Multilevel Agent-Based Modelling for Assignment or Matching Problems

Antoine Nongaillard, Sébastien Picault

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Abstract. Assignment or matching problems have been addressed by various multi-agent methods, focused on enhancing privacy and distribution. Nevertheless, they little rely on the organisational structure provided by Multi-Agent Systems (MAS). We rather start from the intrinsic ability of multilevel MAS to represent intermediate points of view between the individual and the collective levels, to express matching or assignment problems in a homogeneous formalism. This model allows to define relevant metrics to assess the satisfaction of agent groups and allow them to build solutions that improve the overall well-being without disclosing all their individual information.

1 INTRODUCTION AND LITERATURE

A problem of resource allocation aims at distributing a resource set among a population of individuals, optimising a goal defined as the aggregation of individual measures. A matching problem aims at grouping individuals, by optimising a goal defined as the aggregation of assessments made by each individual on other members of their group. In both cases, objectives are often expressed as an aggregation of individual evaluations using the social choice theory [2]. These two families, despite their similarities, are addressed as different problems, because of the possibility or not for "resources" to express preferences towards other members of their group. They are thus resolved by algorithms dedicated to a specific families, or even specific sub-problems.

The most common resolution methods are centralised and based on complete information. Indeed, all preferences or constraints are public and manipulated by an overall solver. The most known algorithms in this field (e.g., the Hungarian algorithm [5] or the Gale-Shapley algorithm [4])focus in identifying optimal solutions in absolute terms, by making the strong assumption of a full and public information. Mechanisms for achieving such a solution from a given starting point is not a concern of these methods.

Recently, these problems have also been modelled using the multi-agent paradigm. On the one hand, one can consider the problem of resources/tasks allocation within a population of agents: MAS are then just an application area [1, 9], for which it seems natural to seek distributed solving methods [6]. On the other hand, MAS can be used as a tool to solve allocation or matching problems in a distributed way. Some of these approaches are a mere distribution of computations [7, 3] and do not consider the *behaviours* required for agents to achieve a solution, but only protocol issues and solution characteristics.

[1] Univ. Lille, CNRS, Centrale Lille, UMR 9189 – CRIStAL (SMAC), F-59000 Lille, France, email: name.surname@univ-lille.fr
This project is granting on the PartEns project, within the research program "*chercheur citoyen*" from the region Hauts de France.

Instead of addressing the very issue of distributing either the preferences or the resolution among a population of agents for a particular problem, we rather try to build a generic multilevel structure which allows the modelling of assignment or matching problems, and the expression of multiple concerns at the same time.

Thus, we propose a multilevel modelling of these problemswhich increases the variety of constraints and preferences that can be expressed at every organisation level, using the ability to build composite metrics.

2 MULTILEVEL MODEL

The multilevel formalism we are proposing assume that all relevant entities of the model (e.g. "individuals", "resources", "groups"...) are represented by agents and linked by a membership relation. Those relations are not necessarily hierarchical, since for example some problems may imply resource sharing or allow individuals to be members of several groups at the same time. In order to implement these features, the formalism we chose is a multilevel agent-based simulation meta-model called "PADAWAN" [8].

The set of all agents is denoted by $\mathbb{A}$; $a_1 \sqsubset a_2$ means that agent a_1 is **contained** by agent a_2 (or a_2 is **host** to a_1).The $\sqsubset$ relationship induces an oriented, cycle-free, *hosting graph* between the agents.

For any agent a we also define its *hosts* and conversely the set of all agents *contained* in a respectively as: $hosts(a) = \{a_i \in \mathbb{A} | a \sqsubset a_i\}$ and $content(a) = \{a_j \in \mathbb{A} | a_j \sqsubset a\}$

Our approach consists in grounding the computation of welfare values in the very membership relations in the MAS. We decompose the individual welfare of any agent into three contributions representing respectively the agent as *an individual*, as *the neighbour of other agents*, and as the *host to other agents*. Thus we have: $w(a) = f_a(\sigma(a), \mu(a), \gamma(a))$ where f_a function can be chosen arbitrarily, depending on the situation to be modelled.

The $\sigma(a)$ contribution represents *the satisfaction of agent a as an individual, which is also situated in a given structure*. Thus, this value can be computed from the state of agent a, but also according to the *perceived* properties of its hosts and of their own "ancestors": $\mathcal{H}(a) = \{h \in \mathbb{A} | a \sqsubset h \vee \exists h' \in \mathcal{H}(a), h' \sqsubset h\}$

For instance, in a problem where individuals have to be assigned to groups within organisations, the satisfaction of a person depends on its own state, on the features of its *role* within its group, on the properties of the group itself, but also on the organisation this group is part of, etc.

The corresponding value can then be computed by using an operator $\bigoplus^a$, *specific to agent a* (and to be defined for each concrete situation), in order to aggregate the perceptions by agent a of its *situation*. This situation is composed of the properties $\chi_a(h)$, perceived by agent a, of itself and of all agents that contain a (either directly or transitively):

$$\sigma(a) = \bigoplus_{h \in \{a\} \cup \mathcal{H}(a)}^{a} \chi_a(h)$$

The $\mu(a)$ contribution represents the *satisfaction of agent a as member of a group*, in other words the contribution of externalities due to the presence of other agents within the same hosts.

$$\nu(a) = \bigcup_{h \in hosts(a)} content(h) \backslash \{a\}$$

The perceived properties of those neighbours are then aggregated using another operator which we denote by $\circledcirc^{a}$:

$$\mu(a) = \circledcirc_{n \in \nu(a)}^{a} \chi_a(n)$$

The $\gamma(a)$ contribution represents the satisfaction of agent a *as the representative of a group of agents*. This satisfaction as a group is intended to measure the *collective welfare* of the agents contained in a, which can be done by aggregating the perceived properties of the agents contained in a, using a third domain-dependent operator, denoted by $\bigoplus^{a}$:

$$\gamma(a) = \bigoplus_{m \in content(a)}^{a} \chi_a(m)$$

3 EXAMPLE

In order to illustrate the specific contribution of our multilevel welfare assessment meta-model, we present below a complex problem involving multiple membership, demonstrating the capabilities of our meta-model to represent various points of view (hence, various objectives), specific to each agents family or to each level.

Here we consider individuals ($\mathcal{I}$) allowed to enrol in several associations ($\mathcal{A}$). These associations can gather into federations ($\mathcal{F}$) and can be funded either by municipalities ($\mathcal{M}$) or by regions ($\mathcal{R}$) (Figure 1). The individuals seek to maximise their participation in the associations offering their preferred activities. The associations and federations intend to assert their size (enrolment) so as to defend their grant requests. The municipalities aim at allocating their available budget as fairly as possible between their local associations. The regions try to do the same between municipalities and federations.

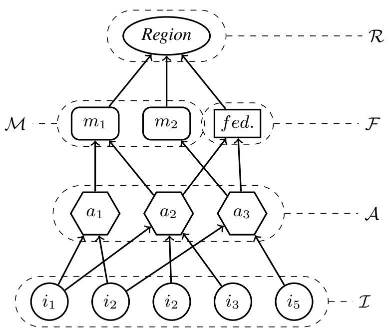

Figure 1. Hosting graph representing a common associative network, with individuals ($\mathcal{I}$) enrolled in several associations ($\mathcal{A}$), possibly grouped into federations ($\mathcal{F}$) and funded by municipalities ($\mathcal{M}$) or regions ($\mathcal{R}$).

In this example we assume that the grant allocation is based on a Nash welfare, in order to prevent the largest structures from monopolising the budget, and yet taking their enrolment into account, hence: $\bigoplus^{\mathcal{R}} = \bigoplus^{\mathcal{M}} = \prod$. On the contrary, an association a which only intends to assert the number of registered members (without consideration for their satisfaction), can simply use $\chi_a(i) = 1$ for every member i and $\bigoplus^{\mathcal{A}} = \sum$. The weight of an association obviously depends on its membership of a federation, thus for each of its hosts h, we assume $\chi_a(h) = 1$ if $h \in \mathcal{F}$, and $\chi_a(h) = 0$ otherwise, with $\bigoplus^{\mathcal{A}} = \sum$. The individuals are rather in search of a trade-off between the participation to their preferred activities and the cumulative cost of these activities (which requires a cost matrix $(c_{i,a})$). Again, $\bigoplus^{\mathcal{I}} = \sum$ can be used. But, in addition, people are highly sensitive to their neighbours, i.e. the other individuals enrolled in the same associations. This can be handled for instance through an affinity-based approach, and an aggregation operator $\circledcirc^{\mathcal{I}}$ either optimistic $(\max)$, or pessimistic $(\min)$.

To summarise, the diversity of objectives within the MAS is made explicit by using a large diversity of metrics, within a structure where all agents are otherwise homogeneous. We argue that this systematisation is the basis for defining generic resolution principles, which can deal with quite different situations, in opposition of classical approaches (either centralised or distributed) where each specific problem is to be solved by its specific method. Indeed, we assume that our meta-model allows the construction of intrinsically multi-agent resolution methods, i.e. relying on local perceptions and interactions between agents, and on generic behaviours subject to context-dependent settings.

4 CONCLUSION, PERSPECTIVES

We proposed a uniform approach to model assignment or matching problems through a multilevel multi-agent system. We have shown the capability of this formalism to express a broad diversity of objectives, representing the viewpoints of the actors of the system. We are currently working on the construction of several protocols, not dedicated to a specific problem, but rather based on the nature of the hosting graph between agents. These algorithmic aspects mix with methodological considerations, so as to identify couplings between the nature and structure of the addressed problems, and the behaviours to give the agents to enable them build a solution in an incremental way.

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