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RALE-ACL — A Language for Information Exchange between Case-Based Agents as Alternative to the FIPA-ACL-Based Communication

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Abstract

In this paper, we present RALE-ACL, a communication language for case-based agents in multi-agent systems (MAS) that utilize case-based reasoning (CBR) as the main means of decision making for their agents. RALE-ACL is the accompanying approach of FLEA-CBR, a methodology for construction of CBR-based approaches and systems that adds more flexibility to the classic 4R cycle of CBR. The main goal of RALE-ACL is to establish a much more CBR-compatible alternative to the KQML- and FIPA-ACL-based languages, that are currently used in many multi-agent systems, but are too generic and therefore only cumbersomely usable for the specific structure and purposes of case-based agents.

Introduction

Communication is the means of exchange of information in the real world as well as in its abstract simulations, for example, the simulations that were implemented using the paradigm of multi-agent systems (MAS). The agents of an MAS are autonomous (to a certain grade) and mostly equally structured software (and frequently also hardware) entities that can perceive changes in their environment and react to them or act on their own initiative to achieve the defined common or personal goals. To communicate with each other, that is, to simulate the communication process of the subset of the real world they represent, the agents require a specific communication architecture that allows for systematic information exchange using an integrated vocabulary.

In the current scientific and industrial practice, a number of communication architectures exists that the MASs use to establish the information exchange among their agents. Mostly, these communication architectures have in common that they are based on two components: a *communication language* and an *ontology* that organizes the terms of the vocabulary. Widely applied are the communication languages *KQML* (Knowledge Query Manipulation Language)[1] and its successor *FIPA-ACL* (Agents Communication Language by the Foundation for Intelligent Physical Agents)[2]. Either of them can be used to give structure to expressions that the agents exchange among each other. Both languages are based on the so-called *speech acts* (Searle 1965), a paradigm for execution of actions by means of speech, and define different speech acts to cover the most situations in which the agents are forced to communicate with each other, for example, task distribution or negotiation.

However, the theory of speech acts and its application to KQML and FIPA-ACL was conceptualized before the most of the modern AI (artificial intelligence) techniques, such as deep learning (DL) or case-based reasoning (CBR) (Kolodner 1993) became widely popular and manifoldly applicable. As a result of this development, the agents that implement one of those techniques as their reasoning mechanism have to deal with the speech acts that are not fully able to represent their nature and have to combine or interpret the existing ones in order to figure out the meaning of other agents' utterances as well as to express themselves.

In this paper, we concentrate on *case-based* agents only and present a specific language, in the form of an extension of FIPA-ACL, tailored for such agents so that they make use of the speech acts suitable exclusively for their purposes and do not have to interpret, combine or otherwise utilize the already existing FIPA-ACL speech acts and the corresponding communication protocols. This communication language is called RALE-ACL and is an add-on to its parent methodology FLEA which will be described in a later section after the description of case-based agents and FIPA-ACL. The structure of RALE-ACL, its advantages, and the application examples compared to their FIPA-ACL equivalents will be presented afterwards. A summary and an outlook to the future development of RALE-ACL conclude this paper.

Case-Based Agents

Intelligent agents and multi-agent systems are an established research area that examines the behavior of agents in an environment simulation. Case-based agents (CBA) are a special type of autonomous intelligent agents, they can be assigned to the category of *analogy-based learning agents*. Other types of agents are, for example, deliberative or reactive agents. CBA differ from other agent types in the way they process the changes perceived in the environment and

[1]http://www.csee.umbc.edu/csee/research/kqml/

[2]http://fipa.org/specs/fipa00037/index.html

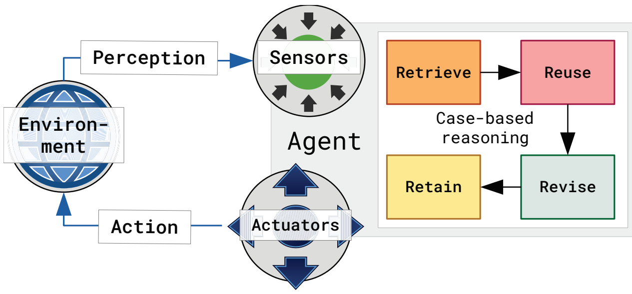

Figure 1: Schematic structure of a case-based agent.

act or react according to these changes. While deliberative or reactive agents, but also other agent types, process real-time information only, the CBA build an analogy model between the current situation and the situations that occured in the past to solve the current problem. That is, the case-based agents perform the so-called CBR cycle (see Fig. 1), where the 4R cycle (Aamodt and Plaza 1994) that consists of the steps *Retrieve*, *Reuse*, *Revise*, and *Retain* is the most influential and widely applied analogy model. A special emphasis in design of the CBA is put on the *learning* component, i.e., the implementation of the *Retain* step that is responsible for learning of experiences made by the agent in order to use them for future analogy building processes.

In the past, a number of multi-agent systems were developed that make use of CBA. For example, in the system eXiT*CBR.v2 (Pla et al. 2013), case-based agents work cooperatively, each using its own case base, on submission of a final prognosis on a health care problem based on previous precedents of similar problems. The approach described in (Coman, Gillespie, and Muñoz-Avila 2015) uses CBR as analogy model for implementation of Rebel Agents (i.e., those that can deny following a goal if it does not concur with their motivation) to provide them with a simulation of emotion-based location ecphory ability. An overview of CBR+MAS systems (Jubair et al. 2018) was published that contains descriptions of different cases of usage of case-based agents within an MAS.

FIPA-ACL Communication Architectures

In a multi-agent system, a communication architecture (CA) is a structured set of possible communication actions and reactions between the agents. The presence of a CA in the system is important as it governs the communication processes during collaboration, cooperation, task coordination, and/or negotiation between the agents. Many CAs that were developed in the past for specific domains of application of the multi-agent systems are based on KQML or FIPA-ACL and accompanied by an ontology. As FIPA-ACL standard is newer and currently implemented in many major MAS programming frameworks (such as *JADE*, *Jadex*, or *JIAC*) we take only this language into account in this paper.

FIPA-ACL uses the previously mentioned speech acts in the form of *performatives*, a special form of speech acts that expresses intention to modify the current state of the environment. According to the current protocol version[3], FIPA defines 22 performatives that can be used to express a speech act during the communication process among agents. Examples for such performatives are `REQUEST` (sender agent requests the receiver agent to perform an action), `PROPOSE` (sender proposes to perform an action), or `REFUSE` (sender refuses to perform an action and explains why).

Several communication architectures were developed that utilize FIPA-ACL together with a domain ontology. For example, CBA use a product ontology for auction communication (Jain and Dahiya 2012), case-based planning agents make use of a specific ontology for wireless sensor networks (Alonso et al. 2013), or an ontology-driven multi-agent system solves the optimal dispatch problem in integrated buildings (Anvari-Moghaddam et al. 2016).

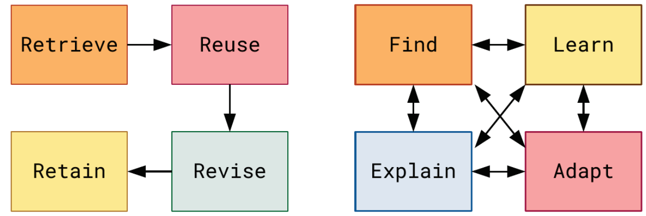

Figure 2: 4R CBR cycle in comparison to FLEA-CBR.

Methodology FLEA and FLEA-CBR

The FLEA methodology (Eisenstadt, Langenhan, and Althoff 2019b) that consists of the components *Find*, *Learn*, *Explain*, and *Adapt* was developed originally for the domain of architectural building design, for which the regular 4R CBR cycle could not be applied in the intended way. The idea behind FLEA and FLEA-CBR (Eisenstadt, Langenhan, and Althoff 2019a) (the extension for development of CBR systems for domains other than architecture, see Fig. 2) is that the 4R steps can also be covered with FLEA and furthermore be applied in a more flexible and custom way during development of the systems using features such as arbitrary mixing or sub-cycling.

RALE-ACL

RALE-ACL is the communication language for case- and FLEA-based agents that provides performatives for design of a communication architecture within CBA-based systems. The need for such specific language arose when the showcase implementation of FLEA-CBR in a framework for AI-based support of floor plan design became too complex, so that the standard set of FIPA performatives could not anymore cover all the specific cases in which the agents of the framework were situated. While developing RALE-ACL for our framework, we decided that this new language for CBA can be of interest for the broader community. That is, similarly to FLEA-CBR, our intention in this paper is to improve the development of CBR systems by making it easier for researchers and developers to design them.

[3]http://fipa.org/specs/fipa00037/SC00037J.html

General Overview

Like its sister methodology FLEA-CBR modified 4R CBR, the language RALE-ACL is intended to modify FIPA-ACL by adding the 'missing' speech acts that fit best to the CBA applications. While FIPA speech acts are generic and do not refer to the agents' reasoning architecture, RALE-ACL refers to the case-based reasoning mechanism of CBA and enriches them with a specific communication set. As CBA's set of actions is normally limited to the actions of the CBR cycle or, in the case of our framework mentioned above, the FLEA-based reasoning cycle, we propose that the communication acts of such agents can be described using five specific performatives: `RETRIEVE` (or `FIND`), `ADAPT`, `LEARN`, and `EXPLAIN`. These performatives cover all the basic operations performed by CBA and make the information exchange between them more precise, such that the agents do not have to interpret the message first, for example, by looking if there is an action description, and figure out what to do. Using these performatives will so reduce the communication ontology as well, as the action will be already included in the performative. In the next sections, a description for each of the proposed performatives is given.

RETRIEVE and FIND The performatives `RETRIEVE` (for pure CBR approaches) and `FIND` (for hybrid CBR+DL approaches) represent FLEA's component *Find*, i.e., the set of actions related to search for the most similar precedents from the dataset that the agents use as their knowledge base. This knowledge base can be the one that is included in the agent's reasoning mechanism but also the one that all agents share among them. If the agent is 4R CBR-based, then it performs the 4R's Retrieve step only and does not perform other steps returning the retrieval results only back to the requester. If the agent is FLEA-CBR-based, then it can contain the Find step only and does not have to include other steps.

In FIPA-ACL terms, `RETRIEVE` and `FIND` can be interpreted as a composite of `REQUEST`, `QUERY REF`, and `INFORM REF` (composites are allowed in FIPA-ACL).

ADAPT `ADAPT` is the performative that the CBA can use to explicitly perform a speech act that is intended to commission another agent to reuse the retrieved cases, i.e., to transfer and adapt the solution from the best cases (i.e., those that were considered most similar according to the similarity assessment result) to the current problem. If the agent is 4R CBR-based, then it has to perform the retrieval process first in order to produce the retrieval results that can be adapted. If the agent is FLEA-CBR-based, then, depending on the system design, it might not need to perform retrieval, but can receive the results directly from other agents.

Due to its specific nature `ADAPT` cannot be directly or approximately interpreted as a composite of existing FIPA-ACL performatives. Its existence for CBA, however, is crucial and makes it a necessary performative.

LEARN The performative `LEARN` can be used to inform the agent that conclusions from the changes in the environment shall be drawn and saved in the corresponding knowledge base. These changes can also be applied by the agent itself, e.g., as a result of the adaptation process. That is, the main goal of this performative is to address the learning process (Retention) in the agent's reasoning mechanism. If the agent is 4R CBR-based, then it has to perform the retrieval and adaptation processes first and then evaluate and learn the results. If the agent is FLEA-CBR-based, then it can directly receive or perceive the adaptation results and learn them.

Identically to `ADAPT`, with `LEARN` it is not possible to compose this performative, directly or approximately, using the existing FIPA-ACL performatives. As mentioned above, the retention process is essential for CBA, that is, this performative is necessary in the RALE-ACL language as well.

EXPLAIN Using the new performative `EXPLAIN` it is possible to send a request for explanation of results produced by the 4R CBR cycle, the FLEA-CBR process or parts of it. Additionally, it is also intended to use this performative to justify the actions performed by an agent, broadcasting this justification to other agents. The introduction of this performative follows the growing importance of the research areas of Explainable AI (XAI) and Responsible AI (RAI), i.e., it provides the agent with ability not only to reason but also explain and take responsibility for its actions. For both 4R CBR-based and FLEA-CBR-based agents it is possible to explain their actions: in 4R CBR the explanation step can be put after each R-step, in FLEA-CBR it is part of the methodology and can be connected to other steps simultaneously.

FIPA-ACL already has some explanatory performatives, such as `NOT UNDERSTOOD` (for situations where an agent did not understood the action of another agent) and `REFUSE` (already described above). Both of them however are intended for specific situations only, whereas `EXPLAIN` can be used for action as well as for reaction. That is, `EXPLAIN` can roughly be seen as a composite of `INFORM`, `REQUEST`, and `NOT UNDERSTOOD` or `REFUSE`.

Compositing and weighting in RALE-ACL

Identically to FIPA-ACL, RALE-ACL can apply *compositing* in situations where one RALE-ACL speech act might not be sufficient to cover the contents of the intended message of the communicative act from one agent to another. It can also be used to commission the agent to perform different tasks sequentially or concurrently, if the situation requires this.

An example of such situation is when one agent requests another agent to retrieve, reuse, and explain the solutions for a certain problem that should be solved with a CBR method: in this case, a composite of `RETRIEVE`, `LEARN` and `EXPLAIN` can be used and sent to this agent whose task is to efficiently perform retrieval, learning, and explaining in a user-friendly manner to the human users of the system.

With *weighting* it is possible to assign weights to the performatives of the composite, for example, using a weighted sum to determine which performative (or which task associated with it) has the highest urgency and should be accomplished first. If the composite performative will be distributed, like in the example above, then the agent that receives these performatives will be informed how urgent the corresponding tasks are and adapt its behaviors accordingly (some MAS frameworks, such as JADE, allow parallel execution of the behaviors implemented in the agent).

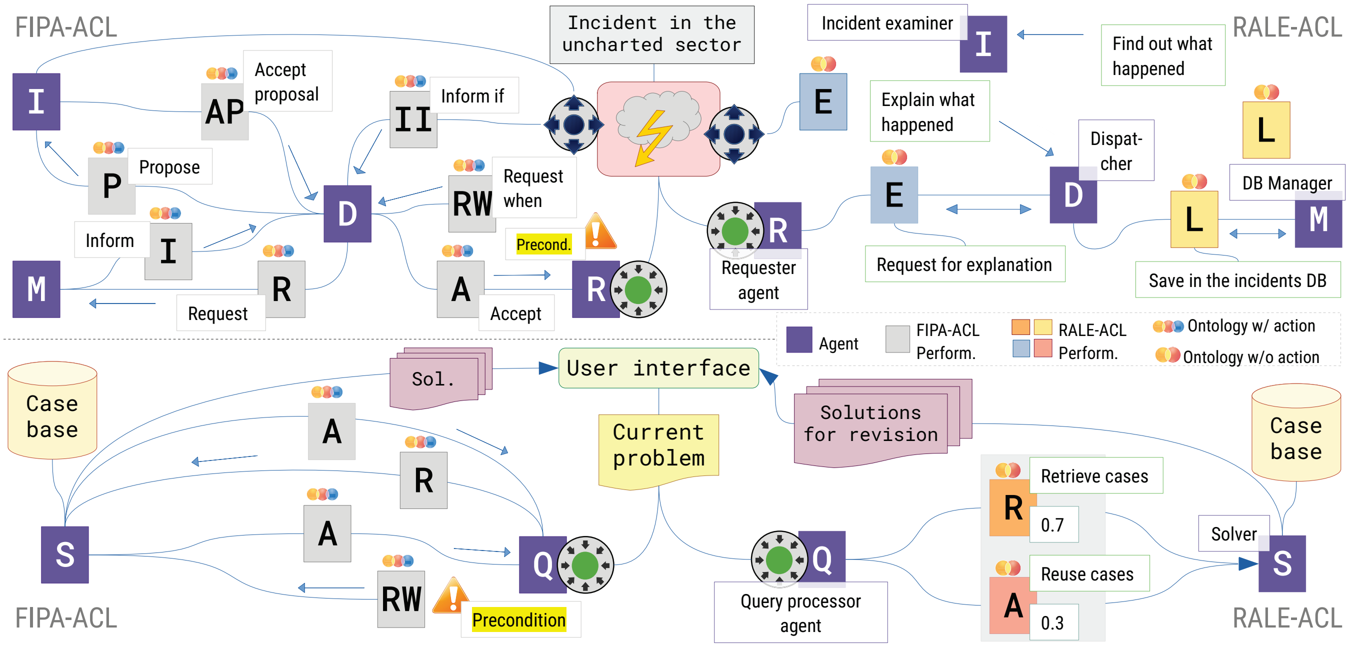

Figure 3: RALE-ACL and FIPA-ACL in comparison. The upper part shows the XAI example, the bottom part shows the retrieval example. For both examples, the FIPA-ACL process is placed on the left, the RALE-ACL equivalent is placed on the right.

Examples

To demonstrate the advantages of the RALE-ACL implementation over the pure FIPA-ACL, we provide two usage examples in Fig. 3. The first example shows an XAI-related process of explanation of an incident in the uncharted part of the environment. The second comparison is a near-real example of retrieval of similar cases and adapting them to the current problem using advanced weighted RALE-ACL.

For both examples it is evident that the number of performatives could be reduced by (nearly) half using RALE-ACL, the communicative acts are more precise, actions could be omitted in the ontology, and the specific requirements of some FIPA-ACL performatives (such as preconditions for `REQUEST_WHEN`) could be left out.

References

Aamodt, A., and Plaza, E. 1994. Case-based reasoning: Foundational issues, methodological variations, and system approaches. *AI communications* 7(1).

Alonso, R. S.; Tapia, D. I.; Bajo, J.; García, Ó.; de Paz, J. F.; and Corchado, J. M. 2013. Implementing a hardware-embedded reactive agents platform based on a service-oriented architecture over heterogeneous wireless sensor networks. *Ad Hoc Networks* 11(1):151–166.

Anvari-Moghaddam, A.; Guerrero, J. M.; Rahimi-Kian, A.; and Mirian, M. S. 2016. Optimal real-time dispatch for integrated energy systems: An ontology-based multi-agent approach. In *2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, 1–7. IEEE.

Coman, A.; Gillespie, K.; and Muñoz-Avila, H. 2015. Case-based local and global percept processing for rebel agents. In *ICCBR (Workshops)*, volume 1520, 23–32.

Eisenstadt, V.; Langenhan, C.; and Althoff, K.-D. 2019a. Flea-cbr – a flexible alternative to the classic 4r cycle of case-based reasoning. In Bach, K., and Marling, C., eds., *Case-Based Reasoning Research and Development*, 49–63. Cham: Springer International Publishing.

Eisenstadt, V.; Langenhan, C.; and Althoff, K.-D. 2019b. Supporting architectural design process with flea. In Lee, J.-H., ed., *Computer-Aided Architectural Design. "Hello, Culture"*, 58–73. Singapore: Springer Singapore.

Jain, P., and Dahiya, D. 2012. An intelligent multi agent framework for e-commerce using case based reasoning and argumentation for negotiation. In Dua, S.; Gangopadhyay, A.; Thulasiraman, P.; Straccia, U.; Shepherd, M.; and Stein, B., eds., *Information Systems, Technology and Management*, 164–175. Berlin, Heidelberg: Springer Berlin Heidelberg.

Jubair, M. A.; Mostafa, S. A.; Mustapha, A.; and Hafit, H. 2018. A survey of multi-agent systems and case-based reasoning integration. In *2018 International Symposium on Agent, Multi-Agent Systems and Robotics*.

Kolodner, J. 1993. *Case-Based Reasoning*. Morgan Kaufmann.

Pla, A.; LóPez, B.; Gay, P.; and Pous, C. 2013. exit* cbr. v2: Distributed case-based reasoning tool for medical prognosis. *Decision Support Systems* 54(3):1499–1510.

Searle, J. R. 1965. What is a speech act. *Perspectives in the philosophy of language: a concise anthology* 2000:253–268.