Foundations of Autonomy and Its (Cyber) Threats: From Individuals to Interdependence: Papers from the 2015 AAAI Spring Symposium

Team Formation by Children with Autism

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Abstract

We explore how children with autism form teams and what kind of difficulties they experience. Autistic reasoning is an adequate means to explore team formation because it is rather simple compared to the reasoning of controls and software systems on one hand, and allows exploration of human behavior in real-world environment on the other hand. We discover that reasoning about mental world, impaired in various degrees in autistic patients, is the key parameter of limiting the capability to form teams and cooperate. While teams of humans, robots and software agents have a manifold of limitations to form teams, including resources, conflicting desires, uncertainty, environment constraints, children with autism have only single limitation which is reduced reasoning about mental world. We correlate the complexity of the expressions for mental states children are capable of operating with their ability to form teams. Reasoning rehabilitation methodology is described, as well as its implications for children behavior in real world including cooperation and team formation.

Introduction

Usually, agents of a multi-agent system (MAS) can be characterized by whether they are cooperative or self-interested. Both types of agents need to collaborate with other agents to achieve their goals in uncertain, dynamic domains. This is true for software, human and hybrid agents. In such environments system constraints, resource availabilities, agent goals are changeable, leading MAS to various states. At the same time, MAS organization needs to be adjusted for environments, there is no single best organization for all possible states. In a broad range of MAS applications, a flexible team forming mechanism is required to facilitate automated forming of teams and autonomous adaptation to the environment (Bai and Zhang 2005a). Both software and human agents develop their team forming skills in the due course, as a result of active learning with reward (Lopes et al 2009).

There are established research areas of team formation in the following settings:

- software and hardware agents;
- human agents;
- hybrid/mixed teams.

A vast body of literature addressed team formation scenarios in the above cases, in a broad range of application domains (Bai and Zhang 2005b). These scenarios are usually complex and very domain-specific, so it is hard to judge how general the conclusions can be drawn. For software and hardware agents, a lot of technical details need to be taken into account. In the case of human agents, psychological analysis makes considerations rather complex and possibly ambiguous.

In this study we focus on the case of *autistic team formation*, which is expected to shed the light on the fundamental properties of the team formation process. Behavior of small children with autism is not as complex as that of controls of the same age. Furthermore, autistic behavior is simpler than that of software agents, since engineering details do not need to be taken into account. Hence we hypothesize that a team of small children with autism is a much more "pure" environment for studying the phenomenon of team formation compared to conventional investigation platforms for team formation.

By the times control children are verbal, their reasoning and especially handling mental actions and states is rather complex so hardly tractable. On the contrary, reasoning of autistic children of the comparable mental age is rather simple and allows exploration of its patterns and difficulties applying to real world situations.

In our previous paper (Galitsky 2013), we proposed a reasoning model for autism in which the core deficits, and other related symptoms, emerge as a result of a basic problem with symbolic reasoning about mental states and actions. Our model provided a developmental mechanism required to explain why primary deficits related to social orientation may be the cause for autism and its broader features. Also, this model explains why intensive early intervention by means of stimulating reasoning about mental attitudes frequently helps to improve autistic reasoning.

In this study we focus on a particular task of team formation, reasoning about mental states. The case of autistic reasoning shows that this kind of reasoning is a bottleneck of the overall team formation capability. Due to peculiarities and limitations of autistic reasoning about mental states, their reduced capabilities of their "Theory of Mind" (Baron-Cohen 1989), children with autism experience tremendous difficulties forming teams. Due to simplicity of autistic reasoning about mental states and actions, as well as reduced learning capabilities of children with autism (Galitsky & Shpitsberg 2014), one can explore simple behavioral patterns during the team formation sessions and trace how these patterns are correlation with reasoning patterns.

Assessing Mental Reasoning Capability to Form Teams

We explore how children with autism form teams to perform simple tasks. The focus of our experiment is to find a correlation between how children do reasoning about mental world, and how they perform team formation tasks. The underlying model for our correlation is a belief-desire-intention (BDI, Rao & Georgeff 1995) model for a multi-agent system.

To assess reasoning capabilities of children, we ask them questions about mental states of characters, and evaluate the correctness of their answers (Galitsky et al 2011). We hypothesise that while team formation, they have to initiate the same questions before they perform speech acts with their proponents and possibly opponents. The questions involve first order mental states (*do you know...?, does she want...?*), second order (*do you want him to believe ...?*), third order (*he believes she wanted him to know that she wanted ...*), and fourth-order (*he know she wanted him to know that she does not want ...*).

We used the following team formation tasks. These are the tasks children with autism of the age 6-10 usually experience difficulties with, being fairly easy for the control group of children. These tasks rely on various physical actions, but the commonality between them is the necessity to reason about beliefs and intentions of other team members.

- hide-and-seek game, where children need to agree who is hiding and who is searching;
- hiding an object in a bag game;
- making one participant do something with the second participant what the third participant wants;
- form a team of buyers to shop for the items of mutual interested;
- form small soccer teams, two vs two (Fig 1);
- form chess playing team taking turns in moves, two vs two.

Each task required 3-4 participants. Sixteen children of the age 6-10 participated in all team building tasks and completed all reasoning exercises.

We split autistic children into four groups with respect to their capabilities in team formation:

1. Active team builder who can initiate a new team;
2. Active team builder which can maintain the team performing tasks and encourage others to do so;
3. Passive team members who can be maintained to be a part of the team being encouraged by other members. They cannot initiate team formation themselves, but they can resume the team activity after it stopped;
4. Passive team members who can be maintained to be a part of the team. They can neither initiate team formation themselves, nor resume the team activity.

Fig.1: An illustration for basketball team formation. This is a text on understanding intentions of others

For each child, we assign him to a group if he is capable of performing the required team formation function in more than a half of scenarios. Notice that some team building scenarios require verbal communication, and some rely on non-verbal one.

The joint results of the reasoning assessment and team formation assessment are shown in Table 1. Rows indicate the percentages of successfully completed reasoning tasks for each group of team formers (averaged through 4 individuals). Rows are grouped from top to bottom according to the order of formulas required to answer the respective question. Dark grey area shows good performance of reasoning tasks (>70%) and light-grey show lower performance (60-70%). The white area shows the level of reasoning complexity this group of team formers cannot reliably achieve. Mental states and actions of reasoning exercise are ordered in the way of increasing complexity (averaged performance). Columns are formed according to four groups of children above

We observe a direct correlation between the reasoning order and team forming capabilities. If children cannot perform even the first-order reasoning tasks, they are neither capable of team forming nor understanding of team forming by others. To be capable of team forming, second-order reasoning needs to be satisfactory.

The third-order mental states are the ones the trainees experience most difficulties. Various skills at these tasks differentiate children with autism into two groups: those

Roles	initiate	maintain	maintain	resume	
knowing an object and its attributes	95	91	82	72	95
not seeing-> not knowing	90	93	78	80	90
intention of yourself	88	90	80	76	95
intention of others	92	87	71	70	95
informing	87	84	78	73	90
information request	91	89	72	71	85
asking to do an	78	83	80	75	90
asking to help	85	80	70	75	90
questioning	81	83	68	70	85
explaining	72	70	61	64	85
agreeing	76	73	64	60	90
pretending	81	76	65	62	90
deceiving	70	64	62	54	80
offending	73	68	58	50	85
forgiving	72	62	61	46	80
reconciling	65	64	50	39	85
disagreeing	72	69	42	40	75
inviting to help	62	59	39	46	70
asking to leave	64	57	40	51	85
interfere	70	50	38	32	70
disagreeing	62	46	32	28	65
resolving a conflict	42	37	17	12	65
negotiating	48	24	12	7	60

Table 1: Comparative performance of reasoning and team formation

who can initiate new teams, and those, who can maintain team activities and resume team operations. For the former group, substantial third-order reasoning is required, and for the latter, just rudimentary third-order skills suffice.

Finally, fourth order mental states are difficult for both children with autism and controls of comparable age (see the rightmost column for evaluation of team formation by the control group).

BDI Model to Represent Reasoning about Mental States

We take the definitions of mental states and actions from belief–desire–intention (BDI) model (Rao & Georgeff 1995). This is a software model developed for programming intelligent agents; however we applied it to explain, simulate and rehabilitate autistic reasoning in “multi-agent” domain (Galitsky & Jarrold 2011). The essence of BDI is its implementation of an agent's beliefs, desires and intentions; it uses these concepts to solve a particular problem in agent programming, providing separation of the activity of selecting a plan (which is the bottleneck of autistic reasoning) from the execution of currently active plans in the physical world (which is easier for children with autism). The details of our model and implementation are available in (Galitsky 2012, Galitsky 2013).

There is a spectrum of clauses for each communicative action such that each clause enumerates particular conditions for respective mental states. As an example, we present four clauses for inform, taking into account that many more clauses are required to form the whole spectrum for this word: *inform(Who,Whom,What)* :-

want(Who,know(Whom,What)), believe(Who,not know(Whom,What)),believe(Who,want(Whom,know (Whom,What))).

The meaning here is as follows: Who informs Whom about What if Who wants Whom to know it and believes that Whom does not know it and wants to know.

inform(Who,Whom,What):-

believe(Who,know(Whom,What)),

want(Who,believe(Whom,know(Who,What))).

The meaning here is close to *confirm*: to inform Whom that not only Whom but Who knows What as well.

inform(Who,Whom,What):-

ask(Whom,Who,What),want(Who,know(Whom,What))

.

This meaning is informing as answering.

inform(Who,Whom,What):-

ask(SomeOne,Who,believe(Whom,What)),

want(Who,know(Whom,What).

Here informing follows *SomeOne*’s request for sharing information.

These clauses form the basis for how we teach children with autism to operate with mental states and actions. Using a multiple choice assessment method, for an entity like *inform*, we let the trainee choose the basis communicative actions like ask and want and link their parameters. Also, each of such communicative action might occur negated (Fig. 3).

Computational Support

To simulate autistic reasoning in mental world, where certain rules and definitions for the communicative actions and mental states of order one to four, we use the reasoning platform NL_MAMS (Galitsky et al 2011). It supports the experiments on team formation, exploration of reasoning about mental world irrespectively of autistic peculiarities, and also assists in rehabilitation. It inputs formal or natural language descriptions of initial states of interacting agents, and outputs deterministic scenarios of intelligent behaviors of these agents. NL_MAMS is capable of analyzing and predicting the consequences of mental and physical actions of themselves and others. The output of the NL_MAMS is the sequence of mental formulas, reflecting the states, which are the results of the committed actions (behaviors) chosen by these agents.

A few versions of the web-based user interface for NL_MAMS have been developed for a number of environments, including describing of mental states of scene characters (Galitsky 2013). A variety of interface components were designed for specifying mental states, including natural language and drop-down box-based.

Evaluation of handling with communicative actions and mental states of orders one to four introduced above was conducted using following means:

- direct introduction of the basic mental entities *want-know-believe* using real-world examples;
- explanation of derived communicative actions and mental states using the basis of entities *want-know-believe* ;
- introduction of the derived mental entities by means of real-world examples;
- conversations that heavily rely on a discourse with mental focus;
- conversations that are based on a pictorial representation of interaction scenarios;
- involving the trainees into actual interactions with other children and asking them to verbally represent these interactions;
- encouraging the parents and rehabilitation personnel to demonstrate a special awareness of mental entities in the real world;
- “picture-in-the-head” and “thought-bubbles” techniques, using “physical” representation of mental attitudes (Swettenham et al 1996, Fig. 2).

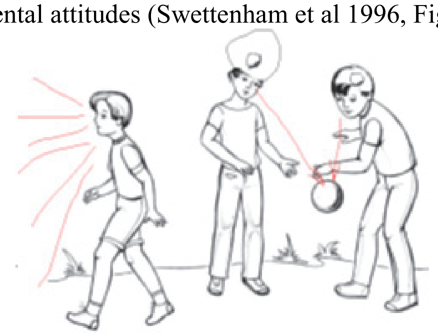

Fig. 2: An exercise using physical representation of mental attitudes

NL_MAMS-based training is intended to assist in all of the above components. Initially a trainer shows how to represent mental states from the above components via NL_MAMS, and discusses yielded scenarios with a trainee. The plausibility and appropriateness of actions yielded by NL_MAMS require special attention from trainees. Then the trainer specifies other initial mental states and asks a trainee to come up with plausible scenarios originating from these mental states.

After a certain number of demonstrations, the trainees are encouraged to use NL_MAMS independently, applying it to real-world mental states the trainees have experienced, as well as abstract mental states. Trainees are presented with both natural language and structured input and output of NL_MAMS, and they are free to choose their favourite way of user interface.

Trainees are the children with high-functioning autism, 6-10 years old, selected so that they are capable of reading simple phrases and communicating mental states in one or another way.

An exercise introducing the mental action of *offending* and *forgiving* is depicted at Fig. 3. After a communicative action is explained via examples and verbal definition is told, trainees are suggested to choose the proper basic entities with negations when necessary to build a definition. This is a partial case of NL_MAMS training of yielding a scenario given an initial mental state: it is adjusted to the definition of *offending*. Expected resultant scenario is just the actions of *offending* or *forgiving* with appropriate parameters for agents and subjects of these actions. These parameters are specified via drop-down boxes; their instances are expected to show the trainees how to generalize the instances of *offending* or *forgiving* towards different agents. Also, multiple ways to express these generalizations are shown: *friend, parent, brother/sister, they/them, he/she, him/her* etc. After the trainees learn how to derive a single-step scenario for a fixed mental action, they are given tasks to compose a scenario with two or more mental actions they have already learned.

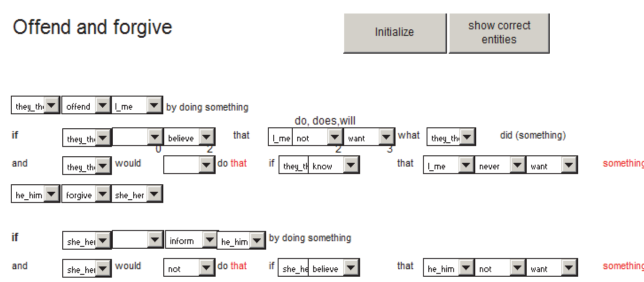

Fig. 3: The form to introduce/teach a communicative action (here, *to offend* and *to forgive*).

Autistic Team Formation in Real World

We observed the team formation behavior in the real world. It was done as a part of the rehabilitation program conducted by the Center for children with special needs “Sunny World” www.solnechnymir.ru. The children in the summer camp were forming teams with the help of rehabilitation personnel and parents, performing various farming tasks. These tasks include harvesting and packaging vegetables into boxes. Children had to agree on who is doing what, how to store and pass vegetables between each other and in what order, and how to handle varying harvesting conditions. The difficulty level for this task is of the order two and three in most cases.

The children who participated in our evaluation study and successfully formed teams in artificial scenarios were also capable of forming teams for the farming tasks. On the contrary, those who could not adequately participate in our assessment had significant difficulties in performing the tasks requiring interaction with other team members.

It was hard to do a performance assessment in farming teams because of lack of repetition and systematic framework in the farming tasks. Unlike the team formation exercises, which also included conflict scenarios, farming ones involved cooperation only, avoiding any kinds of conflicts. However, the overall impression of the personnel and the parents was that doing abstract team formation helped some children to understand mental states sufficiently to from cooperative teams.

Fig.4: Hide-and-seek team as an exercise and in the real world

Team formation in real world shed a light how the notion of *trust* is perceived by the reduced reasoning of children with autism. Trust becomes a mental state with certain rules, compared to the trust states which are learned by control human and software agents. Trust is explicitly defined via communicative actions of *promise* and *believe:*

trust(Who, Whom) :- ∀Subject promise(Whom, Who, Subject), believe(Who, Subject).

and serves as an additional constraint for team formation rule: engage with trusted partners. In this respect the notion of trust is simpler than in general case of adequate reasoners, which need to acquire trust in the course of dynamic process (Lawless et al 2013). The intelligence in the form of rules to reason about mental world cannot be labeled as robust, in our opinion, since autistic reasoning cannot be adjusted to a given environment in an autonomous manner.

Fig.5: A team of children at work (Sunny World 2014).

Discussion and Conclusions

Recent studies (e.g. Dawson et al., 2007) have reported that autistic people perform in the normal range on the Raven Progressive Matrices test, a formal reasoning test that requires integration of relations as well as the ability to deduce behavioral rules and form high-level abstractions. (Morsanyi & Holyoak 2010) compared autistic and control children, matched on age, IQ, and verbal and non-verbal working memory, using both the Raven test and pictorial tests of analogical reasoning. They found that autistic children reasoning capabilities are similar to those of controls on reasoning with relations tests. The authors conclude that the basic ability to reason systematically with relations in the physical world, for both abstract and thematic entities, is intact in autism.

(Gokcen et al 2009) investigated the potential values of executive function and social cognition deficits in autism. While the theory of mind is generally accepted as a whole, a number of researchers suggested that it can be separated into two components (mental state reasoning and decoding). Both aspects of the theory of mind and verbal working memory abilities were investigated with relatively demanding tasks of mental reasoning for parents of children with autism, who had verbal working memory deficits as well as low performance on a mental state reasoning task. The parents had difficulties in reasoning about others' emotions. In contrast to findings in the control group, low performance of mental state reasoning ability was not associated with working memory deficit in index parents. Social cognition and working memory impairments may represent potential genetic risks associated with autism.

In the physical world, children with autism perform relatively well so it should not be a limitation for their team formation capabilities. Autistic participants outperformed non-autistic participants on abstract spatial tests (Stevenson & Gernsbacher 2013). Non-autistic participants did not outperform autistic participants on any of the three domains (spatial, numerical, and verbal) or at either of the two reasoning levels (concrete and abstract), suggesting similarity in abilities between autistic and non-autistic individuals, with abstract spatial reasoning as an autistic strength.

For an abstract reasoning system, experiencing difficulties in forming teams does not necessarily mean that deficiencies are in the domain of reasoning about mental world. It could be general incapability to adjust to a given environment (Galitsky & Peterson 2005), general problems in non-monotonic reasoning (Galitsky & Goldberg 2003, Galitsky 2007), autistic planning (Galitsky & Jarrold 2011) and autistic active learning (Galitsky & Shpitsberg 2014). However, it turned out that the root cause of autistic difficulties in team formation are due to reasoning in the mental domain, as demonstrated by its direct correlation with the real world performance.

We explored team formation at the following level:

1. Abstract reasoning in mental world
2. Team formation in controlled, assessment tasks
3. Team formation in real world

We found a strong correlation between (1) and (2), and a weak qualitative correlation between (2) and (3). We used the computational tool capable of solving similar problems (reasoning about mental states, Galitsky 2013) to what were given to children to simulate the peculiarities of autistic reasoning on one hand and support rehabilitation exercises on the other hand. We used the following hybrid teams of agents: autistic + autistic, autistic + control and autistic + software (educational, assessment).

We found that the main determining feature of autistic team formation is their reasoning capabilities. This observation can be extended to the case of software agents, where behavioral algorithms can be affected by a broad range of circumstances. For software agents, the bottleneck of reasoning about mental states can be less noticeable, but we expect it to be as almost as strong as for the case of autistic reasoning.

Our study has certain implications for how the autonomy features of abstract agents can be modeled via aspects of human behavior. Our finding confirm the theory of social interdependence in its simple form, applied to naïve autistic reasoners: once agents become capable of operating in mental world, they are able to form teams: no special, additional skills are required. Once children form teams, their mental reasoning capabilities improve, but they don't need to learn anything besides mental states and actions to learn forming simple teams. In this respect, our findings back up the traditional individual methodological perspectives (e.g., cognitive architectures). They assume that individuals are more stable than labile from the social interactions in which they engage: once individual reasoning skills are adequate, the collective behavior becomes adequate as well.

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