Some Key Notions In Non-Monotonic Reasoning

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Abstract

This paper explores the role of some basic notions in the study of non-monotonic reasoning, such as validity, logical consequence, context, rules and assumptions.[1] It offers some considerations about the relation between non-monotonicity and the ideal of perfect validity in logical inference and the pertinence of taking into account human limitations. I propose that work on non-monotonic reasoning can benefit from new notions of inference, logicality and reason. The paper is divided into three sections. The first section presents the motivations for this analysis and can be skipped by people familiar with non-monotonic reasoning. The second section offers a taxonomy of terms in the NMR literature. The third section proposes to expand the notion of logicality in three important ways.

KEYWORDS: Non-monotonic reasoning, Logic, Inference, Reason.

I. The Background

We endeavor to increase our knowledge, even if it complicates some matters.[2] Our curiosity spans from trivial daily-life matters to the most abstruse scientific issues. Since the times of Plato we strive for certain, sure knowledge, not mere opinion. Our popular conception of the increase in knowledge is reflected in these words by M. Foster:

> In respect to other things there may be times of darkness and times of light, there may be risings, decadences, and revivals. In science there is only progress. What is gained by scientific inquiry is gained forever; it may be added to, it may seem to be covered up, but it can never be taken away.[3]

[1] Many of these ideas come from joint work in progress with Leah Savion. See for instance, Morado & Savion, 2002.

[2] Markovitch (1989, pp. 4, 20, 127) studies some ways that knowledge elements can be excessive and even harmful to the efficient performance of a specific set of tasks: they can be incorrect, redundant or irrelevant (defined as being useless for finding a solution in a search space).

3 Included in Horblit (1964).

Ironically, in the same pages we find C. P. Snow's remark that “innocence about Science is the worst crime today.” These two quotes illustrate complementary attitudes in scientific research. We strive for an ideal of incremental knowledge where we painstakingly assemble the edifice of knowledge on firm, unshakable foundations. Yet we must be realistic and see science as it is: a human activity that does not always measure up to its ideal. Changes in scientific theories includes abandonment, if not outright rejection of previous beliefs. From the daily disconfirmation of hypotheses emphasized by Popper (1958), to the dramatic revolutions and loss of the previous system of beliefs described by Kuhn (1962), our best pursuits of knowledge are not purely incremental.

Since Aristotle and Euclid, the ideal of knowledge development has been that of the mathematical sciences. Once ascertained, a mathematical theorem remains forever. This notion of inference was brilliantly expounded by Tarski. But work on Artificial Intelligence soon showed that the formal thought processes were paradoxically simpler to reproduce mechanically. The everyday, “commonsensical” inferences revealed themselves as much more difficult to reconstruct, in no small measure because they allowed for error and revision. Voices that decried transferring the cumulative ideal of the mathematical sciences into other disciplines started to gather an audience.[4]

Consider the following examples:

Tweety Example	You are told that Tweety is a bird and you conclude that Tweety flies.[5]
Airline Example	You are told that Airline Canada flies from Vancouver to Toronto, Boston and Los Angeles. Asked whether it flies to Toulouse you say no.[6]
Nixon Example	From the fact that Nixon is a Quaker you infer that he is a pacifist. From the fact that he is a Republican you infer that he is not a pacifist.[7]
Robot Example	After dropping a red block, you assume it is still red.[8]
Coffee Example	You believe that if you put sugar in your coffee, it will taste nice. You then conclude that if you put sugar and diesel oil in your coffee it will taste nice.[9]
Parachute Example	A man fell from a plane. Fortunately, he was wearing a parachute. Unfortunately, the parachute didn't open. Fortunately, he fell from the plane at a low altitude over a large haystack. Unfortunately, there was a pitchfork in the haystack. Fortunately, he missed the pitchfork. Unfortunately, he missed the haystack...[10]

These examples illustrate important problems in our theories about reasoning. For instance, the Tweety Example shows that perfectly normal and sensible ways of reasoning can be fallible or defeasible. By *defeasibility* (or *nonmonotonicity*) I simply

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4 A very influential attack on the monotonicity of logistic systems appeared in Minsky (1974, p. 125).
5 From Reiter (1980, p. 68).
6 From Reiter (1978, p. 301).
7 From Reiter and Criscuolo (1981, p. 98). The subject of the example was simply called ``John" there.
8 A more complex example of this kind is analyzed in McCarthy and Hayes (1969, pp. 36-37).
9 In ter Meulen (1986), p. 138, who calls this is a ``much cherished example".
10 Told in Nute (1990, p. 351).

mean that more information can make us retract the conclusion. For instance, if we were to discover that Tweety is a penguin or that it has a broken wing we would no longer conclude it flies. The term *defeasible reasoning* encompasses the variegated phenomena of non-additive reasoning, commonsense inference, *prima facie* entailments, and fallible reasoning in general.

The importance of this toy example has nothing to do with ornithology and everything with the intuition that reasonable conclusions can be fallible. Daily we must handle incomplete information as in the Airline Example, face competing putative conclusions (Nixon Example), and update our beliefs in a changing world (Robot example).

These problems have increasingly received attention since the late sixties because of their implications to Computer Science, Artificial Intelligence and Philosophical Logic. Sometimes the examples reveal their original concerns with databases (the Airline Example), cybernetics (the Robot example) theory of conditionals (the Coffee Example), or counterfactuals (Parachute Example). But we must not be misled by the novelty of the formulation. These questions have been with us since the beginnings of philosophy and we can trace them back to Aristotle's notion of enthymematic syllogism.[11] But the history of logic went the way of the apodictic syllogism and not the way of the rhetorical syllogism. True, classical logic does offer insights into rational belief revision. It gives us guidelines to add information with its notion of logical consequence, and even to retract information with its principles of *Reductio ad Absurdum* and *Modus Tollendo Tollens*. Unfortunately most formalizations emphasize a traditional axiomatic-deductive model of rational belief change in which we simply add beliefs when information is increased, never subtract them. This "additivity"[12], a hallmark of classical deductive logic, makes it hard to explain why and how we should sometimes rationally abandon beliefs in the face of new evidence. What could such evidence be? Why does it force a deletion of previous beliefs? What would be a sensible way to go about such deletions? There is no consensus among logicians about the answers to these questions.

Since complete certainty in the foundations is not the normal case, we often need to jump from our incomplete knowledge to a needed conclusion in order to advance our research. Even when we are not consciously venturing our best guess, errors creep up in our theory and we uncover inconsistencies. Errors are a fact of life, for humans and for artificial systems, for single agents and for networks of them. Just like humans do, machines need to be able to modify their interpretations in light of new data that the machine finds or produces. To achieve efficiency in their data collection, machines must "guess" at the next contour or phoneme that will appear in their visual or auditory field.[13] Machines also have something akin to indexical beliefs, and it can be cheaper to revise those beliefs than to generate a new copy every time something changes internally or in our environment.[14]

So, an epistemic subject capable of facing minimal challenges in the real world (be it a computer or a human), needs to be able to handle incomplete and/or inconsistent

11 See Morado (2000).

12 For a use of the term "additive" as synonymous with "monoton ic", see Dunlop and Fetzer (1993, p. 87).

13 Humans also undo preliminary parsings of sounds, as in the famous example 'The horse raced past the barn fell." See Post (1989, p. 48).

14 This point is made in Doyle and London (1980, p. 7).

descriptions about what states of affairs actually hold. Normally, we use rules that, even though defeasible, guarantee a minimum of rationality in our research. Those rules belong to the construction of a model of reality and with the possibility of error comes the need to avoid inconsistent conclusions by retracting beliefs.

Defeasible reasoning is an important part of the cognitive work of normal epistemic subjects and it deserves a study of its logical structure. Also, there is the pragmatic side. Since Aristotle logicians have emphasized deduction at the expense of induction, but even today deductive techniques are slow and incomplete. It is no surprise that the purely additive or incremental knowledge accumulation of which Foster talked is still an ideal, as seems also to be often the case with the individual learning of that knowledge or skills.[15] By countenancing defeasibility we acknowledge an inherent unreliability, but one that is reasonable in some areas. We still use humans in many industries, not because they are cheaper or more precise than a robot, but because they are faster. The window for real time response required to answer a missile attack can be too small for the elaborate chains of inference we use in our modern theorem provers. So, from both a theoretical and a practical point of view, often the best we can have is fault-tolerant reasoning.

II. Naming names

A little taxonomy now. Here is a table of the way in which some words are used:

	Reasoning or argument	Inference, rule or conditional	Premisses	Conclusion
Commonsense	Acceptable to the community	Holds with zero background	Considered obvious	Harmonious with common beliefs
Defeasible	Reaches retractable conclusions	Can be blocked if context changes	Retractable if context changes	Retractable if context changes
Default	Uses default rules	Holds unless inconsistent with evidence	Assumed true unless inconsistent with evidence	Supported by a default rule
Plausible	Reaches plausible conclusions	Is supported by context or evidence above some threshold	Supported by available evidence or context	Supportedby plausible rules and premisses
Nonmonotonic	Uses nonmonotonic rules	Yields a nonmonotonic conclusion	N/A	Retractable if information is incremented
Uncertain	Uses uncertain rules or premisses	Has exceptions (it is not deductive)	Fallible or unreliable	Supported by uncertain rules or premisses

15 Lesgold, Glaser, Rubinson, Klopfer, Feltovich and Wang (1988) report that in some learning contexts (a baby' s locomotion, a radiologist' s performance) some subjects may perform worse than other subjects with less and with more instruction. Senger (1989, pp. 88-89) hypothesizes that something similar might happen with respect to improvements in the legal reasoning of Law School students.

This table does not reflect all the sundry ways these terms are used in the literature. For instance, "defeasibility" and "nonmonotonicity" are nowadays used interchangeably in popular glossaries.[16] Terms like *defeasible reasoning* could encompasses the variegated phenomena of non-additive reasoning, parts of commonsense inference, *prima facie* entailments, and fallible reasoning in general. Such a generous policy would eventually lead us to declare that "all of commonsense reasoning is nonmonotonic, and nonmonotonic reasoning is inherently ambiguous [in the sense of liable to have conflicting conclusions]."[17] Yet, parts of commonsense reasoning might well be monotonic in some communities or under several reasonable interpretations. For instance, McCarthy is happy to ascribe common sense to a program that "automatically deduces for itself a sufficiently wide class of immediate consequences of anything it is told and what it already knows."[18] The specification of this class of consequences is vague, but it does not prejudge about the defeasability of its members; we certainly want to include simple tautologies in it.[19]

I want to avoid definitions like "Nonmonotonic reasoning is reasoning from true premises to likely conclusions"[20] because, on one hand, nothing prevents us from inferring nonmonotonically from false statements and, on the other hand, if the likely conclusions are not reversible by further evidence, the reasoning is monotonic.

Nonmonotonic reasoning is defeasible: "retractable if the context changes". The change in the context is increment of information. But there is an alternative notion of nonmonotonicity divorced from defeasibility, since the converse does not hold. Defeasibility does not entail nonmonotonicity because defeasibility can be caused by several kinds of change in the context, only one of which is to enlarge it. This prevents us from extending the term "nonmonotonic" too much.

If we feel in a generous mood we can include commonsense reasoning as a kind of plausible, if uncertain, reasoning. Our decision depends on how independent from subjective community standards is our notion of plausibility (support by the evidence). But whatever we may mean by plausible rules, some of them preserve truth and somes do not. So, they can be monotonic as well as nonmonotonic: certainly tautologies are *at least* plausible. Similarly, while most default rules are nonmonotonic, some are not defeasible. They are the limit cases when the premisses entail the conclusion regardless of the "justification." This is the rather vacuo us sense in which tautological entailments are true "by default." Notice that the fact that nonmonotonic reasoning is defeasible does not mean that all the nonmonotonic patterns of reasoning that comprise nonmonotonic reasoning are also defeasible. To conclude so would be a fallacy of division.[21]

We should note that many types of inference are classified according to formal criteria. The notion of default inference talks about consistency, nonmonotonic inference lacks the logical property of closure under strenghtening of the premisses or antecedents, and uncertain inferences are defined in contrast with deduction. This formal character

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16 See, for instance, Dunlop and Fetzer (1993, p. 40).
17 Stein (1990, p. 174).
18 McCarthy (1968, p. 403).
19 Personally, I like the quip attributed to Einstein that "Common sense is the collection of prejudices acquired by age eighteen." A similar idea that common sense is what you learn at an early age is presented in Minsky (1986).
20 Stein (1990, p. 1).
21 Even "abduction may, on occa sion, have the form of a valid deductive inference," Clark (1982, p. 3).

puts them at a different level than merely commonsense, plausible or defeasible inferences.

Finally, we could try to subsume default reasoning (both in the sense of paradigmatic, and in the sense of employing a rule that only applies if not contradicted by other evidence), into nonmonotonic reasoning, that is, reasoning whose conclusion might need to be retracted after addition of information. This in turn could be subsumed into defeasible reasoning in which retractions can be prompted not only by addition of information but also change or loss.

The notions of defeasible and commonsense reasoning only overlap, this last notion having a strong sociological component. The perception of the community is crucial to decide what we can call commonsensical, but if we restricte this notion to a psychological level we can talk about inferences that appear plausible to some agents and under certain conditions.

Fortunately, parts of deductive logic can be called plausible and some times even commonsensical. It is well known that *Modus Ponens* is almost universally recognized as a valid form of inference. Therefore none of these two notions can be included in that of uncertain reasoning though the uncertain reasoning in which we are interested is at least plausible.[22]

III. A new rationality

In order to start our exploration of the role of notions like validity, logical consequence, context, rules and assumptions in the study of non-monotonic reasoning, I think we can begin with some considerations about the ideal of perfect validity in logical inference and the pertinence of taking into account human limitations.

Survival often requires being able to process information fast. To withhold our inference until a complete description of the universe is available would be fatal. People continuously infer from information that might even be in principle incapable of completion. In such cases the unreasonable behavior might be not to infer. The reasonable path is to strike a balance between our openness to consider new evidence and seek it, and our need to have provisional conclusions and decisions. A mark of rationality is the ability to revise and bracket our provisional conclusions without stopping making them. So, we need models that incorporate the provisional status of our inferred beliefs. We can even make the normative claim that for an agent with cognitive limitations to be rational, some of its conclusions must be retractable. A model for rationality that does not countenance retractability, a purely monotonic model, fails this norm.

The study of non-monotonic reasoning seems to fly in the face of a traditional ideal of perfect validity in logical inference. Within this ideal there is no justification for taking into account human limitations. Logicality and inferential perfection appear hand in hand. But in reality inferences go in a continuum from the ones that guarantee truth-preservation to the ones that guarantee falsehood-preservation. On the first extreme we have deductive inferences, and probably other non-deductive inferences that are nevertheless a priori, analytic or necessary. On the other extreme we have systematic tendencies to err, biases that produce systematic errors. In the middle we have heuristics

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22 Some authors reserve the term "uncertainty" to talk about numerical errors. I will not make this proviso.

that tend to be better or worse, approaching complete biases on one end and perfect algorithms on the other.

I use a notion of algorithm akin to a recipe that guarantees success if followed properly.[23] This sounds like the usual notion but there are important differences. In the first place, what we call algorithms guarantee success only in the sense that whatever result they reach will be correct, but they do not guarantee that a result will be reached. In the second place, our notion of algorithm comprises more than algorithmic inference. Algorithms can be methods that guarantee success on non-inferential tasks like searching, planning, building or painting by numbers.

Since algorithms do not always involve algorithmic inference, we cannot conflate algorithms with deductive procedures. For the same reason our notion of heuristics does not correspond exactly to non-deductive inferences: there are non-inferential heuristics. On the other hand, we should not claim that all deductive relations can be captured algorithmically (not all of them are procedures), nor that all non-deductive inferences correspond to heuristics. There is no inclusion in either direction between the concepts of algorithmic and deductive inference, nor in either direction between heuristical and non-deductive inference.

Heuristics correspond to the psychological notion of cognitive economy. For a long time it was thought that this could not be formalized because physchological notions are often vague and logical theory is not. But, even when heuristics are vague, a theory of them needs not be so. We can aspire to formalizability. As a matter of fact, there have been for a long time formalisms that take into account the use of non deductive rules. Inductive, probabilistic, abductive and statistical logical systems often try to formalize key non-deductive notions, and do so by more than merely adding some domain specific axioms.

We will illustrate the formalization of non-monotonic reasoning with the example of the CWA: Formalization of non-deductive inference received a big boost in the second half of the XX century with Artificial Intelligence research and with the development of the so-called "Deductive Data Bases". To handle DB queries it was necessary to introduce non-deductive principles like the assumption that the data base had all the pertinent information to answer queries. This so-called Closed World Assumption works as an implicit convention that the information locally available to the system is complete for inferences. CWA generates the inference rule: if p is a ground atom and it is not a logical consequence of a system, infer ~p.

The CWA in Data Base management has a parallel in the human ability to jump to conclusions on the basis of insufficient information, treating it as if it was complete. This form of reasoning from ignorance is often a good strategy, because many facts are so salient that the absence of their report counts as evidence against their occurrence. E. g., you can be reasonably certain that there is no train from Vienna to Mexico City due to the lack of evidence for its existence.

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23 Of course, the guarantee only holds if the procedure was followed to the letter. And, since success is a relation between goal and results, a method might be an algorithm for certain purposes and not an algorithm for others. A series of logically impeccable inferences (e.g., adding big prime numbers) might be rational in some circumstances and not others. For instance, the sieve of Erathostenes is an algorithm to generate prime numbers, but not for generating cryptographic seeds. For simplicity's sake, in this paper I disregard this distinction and talk of algorithms as if each one had a unique standard goal that defines its success.

CWA is an example of non-monotonic inference and has been formalized since the 1970s. Non-monotonicity allows the retraction of a conclusion upon addition of premises, without retracting premises. In some formulations it uses an operator M which tries to covey the idea that something is possible as far as the system knows. It ensures consistency and varies along systems and times like a variable. In Circumscription, an axiom is added to classical logic to produce the effect of CWA: it limits the domain of a predicate, and creates minimal models.

In Default Logic, Reiter proposes that reasoning uses default rules, rules with exceptions which are assumed as valid unless they clash with the evidence. Examples include casual, fuzzy, ideal, inductive, prudential, probabilistic, statistical, prototypical, and pragmatic generalizations.[24] According to Reiter, normal defaults are rules to be read as "if A, and it's consistent to infer B, then infer B". There are other formalizations like Autoepistemic Logic where self-reference is the basis of non-monotonic reasoning and belief revision. A rational agent believes all and only facts based on evidence, following the principle that if P were the case, the epistemic system would know about it. Additional information can block the application of the principle, leading to defeasible consequences.

The moral to extract from this (very incomplete) historical account of formalizations of the CWA is that a non-deductive pattern of reasoning can be formal, rigorous, systematic and logical. Can it be called rational?

The notion of rationality hinges not only in executing certain inferences in certain contexts but also in recognizing the obvious and the relevant inferences in that context. This recognition need not entail the ability to describe them, but it entails the ability to make those inferences. Also, in classical deductive logic all inferences are on a par, as long as consistency and deductive closure are mantained. But part of the rationality of a system is finding the most pertinent and economic rules.

Other things equal, you are more logical (and therefore rational) the better you handle obvious inferences. Of course, "better" is a context -dependent evaluation. But, other things equal, the more rules you master without system degradation in speed or accuracy and the better you apply them in terms of pertinence, strategy, coherence with your goals, complexity of the premises, and economy, the more rational you are.[25]

So, we could expand the notion of logicality in at least three ways. First, to allow for degrees of logicality and to be able to say that, other things equal, a certain inferential behavior or lack of it is more logical than another. For this we can use considerations of obviousness of an inference in a given context, familiarity (to the agent) of the form and/or the content of the inference, etc. We need to consider both the properties of the context and the existence of cognitive limitations.

Secondly, we could expand the notion of logicality by incorporating heuristical inferences and in general non-deductive logical structures.

Thirdly, we could expand the notion of logicality to include non-inferential logical abilities. For instance, the skill to know when to apply the inferential rules, or the ability

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[24] Reiter (1980), p. 124.

[25] The clause "other things equal" is all -important here since probably there will be times when the rationality of two agents will not be comparable. For instance, matters will be complicated by the fact that the inclusion of sets of rules possessed by the agents does not form a linear order.

to inmediately recognize logical truths. E. g., if to infer something we had to infer how to infer (or why) we could never infer anything at all.

I believe this notion of logicality is more in accord with the historical use of the term till the mid XIX century,[26] and it could serve as a bridge concept to explain the relation of logicality both to the thought and action of a limited epistemic agent, and to the demands of rigor and formality.

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[26] In Morado (2000a) I proposed that the notion of logical inference has changed according to perceived needs since Classical Greece.

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