On Two Families of Paradigms of Group-Solvability

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ABSTRACT
We advance and compare two families of coalitional paradigms of solvability. A coalitional paradigm is distinguished from a “noncoalitional” paradigm primarily by its focus on what groups of agents can achieve, rather than on what individual agents can do—even if cooperating. As a criterion of group formation, our models engage a kind of pairwise, context-dependent coordination between knowledge-based “learning agents,” eventually able to communicate the complete & local meaning of expressions taken from the literals of a common first-order language.

Categories and Subject Descriptors
I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence—Multiagent systems, coherence and coordination;
I.2.4 [Artificial Intelligence]: Knowledge Representation Formalisms and Methods—Predicate logic; I.2.6 [Artificial Intelligence]: Learning—Induction, knowledge acquisition.

General Terms
Theory, algorithms

Keywords
Formalisms and logics for agents and MAS; coalition formation; coordination, groups, teams, and group-dynamics.

1. INTRODUCTION
The scope of this article falls primarily into the domain of decision making models, see for instance [6, 10] and the references cited there. More precisely, decision making models for coalition formation and teamwork [8, 9, 1]. Our main contribution is to provide a framework to study the important topic of group-learning, where pairwise coordination for group formation is explicitly stated. We do this in the model-theoretic tradition of formal learning theory [7], that descends from the pioneering studies on inductive inference developed by Solomonoff, Putman, Gold, L. Blum and M. Blum among others. First, we define a communication protocol among a set of agents that always move simultaneously and all relevant moves are made by the agents (agents’ moving components are functions in mathematical sense; no randomness ever intervenes). The communication protocol we consider is pairwise, so that the kind of models we discuss is suitable for modeling group situations where communication is not with the whole group, as in an auction, but indeed pairwise, as happens for instance in commercial transactions. Second, we provide some examples of coalition formation and show how coalitions by coordination may be eventually used to solve certain classes of structures, in a sense made precise within a model-theoretic paradigm—we call this paradigm of group-solvability. A key of success for coordination of a set of agents is the existence of some common knowledge that states who has to be the leader in each pairwise interaction of the agents in the set. Third, we rework our paradigms of individual and group learning in order to make computability explicit. Some introduced notions (e.g., “coordination sentence,” “group-solvability”) are proved useful to specify the benefits and the limits of our approach for multi-agent systems. On the one hand, the technique for group formation we provide suggests new ways of structuring goal selection and, especially, goal decomposition in multi-agent systems. On the other, we exhibit a problem solvable by a single learner that a computable learner fails to solve. As an important consequence, we highlight how information-processing limitations of a learner affect the desirability of different paradigms of solvability.

2. INDIVIDUAL SOLVABILITY
Our approach to individual learning follows a first-order perspective. The paradigm is well illustrated by the following game. First, a class of possible realities is specified in advance. “Nature” is conceived as choosing one member from the class to be the ‘actual world’; her choice is initially unknown to “the scientist.” Nature then provides a series of clues about this reality. These clues constitute the data upon which the scientist will base his hypotheses. Each time Nature provides a new clue, the scientist may produce a new hypothesis. The scientist wins the game if there is sufficient guarantee that his successive conjectures will stabilize to an accurate hypothesis about the reality Nature has chosen. The Nature-scientist game is asymmetric, as the kind of agents concerned is not uniformly the same. In contrast, coordination and group learning involve symmetric interactions among general agents, who have identical structure and eventually differ only on their available actions and beliefs. To coordinate, an agent has not only to guess the actual world, say “the context” chosen by another agent, but she has also to play—by interacting with the agent, a series of clues about a “similar” context to the actual one which satisfies the same set of coordination sentences or goals.

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3. COORDINATION

A primary vehicle to extend individual solvability to a cooperative, multi-agent setting is to identify and study the basic processes involved in coordination. Are there fundamental coordination processes ("strategies") that occur in all coordinated systems? If so, how can we represent and analyze these processes? One of the advantages of the definition we use for coordination is that it suggests a direction for addressing these and related questions. Of course, we all have an intuitive sense of what the word "coordination" means. When we watch the Italian volleyball team winning the 2002 Woman’s World Championship or, by a counterexample, when we spend hours waiting our best friend in the wrong place or a plane on the "Malpensa" runway because the airline cannot find a gate for it.

For many purposes, this intuitive meaning is sufficient. However, in trying to characterize in a formal way the behavior of certain computable agents willing to "coordinate," it is sometimes important to have a more precise idea of what we mean by "coordination." For the purposes of this paper, we consider coordination as a particular process of negotiation. In other words, negotiation underpins attempts to coordinate and, by starting from coordination, to cooperate.

4. GROUP SOLVABILITY

There is a sense in which some overall evaluation criterion is necessarily implied by the definition of coordination. The most commonly analyzed case of coordination, that is, managing dependencies between activities in a context, occurs when an individual or group decides to pursue a goal and then decomposes the goal into activities, or subgoals, which together will achieve the original goal. Our criterion of coordination contains the following elements: (a) goal selection from a set \( \pi \) of possibilities. Goal selection corresponds to convergence to a coordination sentence \( \theta \) (the "selected goal") in \( \pi \); (b) goal decomposition into subgoals. Goal decomposition corresponds to group formation, where for each member of the group that eventually solves the goal, there is another member that plays a sub-goal with the aim to help towards a complete solution.

5. RESULTS AND DISCUSSION

Are some methods of coordination appropriate for coordinating people that would not be appropriate for coordinating computable agents? Our first result shows the limits of individual solvability in a computable system, and fixes a cut-off in the competence of computable learners relative to a particular context. In the light of group formation among computable agents, our second result overcomes the limitations of applicability of the kind of theoretical coordination we have advanced in Section 4. In fact, the proof of the result provides a computable procedure of coalition formation. In addition to the processes described above for managing dependencies within a context, two other processes deserve specific attention to us: communication and belief revision.

Communication. Our coordination framework highlights new aspects of communication. For instance, think to the problem of "meaning negotiation" [2, 4]. In any system of autonomous and distributed agents, autonomy is the core condition for agents to make independent assignments of meaning to world objects. The problem of meaning negotiation arises from such assumption, which is related to our framework by the assumption that an agent’s goal is hidden to all other agents. For example, when we view communication as a way of managing a seeker/provider relationship, we may be concerned about how to make meaning relative to the seeker’s needs "usable" by the provider in order to fulfill the seeker’s requests, that is, to coordinate. How, for instance, can the agents establish a common language interpretation over a shared context? As far as we know, for general contexts this is still an open problem. Our framework is a basis of a successive analysis for Web Services [3].

Belief revision. Belief revision is so far mostly defined for agents whose knowledge is a set of sentences, possibly a "theory" (see e.g. [5] and the references cited therein). On the other hand, our group-learning paradigm considers an agent’s beliefs to be represented by a class of models. New paradigms of coordination among ‘revision-based’ rather than ‘knowledge-based’ agents may then be advanced from our work by answering the following question, among others: Is there a natural (justifiable on intuitive grounds), semantic generalization of belief revision in the context of inductive inference, in which revision applies directly to classes of models? We leave this important question to future work.

(A full version of this paper is electronically available at http://sra.itc.it/people/agostini/eararchive.html.)

6. REFERENCES