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A neural cognitive model of argumentation with application to legal inference and decision making

Artur S. d'Avila Garcez [a,*], Dov M. Gabbay [b], Luis C. Lamb [c]

[a] *Department of Computer Science, City University London, EC1V 0HB, London, UK*
[b] *Department of Informatics, King's College London, WC2R 2LS, London, UK*
[c] *Institute of Informatics, Federal University of Rio Grande do Sul, Porto Alegre, 91501-970, Brazil*

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ABSTRACT

Formal models of argumentation have been investigated in several areas, from multi-agent systems and artificial intelligence (AI) to decision making, philosophy and law. In artificial intelligence, logic-based models have been the standard for the representation of argumentative reasoning. More recently, the standard logic-based models have been shown equivalent to standard connectionist models. This has created a new line of research where (i) neural networks can be used as a parallel computational model for argumentation and (ii) neural networks can be used to combine argumentation, quantitative reasoning and statistical learning. At the same time, non-standard logic models of argumentation started to emerge. In this paper, we propose a connectionist cognitive model of argumentation that accounts for both standard and non-standard forms of argumentation. The model is shown to be an adequate framework for dealing with standard and non-standard argumentation, including joint-attacks, argument support, ordered attacks, disjunctive attacks, meta-level attacks, self-defeating attacks, argument accrual and uncertainty. We show that the neural cognitive approach offers an adequate way of modelling all of these different aspects of argumentation. We have applied the framework to the modelling of a public prosecution charging decision as part of a real legal decision making case study containing many of the above aspects of argumentation. The results show that the model can be a useful tool in the analysis of legal decision making, including the analysis of what-if questions and the analysis of alternative conclusions. The approach opens up two new perspectives in the short-term: the use of neural networks for computing prevailing arguments efficiently through the propagation in parallel of neuronal activations, and the use of the same networks to evolve the structure of the argumentation network through learning (e.g. to learn the strength of arguments from data).

1. Introduction

Formal models of argumentation have been investigated in several areas, from multi-agent systems and artificial intelligence (AI) to decision making, philosophy and law [4,8,12,17,30,33]. In artificial intelligence,

* Corresponding author.
E-mail addresses: aag@soi.city.ac.uk (A.S. d'Avila Garcez), dg@dcs.kcl.ac.uk (D.M. Gabbay), LuisLamb@acm.org (L.C. Lamb).

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models of argumentation have been used for commonsense reasoning, modelling chains of *defeasible arguments* to reach a conclusion. Such models are mainly founded on logic-based approaches, which have been the standard for the representation of argumentative reasoning in AI [3].

Recent efforts to bridge the gap between logic-based models of argumentation and cognitive models of computation include [10,11,34]. In [10,11], an equivalence is shown between value-based argumentation [2] and standard connectionist networks [22]. This has created a new line of research in argumentation where (i) neural networks can be used as a cognitive computational model for argumentation and (ii) neural networks can be used to combine argumentation, quantitative reasoning and statistical learning. In [34], behavioural data is used to conclude that in human reasoning, reinstatement does not yield a full recovery of the attacked argument; [1] implements the same idea mathematically through equations that resemble the predator–prey dynamics of species populations. Further work integrating logic and neural networks include [20] where clustering in fuzzy ART networks is used to compute prevailing arguments, and [25] which extends the work in [10] to deal with self-defeating arguments and provides a number of interesting examples. At the same time, some non-standard models of argumentation start to emerge, enriching current models with cognitive abilities; e.g. [15] discusses meta-level attacks, coalitions, disjunctive attacks and argument support, [37] provides an adequate semantics for joint attacks, among much else, [29] seeks to unravel the role of emotions in argumentation, [14,23] propose to handle uncertainty in argumentation through the assignment of probabilities and weights to arguments, and [13,26] offer a qualitative method for reasoning about uncertainty and preferences between arguments.

We argue that the adoption of a cognitive approach to argumentation can offer an adequate framework for dealing with both standard and non-standard argumentation models. In this paper, we show that a cognitive approach can model many different aspects of argumentation in a uniform way, in particular, modelling uncertainty in argumentative reasoning and the accrual of arguments. The approach opens up, through the use of a connectionist system, two new short-term perspectives: (i) the use of neural networks to compute prevailing arguments efficiently through the propagation in parallel of neuronal activation signals and (ii) the use of the same networks to evolve the structure of an argumentation network through learning (e.g. to learn the strength of arguments from data). We believe that this approach also opens a more long-term perspective for the research on argumentation: the use of connectionist models of computation to help investigate and evaluate cognitive models of argumentation. For example, ideas from connectionism about the modelling of attention and emotion could be investigated in the context of argumentation [29,36].

Argumentation has also been proposed as a method for helping machine learning systems [27] where an expert's arguments, or the *reasons* for some of the learning examples, are used to guide the search for hypotheses. This is related to the body of work on abductive reasoning and combinations of abduction and inductive logic programming [24,28]. It is said that *the arguments constrain the combinatorial search among possible hypotheses, directing the search towards hypotheses that are more comprehensible in the light of an expert's background knowledge* [27]. We subscribe to this idea. In fact, experimental results on the integration of learning with background knowledge using neural networks have been shown to outperform symbolic and purely-connectionist systems, especially in the presence of noisy data [9]. In this paper, differently from [27], however, learning from data can be used to inform a process of numerical argumentation, allowing different perspectives of human argumentation, including joint attacks, argument support, meta-argumentation and disjunctive attacks, to be modelled in the same framework, as detailed in what follows.

The remainder of the paper is organised as follows. First, we define the concepts of argumentation and neural cognitive models used throughout the paper. Then, we present an algorithm, generalised from [10], which translates standard and non-standard argumentation frameworks into standard connectionist networks. We show that the resulting neural model executes a sound parallel computation of the prevailing arguments according to a number of standard argumentation semantics, and also according to value-based argumentation models [2], abstract dialectical frameworks [5], and other forms of human argumentation. We illustrate the network computation through examples that include joint attacks, support, meta-argumentation and