Selecting judgment aggregation rules for NAO robots: an experimental approach

(Extended Abstract)

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ABSTRACT

Social choice rules can be used to reach group decisions in multiagent systems. We consider judgment aggregation, the problem of aggregating answers to binary logically related questions. In general "fairness" is usually considered to be the main concern when selecting a social choice rule, however we believe that in judgment aggregation often a more relevant property is how efficient the rule is in truth tracking, that is, how often does it return the correct answer to the binary questions. Whereas "fairness" can be studied axiomatically, truth tracking efficiency needs to be studied experimentally. We accomplish the experimental analysis by constructing a multi-robot system.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems; I.2.4 [**Knowledge representation formalisms and methods**]

General Terms

ExperimentationVerification

Keywords

Judgment aggregation, Truth tracking, multi-robot systems

1. BACKGROUND AND MOTIVATION

Social choice develops and studies methods for reaching group decisions, by aggregating individual opinions. Social choice is used in society in formal contexts, for instance in political elections, in informal context in everyday cooperation when preferences are aggregated, as well as in multiagent systems [1]. How individual opinions should be aggregated depends on the aggregation problem. In preference aggregation and voting the concern is to construct socially "fair" aggregation rules. Judgment aggregation theory is a social choice discipline concerned with the particular problem of aggregating individual binary answers, namely *judgments*, to a set of logically related questions. In some judgment aggregation contexts, when the questions admit objectively correct answer, a more important concern is to design *truth tracking efficient rules* [2]. For example the question "is there a red ball in the box?" has a correct answer, but an agent cannot know it if it cannot look inside the box and can only judge whether the answer is "yes" or "no". An aggregation rule is truth tracking efficient if it generates group decisions equivalent to the correct answers.

"Fairness" conditions can be studied axiomatically. Starting with the work of Kenneth Arrow, social choice theory is marked by impossibility results, which show that no preference aggregation rule exists that satisfies a minimal set of "fairness" conditions. Similar results have been shown to hold for judgment aggregation [3]. Truth tracking efficiency cannot be studied in this manner. One way to analyze this property is trough a probabilistic analysis, as done in [6]. However, to obtain a realistic estimate of the truth tracking efficiency of a judgment aggregation rule one needs to study this property experimentally: using judgment making robots in a setting where the rule is used.

The biggest challenge in experimentally analyzing social choice rules is the technical setup. Unlike a probabilistic analysis, where to add an agent or a question one needs to increase the value of a variable, in a realistic setting each addition of agents and questions is non-trivial. Our aim is to establish the foundations for experimental analysis of judgment aggregation rules. We develop a multi-robot system which aggregates judgment and use it to compare two judgment aggregation rules with respect to truth tracking.

2. JUDGMENT AGGREGATION RULES

Consider as an example the case when three robots (Lucy, Rosy and Jempi) need to determine if a sound is coming from a box (question x). They can make the conclusion x or not x by considering whether sound is heard (question p) and if a box is seen in the direction of sound (proposition q). These questions are related, namely $x \leftrightarrow (p \wedge q)$. Consider the *profile of judgments* given by the robot in Table 1 (white field). A basic question in judgment aggregation is whether to establish the simple majority supported answers on the reasons p and q and then use these to deduce an answer on

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q (so called *premise-based procedure*), or to establish only the simple majority supported answers on the conclusion x (so called *conclusion-based procedure*). The two procedures can lead to different result on x as is in Table 1. In society, in particular in legal contexts where the efficiency in truth tracking is of higher importance than "fairness", the choice between a premise-based and conclusion-based procedure should be made based on the context of the problem [5]. In multiagent systems, experiments can be used to choose the better procedure.

Robots	p	q	x
Lucy	no	yes	no
Rosy	yes	no	no
Jempi	yes	yes	yes
Majority	yes	yes	no

Table 1: An example of judgment aggregation.

3. METHODOLOGY AND RESULTS

Our system consists of five NAO robots[1]. We extend the given example of establishing whether sound is coming from a box so that it is feasible given the sensors of the robots and using the *sound pressure inverse distance law*. This gives us the list of binary questions:

p: NAO can hear sound (with energy value E_1).
q: NAO can see a box at distance L (possibly in the direction of the sound).
r: NAO can hear sound second time (at $L/2$ distance with energy value E_2).
s: Sound energy value E_2 increases in proportion to distance covered, depending on L.
x: Sound is coming from inside the box.

The logical connection rules as the following: $\{(p \wedge q \wedge r \wedge s) \leftrightarrow x, q \rightarrow r, r \rightarrow s\}$.

We execute the technical framework by interfacing the agent programing language GOAL [4] and the NAO's robotic framework NaoQi through an Environment Interface Standard (EIS)-compliant Java interface. The robots send their judgments to an aggregator program, which then determines the group decisions by using either the premise-based or the conclusion-based procedure.

We obtained fifty multi-agent profiles. Of the tested profiles, we observed that thirty of them displayed a different result when the premise-based and conclusion-based procedure was used. This can be seen in Table 2, where I ="Inside" and O ="Outside" and $O(*)$ ="Outside, box close to sound source and in same line of vision".

No. of profiles	Inconsistency	Truth	PBP	CBP
25	Y	I	I	O
5	N	I	I	I
10	N	O	O	O
5	N	O(*)	I	I
5	Y	O(*)	I	O

Table 2: Aggregation Results for Profiles

The results of our experiment indicate that the premise-based procedure is best at truth tracking. When the sound actually comes from inside the box, this procedure scores 100% for almost every case of majority inconsistency seen (row 1 of the Table 2). When the robots hear sound directly without reflections,*i.e.,* when sound source is outside the box and the box is not in the line of vision of sound direction, the robots get accurate results on the direction of the sound and there is no inconsistency between the premise- and conclusion-based procefure(row 3 of the Table 2). When the sound comes from outside the box and in the line of vision of the box, the experiment fails by design and in some cases the conclusion based procedure is close to the truth (due to the nature of the experiment), but this is hard to quantify (row 4 and 5 of the Table 2).

[1] `http://www.aldebaran-robotics.com/`

4. DISCUSSION

Truth tracking efficiency has been probabilistically analyzed in [6], where the authors find that, if the agents have a low probability of making the objectively true judgment, another procedure, the *distance-based procedure*, outperforms the premise-based procedure. We calculated offline the group decisions obtained from the collected profiles of judgments if the distance-based procedure was to be used and obtained that this procedure performs worse than the premise-based procedure. Since we do not have any estimates on the probability of a robot to report an objectively true judgment, our results are not strictly comparable.

The questions in our experiment, which are the reasons that support the conclusion, are not logically independent, so the probabilistic analysis such as the Condoret jury theorem cannot be used to explain the excellent truth tracking qualities of the premise-based procedure. Instead we consider this property to be due to the fact that all reasons in our experiment, unlike the conclusion x, are sensor-read values. It is our assumption that when the conclusion is such that can be read by a sensor, the premise-based procedure would lose its primacy.

The construction of the multi-robot system in which the robots can form judgments needs to be done once, and we have accomplished this step. A reoccurring challenge is to find questions on which there is more than one way to form a judgment by a robot. We have worked with only one set of questions. To the best of our knowledge, ours is the first effort in experimentally testing social choice rules on robots and more work is needed to establish the properties of an experiment that leads to a conclusive evaluation of rule truth tracking efficiency.

5. REFERENCES

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