Knowledge-Based Systems 50 (2013) 25–43

Contents lists available at SciVerse ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

A computational simulation tool for training autistic reasoning about mental attitudes

Boris Galitsky

eBay Inc., San Jose, CA, USA

ARTICLE INFO

Article history:
Received 31 October 2012
Received in revised form 1 March 2013
Accepted 21 April 2013
Available online 17 June 2013

Keywords:
Autistic reasoning
Rehabilitation
Theory of mind

ABSTRACT

It has been discovered more than a decade ago that autistic people cannot properly understand and reproduce mental states and emotions. We hypothesize that people with autism suffer from difficulties in learning social rules from examples. Many remediation strategies have not taken this into account. Therefore an appropriate remediation strategy is to teach not simply via examples but to teach the rule along with it. In this study we suggest a reasoning rehabilitation strategy, based on playing with a computer based mental simulator that is capable of modeling mental and emotional states of the real world. A model of the mental world is presented in 12 steps. We describe our implementation of a natural language multiagent system that simulates this model. In addition we describe the system's user interface for autistic rehabilitation. This system is subject to short-term and long-term evaluation of rehabilitation of autistic reasoning. Case studies with children who used it extensively are presented. Implications specifically in terms of autistic rehabilitation as well as generally in terms of reasoning about mental states are discussed.

1. Introduction

Recent psychological studies have revealed that autistic children can neither reason properly about mental states nor understand emotions [4,40,42,60]. Autism is a multifactor disorder that is characterized by impaired social interaction and communication, combined with repetitive and stereotyped patterns of behavior, and there is a strong need for efficient educational support for such children with special needs. Autism is a developmental disorder which is currently defined in terms of its symptoms [9]. The three main accounts of the psychology of autism can be outlined as follows:

- *Theory of mind account*, which refers to the ability to infer and understand what oneself and others are thinking (knowing, believing, desiring) in order to plan one's own behavior and predict the behavior of others. This ability to reason about mental attitudes is impaired in patients with autism [3]. This reasoning disability leads to difficulties with such mental reasoning-based forms of behavior as pretend play, problems in understanding false beliefs, and the ability to tell lies.
- *Weak central coherence account*, which refers to the inability of individuals with autism to process information in context, even having a remarkable ability to remember details [11,12]. For example, autistic individuals seem to have more difficulty than controls in recalling sentences or a main plot of a story, being as good as controls at recalling unconnected word strings [29].
- *Executive dysfunction account*, which refers to the inability of autistic individuals to maintain appropriate problem-solving behavior [39,48]. This is often manifested in the form of behavior that perseveres inappropriately despite changing goals [38].

In this study we focus on the first account above and develop a tool which assists the learning process of reasoning about mental attitudes. To do that, we subject the theory of mind and its impairment under autism to a formal analysis, propose a formal model of reasoning about mental attitudes (adequate for such learning), and build the learning tool in accordance to this model. This tool is based on a simulation of reasoning about mental states and actions by conflicting software agents. We present the deployment of the natural language multiagent mental simulator NL_MAMS for mental and emotional development of autistic children.

Limited skills of autistic reasoning about mental states are usually within the theory of mind account characterized as a lack of theory of mind in people with autism. In this study we treat the theory of mind from the perspective of logical artificial intelligence, providing a more systematic way to characterize mental states, mental actions and how their representation is corrupted under autism. Building the adequate model of the mental world

E-mail address: boris.galitsky@ebay.com

0950-7051/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.knosys.2013.04.018

and emotions is important for teaching the individuals, whose understanding of mental world is impaired.

In our previous studies we have analyzed each of the above three accounts in terms of models of underlying reasoning. The theory of mind account has been a subject of the systematic exploration of the reasoning about mental states by individuals with mental disorders [16,17]. The theory of mind account has been extended to reflect the computational experience of "teaching" computers to reason about mental attitudes: an adequate formalization of the mental world has been built to represent a number of autism phenomena. These studies addressed the peculiarities of autistic reasoning about knowledge, beliefs, intentions, and about other mental states and actions. Involving the formalisms of logical artificial intelligence, and the BDI (Belief–Desire–Intention) model in particular [6], the system for representation of reasoning about mental states and actions has been built. Our system is capable of simulating the verbal behavior of autistic as well as control patients [19]. We have also analyzed various forms of autistic reasoning about action, time, space and probabilities, and have found that their deductive reasoning skills are stronger than their inductive, abductive, and analogical forms of reasoning [21]. We developed a set of exercises and built the software implementations focussing on selected reasoning patterns, teaching autistic trainees to reason properly about mental states in accordance to the traditions of axiomatic method, since the natural ways of teaching (by example) usually do not help [20]. Also, it has been shown that the training of reasoning about beliefs, desires and intentions assists the emotional development [17]. A series of interactive rehabilitation software tools have been developed which stimulate various forms of commonsense reasoning, conversation and decision-making in autistic trainees [41].

The second and third accounts of autism above have been characterized in terms of default reasoning [41,61], where typical and atypical situations are treated differently, in contrast to classical reasoning.

In this paper, we propose a new conceptual reasoning model for autism in which the core deficits, and other related symptoms, emerge as a result of a basic problem with symbolic reasoning. Our model attempts to provide the developmental mechanism required to explain why primary deficits related to social orientation may be the cause for autism and its broader features, and why intensive early intervention by means of stimulating reasoning about mental attitudes frequently helps to improve autistic reasoning.

Beyond the Introduction, the paper is organized as follows. We firstly discuss the experimental results of theory of mind training and propose how they can be improved using a symbolic logic-based treatment of this theory using the software tool. Then in Section 1 we introduce a formal model for the theory of mind, keeping in mind that it will be used as a basis to develop the software-assisted rehabilitation strategy. The reader who prefers to avoid technical details may want to skip Sections 1 and 2 and proceed to Section 3.5.

In Section 2 the mental simulator NL_MAMS is presented, the system that is capable of automated reasoning within our framework of the mental world. User interface and implementation of the simulator is followed by evaluation of its reasoning capabilities and the description of its deployment for the rehabilitation of reasoning. Section 3 presents the NL_MAMS-assisted rehabilitation strategy and describes its evaluation. Towards the end of the paper, we analyze educational value of the proposed rehabilitation strategy and describe a case study. In describing the theory of mind, we will be relying on the language of logic programming, this being a convenient way to introduce the mental world both to computers and autistic children.

1.1. Teaching theory of mind to autistic patients

The possibility to teach autistic children theory of mind has been assessed in multiple studies because of potentially important clinical implications. If it is true that a deficit in reasoning about mental attitudes leads to impairment in social interaction and understanding of oneself and others, then an efficient method for teaching theory of mind may assist in overall autism rehabilitation. Autism training studies, including the current one, are valuable sources of knowledge regarding how improved reasoning patterns affect trainees' behavior including social interaction.

The theory of mind training studies conducted so far have shown that some individuals with autism can be taught to pass the particular tasks of reasoning about mental states [53,5,55]. In most cases, it is natural to assume that trainees indeed apply one or another reasoning pattern rather than memorizing exact answers. Regrettably, in most cases, the studies of how individuals with autism acquire mental reasoning patterns are lacking an accurate formulation of these patterns, backed up by computational experiments. We believe the latter is essential to differentiate between mental and non-mental components of reasoning process.

Another problem with teaching particular patterns of reasoning about mental states is a verification of how children can generalize from acquired mental reasoning patterns. Because the majority of theory of mind training studies have not considered deductive links between the mental reasoning patterns to be thought, it is unclear how the acquisition of one pattern should have affected others. We believe that the question of mutual dependence of reasoning patterns should be addressed from a computational perspective. Indeed, applying axioms about intention, knowledge and beliefs to be introduced, we subject their generalizations to a formal treatment and observe how they can be taught (Sections 2 and 4).

A number of earlier studies have focused on theory of mind tasks, demonstrating that members of high-functioning group of individuals with autism are able to pass first-order [2], second order and even third-order tasks [62]. Also, the tasks include interaction and conversational skills concerning maintaining the topic of conversation and adjustment of conversation topics for others, interpretation and expression of non-verbal signals, listening and expressing interest in others. Also, the series of role-play tasks which imitate the second-order belief task.

The results of these theory of mind training studies is that the performance of the group which has undergone training has improved (at least with the second order tasks) with respect to controls. However, frequently children were able to apply non-mental state rules, and were not able to show the results of their training in their behavior. Only a smaller proportion of high-functioning autistic children are believed by these authors to improve their social skills as a result of training. In terms of generalization, children were able to apply acquired mental rules to other subjects and objects. However, it is still unclear what was being generalized – new knowledge about inferring mental states or a non-mental-state rule that allowed participants to pass tests. Disappointingly, children with autism can hardly transfer their reasoning skills from one mental domain to another (e.g. recognition of emotion, pretence, false belief; [63]).

We believe that the reasons for the rather low efficiency of the above training, in addition to autism-specific reasoning impairments, concern the consistency and persistency of the training and the thoroughness of coverage of the domain of mental reasoning. Here we discuss how to develop the experimental studies, verifying whether treatment of autistic theory of mind reasoning is efficient or not, into long-term rehabilitation strategies which are viable for a wide audience of individuals with autism.