On the Peculiarities of Default Reasoning of Children with Autism

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Abstract

We employ the formalism of default logic to model certain phenomena of autistic reasoning. Our main finding is that while people with autism may be able to process single default rules, they have a characteristic difficulty in cases where multiple default rules conflict. Even though default reasoning was intended to simulate the reasoning of typical human subjects, it turns out that following the operational semantics of default reasoning in a literal way leads to the peculiarities of autistic behavior observed in the literature.

Introduction

The syndrome of autism was first identified in the 1940's and exhibits a variety of phenomena: some of an interpersonal and some of a pragmatic character. One problem confronting the understanding of the syndrome is that of conceptualization: although the practitioner becomes accustomed to recognizing and responding to the various tendencies exhibited in the syndrome, it can nevertheless be difficult adequately to describe them. Various theories attempt to provide conceptualizations of the syndrome: the best known being the 'theory of mind' account (Baron-Cohen 1995), the 'central coherence' account (Happe 1996), and the 'executive function' account (Russel 1997). These theories all, however, have well-known difficulties, and there is a need for further contribution to the conceptualization of the syndrome or parts of it.

In this paper, we draw on a branch of logic in order to articulate the character of some major subsets of the phenomena belonging to the syndrome. This branch is the logic of default practical reasoning, that is, of reasoning which is practical in the sense that its conclusions specify actions, and default in the sense that additional context can cause a conclusion to be modified or withdrawn. This allows us to characterize some phenomena of autism in a fresh and precise way and suggests new lines of empirical experimentation. An advantage of this approach is that it allows us to benefit from the rich vocabulary of concepts, notations and distinctions which has been developed during the history of logic. We describe the peculiarities of autistic reasoning in terms of posing the problems a logician needs to solve while applying particular formalisms to implement the decision-making.

Default reasoning is intended as a model of real-world commonsense reasoning in cases which include typical and non-typical features. A default rule states that a situation should be considered as typical and an action should be chosen accordingly unless the typicality assumption is inconsistent. We observe that autistic intelligence is capable of operating with stand-alone default rules in a correct manner most of times.

When there is a system of conflicting default rules, the formal treatment (operational semantics) has been developed so that multiple valid actions can be chosen in a given situation, depending on the order in which the default rules are applied. All such actions are formally accepted in such a situation, and the default logic approach does not provide means for preference of some of these actions over the other ones. Analyzing the behaviour of people with autism, we will observe that unlike the controls, children with autism lack the capability to choose the more appropriate action instead of a less appropriate. In this respect we will see that the model of default reasoning suits autistic subjects better than controls.

This study branches out of our earlier studies of counterfactual reasoning (Peterson and Bowler 2000, Peterson et al 2004) and reasoning about mental states of autistic patients (Galitsky 2002), and extends the lines of our existing rehabilitation strategies (Galitsky 2003a).

Characterizing autistic reasoning

In this study we argue that the inability to use default rules properly leads to certain phenomena of autistic reasoning identified in the experimental studies (e.g. Happe 1996, Russel 1997, Pilowsky et al 2000):

1. Non-toleration of novelty of any sort;
2. Incapability to change plan online when necessary;
3. Easy deviation from a reasoning context, caused by an insignificant detail;
4. Lack of capability to distinguish more important from less important features for a given situation;
5. Inability to properly perceive the level of generality of a feature appropriate for a given situation,

Note that these peculiarities of reasoning can be distinguished from reasoning about mental attitudes, which are usually corrupted in a higher degree in case of autism (Baron-Cohen 1995).

Our approach considers the mechanisms of how typical reasoning is performed from the computational prospective, and then compares these mechanisms with the limitations of experimentally observed autistic reasoning. We take advantage of significant achievements of logical artificial intelligence in modelling human reasoning and understanding the mechanisms of solving the problems suggested to autistic and controls during the experiments. This computational approach therefore complements the findings of psychological experimentation in the study of autism.

Default reasoning is a particular machinery intended to simulate how human reasoning handles typical and atypical features and situations. Apart from reasoning about mental attitudes which is essential in presenting autism, we apply default reasoning to conceptualize a wide range of phenomena of autistic reasoning, taking advantage of the experience of computer implementation of default reasoning. Peculiarities of autistic reasoning can then be matched against the known possibilities of malfunctioning of artificial default reasoning systems.

In the context of artificial intelligence, the phenomena of autistic reasoning are of particular interest, since they help us to locate the actual significance of formal models of default reasoning. At the same time, we expect this study to shed light on how autistic reasoning may be improved by default reasoning-based rehabilitation techniques.

Handling a single default rule by autistic reasoning

An abstract default logic distinguishes between two kinds of knowledge: the usual formulas of predicate logic (axioms, facts) and “rules of thumb” (defaults, see Antoniou 1997). Corrupted reasoning may handle improperly either kind of knowledge, and we pose the question which kind may function improperly in autistic reasoning. Moreover, we consider the possibility that an improper interaction between the facts and rules of thumb may be a cause for corrupted reasoning.

Default theory (Brewka et al 1995, Bochman 2001) includes a set of facts which represent certain, but usually incomplete, information about the world; and a set of defaults which cause plausible but not necessarily true conclusions (for example, because of the lack of a world knowledge or a particular situation-specific knowledge). In the course of routine thinking of human and automatic agents some of these conclusions have to be revised when additional context information becomes available.

Let us consider the traditional example quoted in the literature on nonmonotonic reasoning:

$$\frac{bird(X):\ fly(X)}{fly(X)}$$

One reads it as *If X is a bird and it is consistent to assume that X flies, then conclude that X flies.* In the real life, if one sees a bird, she assumes that it flies as long as no exceptions can be observed.

fly(X):- not penguin(X). fly(X):- not sick(X).
fly(X):- not just_born(X). …

Exceptions are the potentially extensive list of clauses implying that X does *not fly*. It would be inefficient to start reasoning based on exceptions; it should be first assumed that there are no exceptions, then verified that this is true and then proceed to the consequent of a default rule.

A penguin (the bird which does not fly) is a *novelty* (it is atypical). Conventional reasoning first assumes that there are no novelties (there is no exception) and then performs the reasoning step, concluding that X flies. If this assumption is wrong (e.g. X-novelty is taking place) then the rule is inapplicable for penguins and it cannot be deduced that X flies. It is quite hard for autistic reasoning to update this kind of belief because it handles typical and atypical situations in the same manner, unlike the default rule machinery suggests. It is quite computationally expensive to handle typical and atypical situations similarly, because a typical situation is compact and most likely to occur, and an atypical situation comprises an extensive set of cases (clauses) each of which is unlikely to occur.

Let us now view this example from the perspectives of five phenomena mentioned above:

Unlike normal subjects, and similar to software systems, autistic subjects can hardly tolerate the *Additional_features_of_envir_do_not_change_routine* when they have a *Usual_intention* to *Follow_usual_routine*:

$$\frac{\textit{Usual\_intention} : \textit{Additional\_features\_of\_envir\_do\_not\_change\_routine}}{\textit{Follow\_usual\_routine}}$$

This default rule schema is read as follows: when there is a *Usual_intention*, and the assumption that *Additional_features_of_envir_do_not_change_routine* is consistent, then it is OK to *Follow_usual_routine*. There should be clauses specifying the situations where this assumption fails:

Additional_features_of_envir_not_change_routine:- not (alarm(fire) ∨ *desire(DoSometrhingElse)* ∨…).

This clause (assumption) fails because of either external reasons or internal ones, and the list of potential reasons is rather long.

A child knows that birds fly. The child sees observes that penguins do not fly	
Child updates the list of exceptions for not property flies	Child adds new rule that penguins do not fly
The flying default rules stays intact.	It is necessary to update the existing rule of flying and all the rest of affected rules
The process of accepting new exceptions is not computationally expensive	This process takes substantial computational efforts and, therefore, is quite undesirable and overloading.
Observing a novelty and remembering exceptions is a routine activity	Observing a novelty is stressful

A good example here is that the autistic child runs into tremendous problems under deviation in an external environment which typical cognition would consider to be insignificant.

We proceed to the phenomenon of Incapability to change a plan online when necessary. A characteristic example is that of an autistic child who does not walk around a puddle which is blocking her customary route to school, but rather walks through it and gets wet as a result. This happens not because the autistic child does not know that she would get wet stepping through a puddle, but because the underlying reasoning for puddle avoidance is not integrated into the process of reasoning. Let us consider the reasoning steps a default system needs to come through.

Initial plan to follow a certain path is subject to application (verification) by the following default rule:

$$\frac{\textit{need(Child, cross(Child, Area))} : \textit{normal(Area)}}{\textit{cross(Child, Area)}}$$

abnormal(Area) :- wet(Area) v muddy(Area) v dangerous(Area).

Here we consider a general case of an arbitrary area to pass by, *Area=puddle* in our example above. The rule sounds as follows: “If it is necessary to go across an area, and it is consistent to assume that it is normal (there is nothing abnormal there, including water, mud, danger etc.) then go ahead and do it). A control individual would apply the default rule and associated clause above to choose her action, if the *Area* is normal. Otherwise, the companion default rule below is to be applied and alternative *AreaNearBy* is chosen.

$$\frac{\textit{need(Child, cross(Child, Area)), abnormal(Area)} : \textit{normal(AreaNearBy)}}{\textit{cross(Child, AreaNearBy)}}$$

Note that formally one needs a similar default rule for the case something is wrong with *AreaNearBy*: abnormal(AreaNearBy). A control individual ignores it to make a decision with reasonable time and efforts; on the contrary, autistic child keeps applying the default rules, finds herself in a loop, gives up and goes across the puddle. In other words, autistic reasoning literally propagates through the totality of relevant default rules and run into the memory/operations overflow whereas a normal human reasoning stops after the first or second rule is applied.

What are the peculiarities of how autistic children apply a newly acquired rule? First of all, they do their best in applying it, however, they follow it literally. Let us consider the following example:

> An autistic girl was advised by her parents not to speak with strangers in the street. On one occasion a policeman approached the girl and started asking questions, but was ignored by her. In spite of his multiple attempts to encourage the girl to communicate, they failed and he became upset.
>
> After the parents were told about the incident they suggested that the girl should not have treated policemen as a stranger. They also confirmed that the girl new who policemen were. The girl required that she needed the new explicit rule overwriting the initial one that a policeman was not a typical stranger and should have been treated differently.

On the basis of the analysis presented here, this anecdote could be given the following interpretation:

1. The subject is doing her best to follow the rule, and readily accepts new rules
2. The girl did know that the approaching man was a policeman, but she did not know him as a person, therefore she categorised him as a stranger in the context of the behavioural rule.
3. In this situation the girl was familiar with who policemen are, as she knew that policemen should not be ignored.

4. However, she was not able to handle a policeman as an exception in the rule for stranger.
5. If she had had the explicit rule for how to respond to strangers who are policemen then she would have followed it.

We conjecture that the girl had sufficient knowledge of the subject and was capable of applying the rules, taken separately. What she was not able of doing was to *resolve a conflict between considering the same individual as a stranger and as a policemen* in the context of decision whether to communicate or to ignore.

$$\frac{in\_street(me)\ \text{:-}\ stranger(Person)}{not\ talk(me,\ Person)}$$

Usually, strangers do not fall into a special category; however, exceptions are possible:

stranger(Person):-not (policeman(Person) $\vee$
rescue(Person) $\vee$ *military(Person* $\vee$…).

Indeed, the girl is likely capable of identifying the categories of persons above. However, it is not the case in the above context of a *stranger* rule, which is indeed an opposing rule to the one for handling exceptions:

talk(me, Person):- not (Person).

If the parent would incorporate the rule above into the default rule explicitly, then it is likely that the girl would treat the policemen properly.

Handling conflicting default rules

In this section we proceed to the situation where there are multiple (conflicting) default rules, and the results of their execution depend on the order these rules are applied. Here we propose an informal description for such situations, introducing *operational semantics* for default reasoning.

The main goal of applying default rules is to make all the possible conclusions from the given set of facts. This is the bottleneck for autistic reasoning: a child may come to a single conclusion without being aware than other solutions may be as valid. A control subject is usually capable of identifying the totality of conclusions and of applying some kind of preference criteria to select a more appropriate one. Presenting the operational semantics, we bear in mind that in contrast to controls, autistic reasoning follows it literally. Following the operational semantics of default reasoning in case of conflicting rules provides conclusions similar to what autistic subjects produce, because both lack the machinery to apply preference and select a more adequate solutions, taking into account circumstances which are neither expressed by facts nor rules in the default system.

What is the nature of conflict under operational semantics? If one applies only one default, we can simply add its consequent to our knowledge base. The situation becomes more complicated if we have a set of defaults because, for example, the rules can have consequents contradicting each other or, a consequent of one rule can contradict the justification of another one. In order to provide an accurate solution we have to introduce the notion of *extensions***:** current knowledge bases, satisfying some specific conditions.

Suppose D is a set of defaults and W is a set of facts (our initial knowledge base). Let Δ be an ordered subset of D without multiple occurrences (it is useless to apply the default twice because it would add no information). We denote a deductive closure (in terms of classical logic) of Δ by $In(\Delta)$: $W \cup \{cons(\delta) \mid \delta \in \Delta\}$. We also denote by $Out(\Delta)$ the set $\{\neg\psi \mid \psi \in just(\delta),\ \delta \in \Delta\}$. We call $\Delta=\{\delta_0, \delta_1, \ldots\}$a process iff for every k δ_k is applicable to $In(\Delta_k)$, where Δ_k is the initial part of Δ of the length k.

Given a process Δ, we can determine whether it is successful and closed. A process Δ is called successful iff $In(\Delta) \cap Out(\Delta) = \varnothing$. A process Δ is called closed if Δ already contains all the defaults from D, applicable to $In(\Delta)$.

Now we can define extensions. A set of formulae $E \supset W$ is an extension of the default theory $\langle D, W\rangle$ iff there is some process Δ so that it is successful, closed, and $E=In(\Delta)$.

Let us consider an example of a *lost toy*; a child needs to decide on which action to choose. Let us suppose that W is empty and D is the set of

$$\delta_1 \quad \frac{true : not\ toy\_lost(X)}{not\ toy\_lost(X)}$$

$$\delta_2 \quad \frac{true :\ toy\_lost(X)}{search(X,\ toy\_lost)}$$

These rules describe a situation when children toys are normally not assumed to be lost if not immediately seen, but, if it's consistent to assume that the toy has been taken by someone, then it is worth searching for.

After we have applied the first rule, we extend our knowledge base by *not toy_lost(X)*:

$In(\{\delta_1\}) = \{\ not\ toy\_lost(X)\ \}$,

$Out(\{\delta_1\}) = \{\ toy\_lost(X)\ \}$.

The second rule is not applicable to $In(\{\delta_1\})$. Therefore the process $\Delta = \{\delta_1\}$ is closed. It is also successful, so $In(\{\delta_1\})$ is an extension. Suppose now we now apply δ_1 first:

$In(\{\delta_2\}) = \{\ search(X,\ toy\_lost)\ \}$,

$Out(\{\delta_2\}) = \{\ \text{not}\ toy\_lost(X)\ \}$.

The rule δ_1 is still applicable now, so $\{\delta_2\}$ process is not closed. Let us apply δ_1 to $In(\{\delta_2\})$:

$In(\{\delta_2,\delta_1\}) = \{\ search(X,\ toy\_lost),\ not\ toy\_lost(X)\ \}$,

$Out(\{\delta_2,\delta_1\}) = \{\ \text{not}\ toy\_lost(X),\ toy\_lost(X)\ \}$.

Now $In(\{\delta_2,\delta_1\}) \cap Out(\{\delta_2,\delta_1\}) \neq \varnothing$ so $\{\delta_2,\ \delta_1\}$ is not successful and $\{\ search(X,\ toy\_lost),\ not\ toy\_lost(X)\ \}$ is not an extension. This comes in accordance with our intuitive expectations, because if we accept the later statement to be a possible knowledge base, then we conjecture that the toy will be searched always, not only when we suspect that it has been taken by someone.

However, if there are two extensions (possibilities for actions), then more than one action are deemed formally legitimate. In a real life situation normal individuals, unlike autistic ones, possess additional machinery to select appropriate actions. On the contrary, autistic children, if capable of using default rule, follow the above methodology literally. They therefore may choose an action inadequate from the perspective of control subjects, but nevertheless correct from the perspective of formal default reasoning.

Due to literal following of the operational semantics, autistic children have significant difficulties understanding natural language sentences and reacting to commands including multiple ambiguous words. Analyzing combinations of meaning, autistic reasoning may produce formally valid but inadequate (from the viewpoint of control subjects) representations.

We conclude this section by the training example we have been using in the autistic rehabilitation Center "Sunny World" (Moscow, Russia). The exercise teaches autistic children to operate with multiple possible interpretations of natural language expressions. Indeed, autistic children have problems understanding situations where there are multiple ambiguous words in a query and the totality of overall meaning for a sentence is a combination of meanings of these words. Let us consider the following expression (in Russian):

"Эта *картина* заставила его забыть о своем *состоянии*"

The first ambiguous word, *картина*, has two following meanings:

1.1) A work of art, a painting;

1.2) A set of events observable at a certain time.

The meanings of the second word, *состояни*е (normalized), are:

2.1) Monetary assets of an individual;

2.2) Mental and physical state of an individual.

The respective default theory has four extensions with the following meanings:

1.1-2.1) This painting made him forgot about his poverty/wealth;

1.2-2.1) This accident made him forgot about how poor/rich he was;

1.1-2.2) This painting made him ignore his feeling unwell;

1.2-2.2) This accident distracted him from his thoughts.

The children are demonstrated that all above meaning are valid; however, some of them are more appropriate than others in a certain context. This is also the case under disambiguation for question answering (Galitsky 2003b).

An easier training example which was attempted by more than 10 children with autism is depicted at Fig. 1. The focus of this exercise is to develop the capability of changing plans online. The user interface represents a decision-making procedure in changing environment via list boxes.

Conclusions

This paper has drawn on a branch of logic in order to provide a framework for the understanding of the elusive phenomena of autistic reasoning. Our thesis is that difficulty arises in autism specifically in those situations where two default rules conflict, and this provides a relatively precise tool for understanding some of the phenomena of autism. This will be a basis for our further work which will investigate the following conjectures:

1. Non-toleration of novelty of any sort, because it requires update of the whole commonsense knowledge, since it is not adequately divided into typical and atypical cases, norms and exceptions;
2. Incapability to change plan online when necessary, because it requires substantial computational efforts to exhaustively search the space of all possibilities;
3. Easy deviation from a reasoning context, caused by an insignificant detail, because there is a high number of issues to address at each reasoning step; each such issue is seemed to be plausible;
4. Lack of capability to distinguish more important from less important features for given situation, because feature importance is mainly measured in the context of being a justification of default rule.
5. Inability to properly perceive the level of generality of features appropriate for a given situation is due to the problem of estimating which generality of a given feature is most typical, and which is less typical to be applied as a justification of a default rule.

We observed that loss of reasoning efficiency due to improper use of default rules leads to a wide range of reasoning problems reflected in behavioral characteristics of autistic subjects.

Finally, we mention the methodology for experimental testing of our hypothesis that inability of applying default rules leads to a series of significant deviations of reasoning capabilities in autism. A typical situation where a default rule is naturally applied arises while understanding an ambiguous sentence (command), where one meaning is typical and another is atypical. Conducting a conversation with an autistic individual, an experimenter may ask ambiguous questions or give ambiguous commands, and track the reactions of the patient. Five phenomena of this study can be addressed in such a scenario, and observed in terms of how handling ambiguity via default rules influences these phenomena. We have conducted preliminary experiments along this line, and more detailed experimental observations of this sort are the subject of our further study.

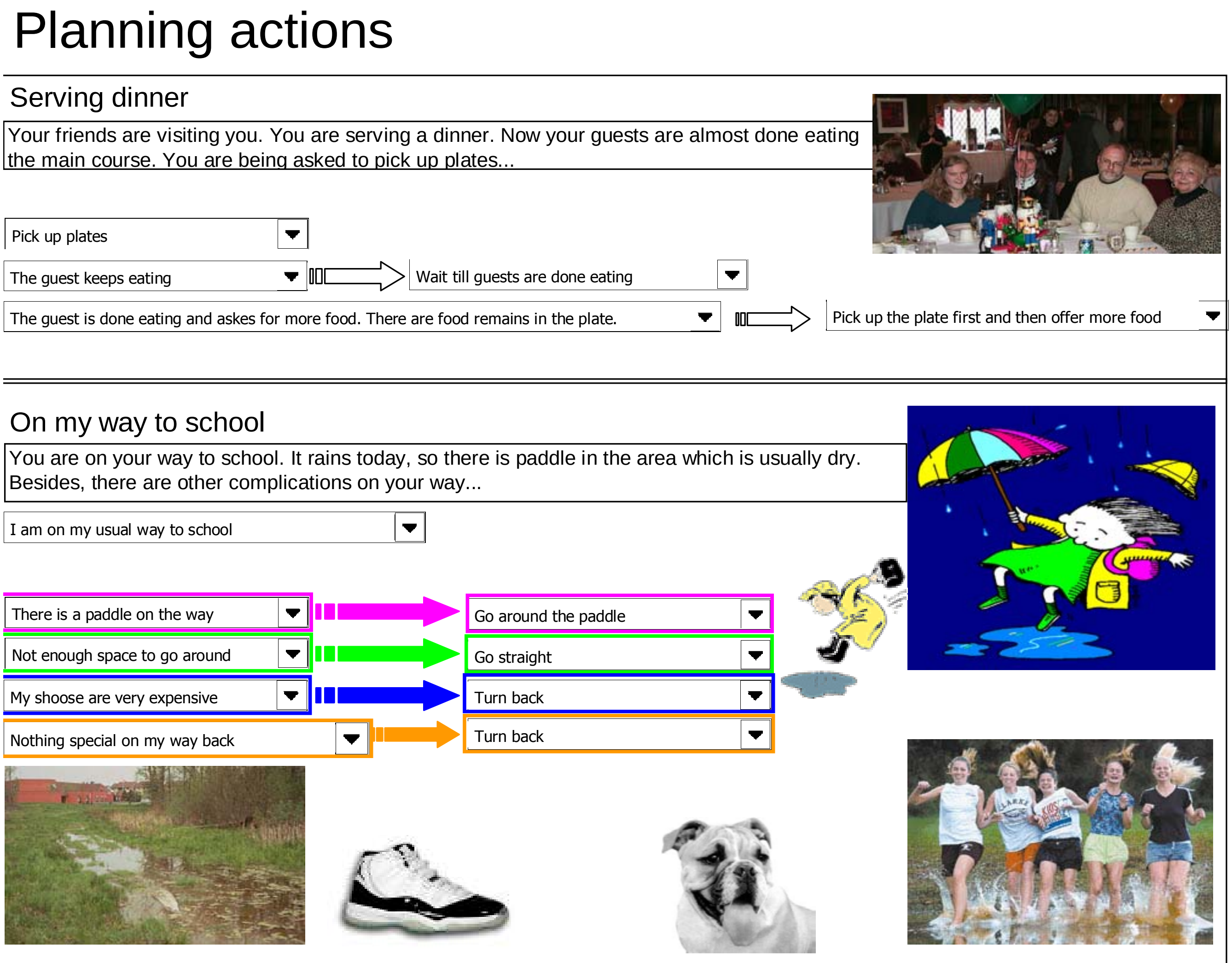

Fig. 1 The screen-shot of the interactive form for the rehabilitation of autistic reasoning.

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