

# The Importance of Being Neural-Symbolic – A Wilde Position

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## Abstract

We argue that Neural-Symbolic Integration is a topic of central importance for the advancement of Artificial General Intelligence.

## What We Want

Artificial General Intelligence – the quest for artificially created entities with human-like abilities – has been pursued by humanity since the invention of machines. It has also been a driving force in establishing artificial intelligence (AI) as a discipline. 20th century AI, however, has developed into a much narrower direction, focussing more and more on special-purpose and single-method driven solutions for problems which were once (or still are) considered to be challenging, like game playing, speech recognition, natural language understanding, computer vision, cognitive robotics, and many others. 20th century AI can, in our opinion, be perceived as expert system AI, producing and pursuing solutions for specific tasks. We don't say that this is a bad development – quite in contrast, we think that this was (and still is) a very worthwhile adventure with ample (and in some cases well-proven) scope for considerable impact on our society.

The pursuit of Artificial General Intelligence (AGI), however, has been declining in the 20th century, presumably because the original vision of establishing systems with the envisioned capabilities turned out to be much harder to realise than it had seemed in the beginning. But in recent years a rejuvenation of the original ideas has become apparent, driven on the one hand by the insight that certain complex tasks are outside the scope of specialised systems, and on the other hand by rapid developments in the neurosciences based on the invention of substantially refined means of recording and analysing neural activation patterns in the brain. These are accompanied by interdisciplinary efforts within the cognitive science community, including psychologists and linguists with similar visions.

It is apparent that the realisation of AGI requires the cross-disciplinary integration of ideas, methods, and theories. Indeed we believe that disciplines such as (narrow) artificial intelligence, neuroscience, psychol-

ogy, and computational linguistics will have to converge substantially before we can hope to realise human-like artificially intelligent systems. One of the central questions in this pursuit is thus a meta-question: What are concrete lines of research which can be pursued in the immediate future in order to advance in the right direction? The general vision does not give any answers to this, and while it is obvious that we require some grand all-encompassing interdisciplinary theories for AGI, we cannot hope to achieve this in one giant leap. For practical purposes – out of pure necessity since we cannot shred our scientific inheritance – we require the identification of next steps, of particular topics which are narrow enough so that they can be pursued, but general enough so that they can advance us into the right direction.

## What We Propose

Our proposal for such a research direction starts from two obvious observations.

- The physical implementation of our mind is based on the neural system, i.e. on a network of neurons as identified and investigated in the neurosciences. If we hope to achieve Artificial General Intelligence, we cannot expect to ignore this neural or subsymbolic aspect of biological intelligent systems.
- Formal modelling of complex tasks and human thinking is based on symbol manipulation, complex symbolic structures (like graphs, trees, shapes, and grammars) and mathematical logic. At present, there exists no viable alternative to symbolic modelling in order to encode complex tasks.

These two perspectives however – the neural and the symbolic – are substantially orthogonal to each other in terms of the state of the art in the corresponding disciplines. Neural systems are hard if not impossible to understand symbolically. It is quite unclear at present how symbolic processing at large emerges from neural systems. Symbolic knowledge representation and manipulation at the level required for AGI is way outside the scope of current artificial neural approaches.

At the same time humans – using their neural-based brains – are able to deal successfully with symbolic

tasks, to manipulate symbolic formalisms, to represent knowledge using them, and to solve complex problems based on them. So apparently there is a considerable mismatch between human neurophysiology and cognitive capabilities as role models for AGI on the one hand, and theories and computational models for neural systems and symbolic processing on the other hand.

It is our believe that significant progress in AGI requires the unification of neural and symbolic approaches in terms of theories and computational models. We believe that this unification is central for the advancement of AGI. We also believe that the pursuit of this unification is timely and feasible based on the current state of the art, which is what we discuss next.

## Where We Are

We briefly mention some recent developments in neural-symbolic integration which we consider to be of particular importance. For further information on related topics and the state of the art, we recommend to consult (Bader and Hitzler, 2005; Hammer and Hitzler, 2007).

The line of investigation we want to mention takes its starting point from computational models in (narrow) AI and machine learning. It sets out to realise systems based on artificial neural networks which are capable of learning and dealing with symbolic logic. While this can be traced back to the landmark paper (McCulloch and Pitts, 1943) on the relation between propositional logic and binary threshold neural networks, it has been largely dormant until the 1990s, where first neural-symbolic learning systems based on these ideas were realised – see e.g. (Towell and Shavlik, 1994; d’Avila Garcez and Zaverucha, 1999; d’Avila Garcez et al., 2002). While these initial systems were still confined to propositional logics, in recent years systems with similar capabilities based on first-order logic have been realised – see e.g. (Gust et al., 2007; Bader et al., 2008). It is to be noted, however, that these systems – despite the fact that they provide a conceptual breakthrough in symbol processing by artificial neural networks – are still severely limited in their scope and applicability, and improvements in these directions do not appear to be straightforward at all.

Our selection is obviously purely subjective, and there are plenty of other related efforts which could be mentioned. The line of investigation which we presented, however, appears to be typical and representative in that it is driven by computer science, machine learning, or AI perspectives. *We know of no work in the area which is mainly driven by the AGI perspective, and this includes our own achievements on the topic.*<sup>1</sup>

<sup>1</sup>There are some investigations which are driven from a neuroscience perspective, see e.g. (Yang and Shadlen, 2007), but they do not yet cover higher-level cognitive modelling in any reasonable sense.

## Where To Go

We need to advance the state of the art in neural-symbolic integration in order to get closer to the AGI vision. For this, we need to improve on the established approaches in order to find out to what limits they can be pushed. In particular, this requires us to adapt and improve them in order to become functional in cognitive systems application scenarios.

At the same time, however, we also require new ideas borrowed from other disciplines, in order to establish neural-symbolic systems which are driven by the AGI vision. Results from cognitive psychology on particularities of human thinking which are not usually covered by standard logical methods need to be included. Recent paradigms for artificial neural networks which are more strongly inspired from neuroscience – see e.g. (Maass, 2002) – need to be investigated for neural-symbolic integration. On top of this, we require creative new ideas borrowed e.g. from dynamical systems theory or organic computing to further the topic.

The challenges are ahead, and we hope to have conveyed the vital Importance of Being Neural-Symbolic.

## References

- Bader, S. and Hitzler, P. (2005). Dimensions of neural-symbolic integration – a structured survey. In Artemov, S. et al., editors, *We Will Show Them: Essays in Honour of Dov Gabbay*, volume 1, pages 167–194. King’s College Publications, London.
- Bader, S., Hitzler, P., and Hölldobler, S. (2008). Connectionist model generation: A first-order approach. *Neurocomputing*, 71:2420–2432.
- d’Avila Garcez, A., Broda, K., and Gabbay, D. (2002). *Neural-Symbolic Learning Systems — Foundations and Applications*. Springer, Berlin.
- d’Avila Garcez, A. and Zaverucha, G. (1999). The connectionist inductive learning and logic programming system. *Applied Intelligence, Special Issue on Neural networks and Structured Knowledge*, 11(1):59–77.
- Gust, H., Kühnberger, K.-U., and Geibel, P. (2007). Learning models of predicate logical theories with neural networks based on topos theory. In (Hammer and Hitzler, 2007), pages 233–264.
- Hammer, B. and Hitzler, P., editors (2007). *Perspectives of Neural-Symbolic Integration*. Springer, Berlin.
- Maass, W. (2002). Paradigms for computing with spiking neurons. In van Hemmen, J. et al., editors, *Models of Neural Networks*, pages 373–402. Springer.
- McCulloch, W. and Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biophysics*, 5:115–133.
- Towell, G. and Shavlik, J. (1994). Knowledge-based artificial neural networks. *Artificial Intelligence*, 70(1–2):119–165.
- Yang, T. and Shadlen, M. (2007). Probabilistic reasoning by neurons. *nature*, 447:1075–1080.