An Abductive Multi-Agent System for Medical Services Coordination

Anna Ciampolini, Paola Mello, and Sergio Storari

Abstract We present MeSSyCo, a multi-agent system that integrates and coordinates heterogeneous medical services. Agents in MeSSyCo may perform different tasks such as diagnosis and intelligent resource allocation and coordinate themselves through an infrastructure based on a combination of abductive and probabilistic reasoning. In this way a set of specialized medical service providers could be aggregated into a system able to perform more complex medical tasks.

1 Introduction

Patients management usually needs complex and dynamic tasks since it requires the coordination of the services offered by several different and distributed medical organizations and resources (e.g., hospital departments, physicians, ambulances, etc.). The multi-agent paradigm seems to be the most appropriate approach to provide such features, and has been used in several works such as, e.g., in [7] and [9].

Following these considerations, this paper presents MeSSyCo, a multi-agent system whose main purpose is the coordination and integration of heterogeneous knowledge-based medical services. This system, recently proposed also for emergency scenario management [10], can be used to represent virtual organizations: each service provider is encapsulated into an agent; the coordination infrastructure allows the interaction of several (possibly heterogeneous) agents. Services may be implemented either by traditional programming technologies or by using knowledge-based systems with automatic reasoning mechanisms. In this way, the

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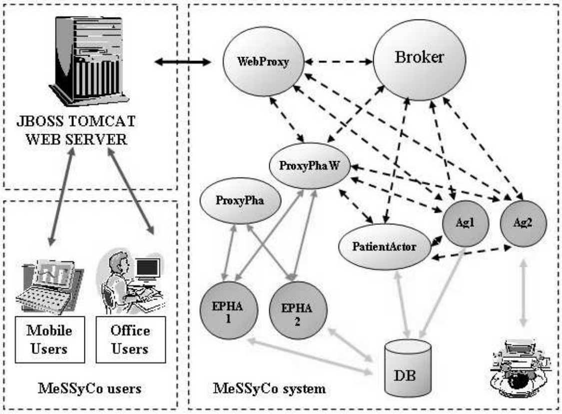

Fig. 1 Schema of the MeSSyCo system architecture.

MeSSyCo system is able to perform complex tasks such as intelligent resource allocation (identifying the most suitable resources), distributed service coordination (answering to complex service requests) and distributed diagnosis (combining heterogeneous knowledge to provide more precise diagnosis).

The MeSSyCo infrastructure is based on ALIAS [1], an extension of logic based abduction [3] to the multi-agent context. Abduction, a well known automatic hypothetical reasoning mechanisms that allows reasoning in presence of incomplete knowledge, is suitable for medical diagnosis since, given a set of symptoms, it can produce a set of plausible diagnosis for them.

In a real medical scenario, diagnosis should be further improved by considering probabilistic reasoning (see for example [6]). Merging such reasoning approach with the abductive one, make possible to associate a probability value to each plausible diagnosis and thus to identify the most realistic one.

To this purpose, in this paper we present a system that integrates the Probabilistic Horn Abduction (PHA) formalism [8], a well known approach particularly suited for medical diagnosis, with the coordination mechanisms provided by ALIAS.

2 The MeSSyCo Architecture

MeSSyCo can be considered a JADE [4] implementation of ALIAS [1] with some extensions regarding the distributed probabilistic reasoning and the identification of most appropriate service provider among the available ones. Its architecture, shown in Figure 1, is characterized by two kind of agents: the *application agents* and the *system agents*.

Each entity providing services within an organization is modeled by an application agent (shown in Figure 1 as *Ag1*, *Ag2*) which provides several services. Each application agent contains a reasoning module, described in Section 3, which stores the knowledge used to provide each agent service. This knowledge may be elicited, for example, from clinician interviews or medical literature. It is also necessary to express how these entities interact with the others in order to accomplish their objectives.

System agents, shown in Figure 1, implement the services necessary to the correct functioning of the whole system. The *Broker* agent is an extension of the FIPA [2] *Directory Facilitator* agent, whose role is to identify, upon request, the most suitable agents that match with given requirements (specified in the request). Agents using the Distributed Probabilistic Horn Abduction (DPHA) reasoning methodology (described in Section 3), register their services into a dedicated broker named *ProxyPha*, that is the gateway between the non-DPHA agent and the DPHA agents. The *PatientActor* agent is a prototype agent able to retrieve information about a patient. The *WebProxy* agent allows secure access to MeSSyCo services.

3 Distributed Probabilistic Horn Abduction

In MeSSyCo we use a mix of abduction [3] and probabilistic reasoning for performing distributed diagnosis and selecting the "best" diagnosis among the set of plausible ones. The possibility of merging logical and probabilistic notions of evidential reasoning in a unifying computational framework based on abduction has been the subject of several works in literature.

A framework for merging abduction and probabilistic reasoning, has been proposed by Poole and named Probabilistic Horn abduction (PHA) [8]. This framework uses Horn-clauses with probabilities associated with hypotheses (abducibles) and incorporates assumptions about the rule base and independence assumptions among hypotheses. The language is that of pure Prolog with special disjoint declarations that specify a set of disjoint hypotheses with associated "a priori" probabilities. If Δ is the set of minimal explanations e_i of conjunction of atoms g from theory TH, we have that the probability of g is the sum of the probabilities of the e_i in Δ. If $\{h_1,...,h_n\}$ are the hypotheses h_i in a minimal explanation e_i, then the probability of e_i is the product of the probabilities of the h_i in e_i. Poole showed how PHA can represent a discrete Bayesian network and how, given a set of evidences, it is possible to compute the "a posteriori" probability of the abducibles.

Starting from PHA and ALIAS, in MeSSyCo we defined the Distributed Probabilistic Horn Abduction (DPHA). The novelty is, with respect to Poole's work, that we coordinate several PHA agents, each enclosing its own knowledge base (KB). The goal of DPHA is to use these KBs in order to perform a probabilistic evaluation similar to the one achievable by a single agent with a complete KB. The agent KB contains: a set of rules describing relations among domain variables; a set of `disjoint` clauses describing the "a priori" probabilities of the abducibles and the probabilistic relations among domain variables.

The result of the execution of a DPHA service S is a set of N Plausible Set of Conclusions (PSC_k) $\{PSC_1,\ldots,PSC_k,\ldots,PSC_N\}$ where each PSC_k is expressed by

$([\,[C_{k1}, p(C_{k1})], \ldots, \, [C_{kM_k}, p(C_{kM_k})]\,], \; p(path_k), \; bunch_k)$, where C_{ki} is a conclusion (e.g. a pathology); $p(C_{ki})$ is the "a priori" probabilities associated to the C_{ki} conclusion; $p(path_k)$ is the probability associated to the reasoning path followed to obtain the PSC_k; $bunch_k$ is the set of agents who have collaborated to define PSC_k .

In the case of diagnosis, a conclusion (i.e., an *abducible*), represents a single pathology that may explain (possibly in combination with other pathologies) one or more symptoms. The probability associated with the query and with each PSC is computed in the same way proposed by Poole in PHA.

Suppose to have a Bayesian network which describes the relation among two abducibles, *Tuberculosis* (*tub*) and *Bronchitis* (*bro*), and one symptom, *Dyspnoea* (*dys*). This Bayesian network is represented in the DPHA KB of an agent *ag* as:

```
disjoint([ tub(y):0.4, tub(n):0.6 ]).
disjoint([ bro(y):0.3, bro(n):0.7 ]).
disjoint([c_dys(y,y,y):0.95, c_dys(n,y,y):0.05 ]).
disjoint([c_dys(y,y,n):0.85, c_dys(n,y,n):0.15 ]).
disjoint([c_dys(y,n,y):0.65, c_dys(n,n,y):0.35 ]).
disjoint([c_dys(y,n,n):0.05, c_dys(n,n,n):0.95 ]).
dys(Vd) <- tub(Vt),bro(Vb),c_dys(Vd,Vt, Vb)
```

If an agent asks *ag* to explain dyspnoea dis(y), *ag* provides a set of four PSCs. The first explanation is $\{(tub(y), 0.4), (bro(y), 0.3), (c\_dys(y,y,y), 0.95)\}$ and it is transformed in: $PSC_1 = ([\,[(tub(y), 0.4], \; [bro(y), 0.3]\,], \; 0.95, \; ag)$. The "a posteriori" probability of the $tub(y)$ can be computed subdividing the probabilities of the PSCs containing the $tub(y)$ abducibles with the sum of the probabilities of all the PSCs.

4 MeSSyCo Coordination Language

The MeSSyCo Coordination Language (MCL), derived from the coordination language described in [5], is used by agents to interact with other agents. As in ALIAS, coordination among agents is expressed in MCL using two composition operators: the collaborative operator # and the competitive operator (;). MCL language provides also a communication operator (>) that is used to submit queries to other agents. Competition is used when the same medical service can be provided by several agents whereas collaboration is used when a set of required services could not be provided by a single agent.

The query $A0 : A1 > (G1, ServiceSupplyType1, InitCond1, Abdin1)$ expresses that $A0$ asks $A1$ to solve $G1$, considering the prior knowledge $InitCond1$, the abducibles contained in $Abdin1$, the modality specified in $ServiceSupplyType1$; if $G1$ succeeds in $A1$, N ($N > 0$) Plausible Sets of Conclusions $PSC_{1i} (i \in [1, \ldots, N])$, consistent in the bunch $\{A0, A1\}$, could be obtained for $G1$.

A MCL collaborative query q formulated by $A0$ for service $G1$ provided by $A1$ and service $G2$ provided by $A2$ uses the collaborative operator # between the two distinct service requests. The result is a set of PSCs of the agent bunch $\{A0, A1, A2\}$, obtained computing the Cartesian product of the agent solutions. Each PSC_k is obtained making the union of the abducibles in PSC_{1i} and in PSC_{2i}: if they contains the same abducible but with a different value of the associated variable, for example $con(y)$ and $con(n)$, PSC_k is inconsistent and deleted; if they contain the same abducible with the same value of the associated variable, in PSC_k we associate to it a probability that is the average of its probabilities in PSC_{1i} and PSC_{2i}. The probability associated to the reasoning path of PSC_k is obtained computing the product of the probability of the one of PSC_{1i} with the one of PSC_{2i}. The bunch of PSC_k is $\{A0, A1, A2\}$.

In the competitive query, $A0$ asks the service G to $A1$ and $A2$ by using the ; operator. The resulting set PSCq contains all the PSC for G, obtained joining both the PSC_{1i} of the bunch $\{A0, A1\}$ the PSC_{2j} of the bunch $\{A0, A2\}$. If both $A1$ and $A2$ fail, the competitive query fails.

5 Conclusion and Future Works

In this paper we focused on the definition and development of a multi-agent architecture for the management of heterogeneous medical services which uses abduction enriched with probabilistic notions to express agent reasoning in the case of diagnosis and also to manage the coordination between different agents. The resulting coordination framework, named Distributed Probabilistic Horn Abduction (DPHA), is able to join the results of distinct agent services into a unique abductive answer.

In the future, we plan to complete the MeSSyCo implementation, facing other important aspects related to the medical application field like data security and experiment it in real world scenario.

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