Success of Default Logic

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Abstract. Ray Reiter's *Logic for Default Reasoning* was published almost twenty years ago, but it is widely used today by researchers in knowledge representation, commonsense reasoning and logic programming. This note is a collection of random comments on aspects of this success story.

Someone defined success in science as writing a paper that is going to be referenced by colleagues for as long as ten years after its publication. Ray Reiter's *Logic for Default Reasoning* [15] was published almost twenty years ago, but it is widely used today by researchers in knowledge representation, commonsense reasoning and logic programming. This note is a collection of random comments on aspects of this success story.

1. Default logic, along with circumscription [9] and nonmonotonic logic [12], is one of the three original nonmonotonic formalisms described in the 1980 Special Issue of the journal *Artificial Intelligence*. These papers differed from all earlier research on formal logic in such a radical way that their authors could hardly be expected to define their systems "the right way" on the very first attempt.

Indeed, technical papers on circumscription today hardly ever refer to the definition given by John McCarthy in 1980: a few years later he came up with important enhacements and generalizations, such as prioritized circumscription [10], that turn his idea into a widely applicable tool. In place of the original definition of nonmonotonic logic due to Drew McDermott and Jon Doyle, researchers prefer to use its modification proposed in the mid-eighties by Bob Moore—autoepistemic logic [13].

Literature on default logic has its share of "revisionist" papers also. Many of them have to do with the use of bound variables in default theories (see [1] on problems caused by Skolemization). But even quantifier-free default logic is rich and useful. It is remarkable how much of the modern research related to default logic refers to Ray Reiter's original publication, and not to any of the ingenious attempts to improve on his definition.

2. In 1987, Nicole Bidoit and Christine Froidevaux observed that default logic can be used to model negation as failure in logic programs [2]. It follows that any Prolog system can be viewed as a partial implementation of default logic. For instance, given the program

```
p :- \+ q.
q :- \+ r.
```

Prolog responds `no` to queries `p` and `r` and `yes` to query `q`; this fact tells us that p and r do not belong to the extension for the default theory

$$\frac{:\ \neg q}{p} \quad \frac{:\ \neg r}{q}$$

and that q does. Since Prolog is older than default logic, we can say that default logic was partially implemented even before it was defined!

Other nonmonotonic formalisms mentioned above are closely related to logic programming too [4, 7], but in the case of default logic the match is particularly good. Extended logic programs in the sense of [5] are essentially the default theories that are built entirely from literals; an "answer set" (or "stable model") for a logic program is simply an extension in the sense of default logic intersected with the set of literals.

The idea that logic programming is a subset of default logic has had a major influence on declarative logic programming. Having proved a theorem about logic programs, a researcher can ask whether it can be generalized to default logic. Given a fact about default logic, we may inquire what it tells us about logic programs.

3. One of the goals of the theory of nonmonotonic reasoning is to solve the frame problem by formalizing the commonsense law of inertia. The method for doing that in default logic proposed in Reiter's 1980 paper uses the "frame default" which can be written, in the situation calculus notation, as follows:

$$\frac{P(s)\ :\ P(do(a,s))}{P(do(a,s))}. \tag{1}$$

It says, informally speaking, that if property P holds before executing action a and it is consistent to assume that P holds after executing a also then this assumption is indeed true. The definition of an extension shows how to make postulates like this precise.

Whether or not (1) provides a satisfactory solution to the frame problem may depend, of course, on how other properties of actions are formalized. There are several options here. For instance, we can express that an action A makes P true when a precondition Q is satisfied by axiom

$$Q(s) \supset P(do(A,s)) \tag{2}$$

or by an inference rule—a default without justifications:

$$\frac{Q(s)}{P(do(A,s))}. \tag{3}$$

Steve Hanks and Drew McDermott [6] investigated the use of formal nonmonotonic reasoning for solving the example of the frame problem known today as the Yale Shooting story. Several formalizations discussed in their paper turned out to be inadequate, and they arrived at the grim conclusion that all nonmonotonic logics considered in their paper—including default logic—"are inherently incapable of representing this kind of default reasoning."

The flurry of publications on this subject in the late eighties described new nonmonotonic formalisms that might be more successful, as well as modifications of the existing formalisms that looked more promising and new ways of applying the existing formalisms to the frame problem. One interesting proposal, due to Paul Morris [14], was to use default logic in a different way: to express the commonsense law of inertia as a nonnormal default.

The amazing fact that transpired later is that there is no need to change anything in Reiter's original proposal. Normal default (1) provides a completely satisfactory solution to the frame problem provided that the rest of the default theory is set up correctly. This was demonstrated by Hudson Turner [16]; see Section 5.2 of that paper for a detailed comparison of his approach with the work done earlier by Hanks and McDermott and by Morris. Essentially, Turner makes three points:

- effects of actions should be described by inference rules like (3) rather than formulas like (2);
- we should include defaults

$$\frac{:\ P(S_0)}{P(S_0)} \quad \text{and} \quad \frac{:\ \neg P(S_0)}{\neg P(S_0)} \tag{4}$$

to guarantee that every extension contains a complete description of the initial situation;[1]

- any assumptions about situations other than S_0 should be stated as constraints:[2] instead of $P(do(A, S_0))$, we should postulate

$$\frac{\neg P(do(A, S_0))}{False}. \tag{5}$$

This way of using default logic is attractive for two reasons. First, it is applicable to actions with indirect effects. In other words, it solves the ramification problem. Second, the preconditions, justifications and conclusions in defaults (1) and (3)–(5) are literals. In other words, these defaults can be viewed as rules in an extended logic program and processed using computational methods of logic programming.

In a recent paper by Richard Watson [18] these ideas found their first practical application.

4. We need nonmonotonic reasoning for many reasons, and we learn of new reasons as time goes by.

In 1990, Hector Geffner [3] explained why causal reasoning is nonmonotonic. In a useful modification of Geffner's logic due to Norman McCain and Hudson Turner [8], the existence of a causal dependency between propositional formulas F and G is represented by a "causal rule"

$$F \Rightarrow G. \tag{6}$$

The semantics of such rules defines when an interpretation of the underlying propositional language is "causally explained" by a set of causal rules. This definition uses a fixpoint construction somewhat reminiscent of the definition of an extension in default logic.

But this is more than an analogy: Turner's forthcoming paper [17] shows how to *embed* the causal logic from [8] into default logic. Replace every rule (6) in a causal theory by default

$$\frac{:\ F}{G}$$

[1] This is not necessary for temporal projection problems with complete initial conditions.

[2] For an assumption about S_0, both ways of stating it are equivalent.

and consider all complete consistent extensions for this set of defaults. These extensions turn out to be in a 1–1 correspondence with the causally explained interpretations.

Instead of restricting attention to complete extensions, we could have added defaults

$$\frac{:\ P, \neg P}{False}$$

for all atoms P.

5. To sum up, default logic has brought us several pleasant surprises. In spite of all the controversy surrounding the Yale Shooting example, the original default logic approach to the frame problem turned out to be correct and quite general. Default logic provides a useful model of negation as failure in logic programming, and also of the relation between cause and effect, although it was not intended for any of these purposes. There is no doubt that other surprises like these expect us in the next century.

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