it will keep reminding the user to take a medication dose even if his calendar indicates he will be away from home when it is time to take his medication, rather than adapting the reminder to user's schedule) nor is able to alert caretakers if potentially dangerous deviations from user's routine are detected.

COAALAS focuses on making devices intelligent enough to organize, reorganize and interact with other actors providing smart devices with an awareness of their social role in the system (including commitments and responsibilities). This way, smart devices are capable of reacting to deviations from the expected patterns of behaviour, effectively adapting to a wide range of AAL situations that could have an impact on the well-being of the user.

The particularities of each elder's disabilities makes any custom solution difficulty exportable to a whole population of elders. Furthermore, if the characteristics of a particular elder's disability change over time (*e.g.*, the disability is degenerative) the applicability of a custom solution is also limited in time. In order to tackle these issues, we focus on COAALAS, a system based on an adaptable and extensible architecture. By using COAALAS elder-care experts can easily adapt the system capabilities to each patient's current state. What's more the extensibility of COAALAS (through the addition of more agents and services) provides a virtually endless amount of tools for elder's support.

Once COAALAS has been properly designed and its features analyzed, the next step is to use it for implementing a working system where we can verify the theoretical assumptions of our approach. In that regard we have decided to adapt the project *SPiDer* to the COAALAS architecture. We decided to use *SPiDer* as basis because, to the best of our knowledge, it is the most appropriate project for this task (see §4). While COAALAS provides the theoretical framework upon which complex MAS can be built, *SPiDer* provides a working implementation of a MAS which could benefit from high-level organizational properties[11].

To obtain a complete integration of both projects we started by analyzing the capabilities provided by the existing agents and services within the *SPiDer* project. From those we obtained the roles as presented in this paper. At this point we can therefore assert that the architecture of both projects is compatible, as their formalisms match. Furthermore, based on this analysis the following tasks can be addressed, which include defining norms and landmarks to complete the organizational level features of COAALAS, and defining the coordination level through plans and tasks. Finally the service level already found within *SPiDer* must be addapted to make use of the full functionalities of COAALAS. That will be the main future work of this project.

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