Can the *g* Factor Play a Role in Artificial General Intelligence Research?

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Abstract. In recent years, a trend in AI research has started to pursue human-level, general artificial intelligence (AGI). Although the AGI framework is characterized by different viewpoints on what intelligence is and how to implement it in artificial systems, it conceptualizes intelligence as flexible, general-purposed, and capable of self-adapting to different contexts and tasks. Two questions remain open: a) should AGI projects simulate the biological, neural, and cognitive mechanisms realising the human intelligent behaviour? and b) what is the relationship, if any, between the concept of general intelligence adopted by AGI and that adopted by psychometricians, i.e., the *g* factor? In this paper, we address these questions and invite researchers in AI to open a discussion on the theoretical conceptions and practical purposes of the AGI approach.

1. INTRODUCTION: THE AGI HYPOTHESIS

The dream of the first generation of AI researchers was to build a computer system capable of displaying a human-like intelligent behaviour in a wide range of domains. Since human intelligence is highly flexible with respect to different tasks, goals, and contexts, making the dream come true would have required developing a general-purpose thinking machine.

In spite of some initial success (e.g., Newell and Simon's General Problem Solver [1]), the attempts of researchers did not result in a domain-general AI. What they achieved was, rather, the development of highly specialised artificial systems that behave intelligently in narrow domains, namely, "narrow AI". These kinds of artificial systems can carry out domain-specific intelligent behaviours in specific contexts and are, thus, unable to self-adapt to changes in the context as general-intelligent systems can do [2-4].

The realisation of a human-level artificial intelligence has seemed unfeasible to many scholars until recent years. However, in the last two decades, the AI community has started to pursue the goal of a human-level artificial general intelligence (AGI). This is attested by several conferences, publications, and projects on human-level intelligence and related topics [4-5]. Although these projects point to many different directions to be followed by AGI research, they represent a new movement towards the concrete realisation of the original dream of a "strong AI".

Two important movements intertwined with AGI emphasize the importance of the simulation of the human mind. The first, known as Biologically Inspired Cognitive Architectures (BICA), aims to integrate many research efforts involved in creating a computational equivalent of the human mind. The second, which has been initially proposed during the First Annual Conference on Advances in Cognitive Systems (Palo Alto, 2012), aims to achieve the goals of the original AI and cognitive science, that is, explaining the mind in computational terms and reproducing the entire range of human cognitive abilities in computational artefacts [3].

As we mentioned, the AGI community understands general intelligence as the ability, displayed by humans, to solve a variety of cogni-

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tive problems in different contexts. Thus, nearly all AGI researchers converge on treating intelligence as a whole: indeed, intelligence appears as a total system of which one cannot conceive one part without bringing in all of it [5-6]. Ben Goertzel [4] delineates the core AGI hypothesis as following: the creation and study of a synthetic intelligence with sufficiently broad scope and strong generalization capability is qualitatively different from the creation and study of a synthetic intelligence with significantly narrower scopes and weaker generalization capability.

What is general intelligence? How can it be implemented in artificial systems? In order to address these questions, it is necessary to open a discussion on both theoretical and practical issues in AGI research.

In this paper, we aim to clarify what relationship exists, if any, between the concept of human general intelligence and the AGI hypothesis. General intelligence was first conceptualised in the early twentieth century within psychometric research. Remarkably, as we shall show, psychometrics is quite a different kind of psychological science than the one traditionally tied to AI, that is, cognitive science. We shall argue that AGI researchers cannot safely rely on the psychometric concept of general intelligence and should, rather, look at intelligence as emerging from several distinct biological and cognitive processes.

In Section 2, we analyse different viewpoints on whether AGI research should emulate or simulate human intelligence. Since many AGI projects are inspired by psychological, neuroscientific, and biological data about human intelligence, scholars in AI should care about the psychometric theory of general intelligence, its promises and perils. In Sections 3 and 4, we summarise the fundamental aspects of such a theory by emphasising the widespread disagreement about the existence of general intelligence. In Section 5, we outline important implications for contemporary research on Artificial General Intelligence.

2. EMULATING OR SIMULATING GENERAL INTELLIGENCE?

Human intelligence is defined by psychometricians as a domain-general cognitive ability, namely, the *g* factor (see Section 3 for further details). Wang and Goertzel [5] have rapidly dismissed any connection between AGI research and the psychometric concept of general intelligence. According to them, projects in AI are not interested in the psychological description of human intelligence, if not in a weak sense.

However, this conclusion seems to be, at best, premature. Indeed, some attempts in AGI research have encompassed a notion of intelligence that should be evaluated through the lenses of empirical findings. Since general intelligence represents to many psychologists, neuroscientists, and geneticists the most important and well-studied aspect of human psychology [7, 8], we cannot see any strong argument against the possible role of the *g* factor in (at least some) research in AGI. Let us see why.

An AGI project can aim to either emulate or simulate human intelligence. In the case of emulation, an artificial system will display a human-like intelligent behaviour regardless of details about its realisation or implementation.[3] In the case of simulation, instead, an artificial system will display general intelligence not only at the behavioural level but also at the mechanistic and processing level. In other words, human-level artificial intelligence is realized by underlying mechanisms which are analogue to those realising human intelligence. The former case likely represents the notion of AGI that Wang and Goertzel [5] have in mind. Our targets are, instead, examples of AGI research characterised by the latter approach.

Before analysing this approach in more details, it is worth considering that whether AGI

[3] Here, behavioural assessments, such as Turing's test and Nilsson's employment test, can address whether we have achieved a human-level artificial intelligence: in brief, systems with true human-level intelligence should be able to perform human-like tasks [9].

projects should emulate or simulate human intelligence, and the relationship between BICA and AGI, are controversial topics. Franklin and colleagues [3, 10] agree that an AGI agent may be successfully developed by using an architecture that is not biologically inspired. However, they argue, the goals of AGI and BICA are essentially equivalent. Indeed, AGI hopes to solve the problem already solved by biological cognition, namely, to generate adaptive behaviour on the basis of sensory input. Since biological minds represent the sole examples of the sort of robust, flexible, systems-level control architectures needed to achieve human-level intelligence, copying after these biological examples—as BICA projects do—represents a valuable strategy.[4]

Wang [11] disagrees with this point of view. According to him, in a broad sense, all AI projects take the human mind as the source of inspiration. Nonetheless, few AI researchers have proposed to duplicate a human cognitive feature without providing a reason why this is needed—consider that computers and human beings are different from each other in many fundamental aspects. Therefore, the important decision for an AGI project is *where* to be similar to the human mind and *why* this similarity is desired.

Our aim is not to take a side in this controversy, but rather to show that some AGI projects are, in fact, inspired by empirical data on human intelligence. Hassabis and colleagues' review [12] provides several examples of how neuroscience has inspired both algorithms and artificial architectures. Moreover, neuroscience seems to be able to provide validation of already existing AI techniques as well: if a known algorithm is found to be implemented in the brain, then this is strong support for its plausibility as an integral component of an intelligent system. In this view, brain studies have helped developing AI architectures by enlightening the functioning of central aspects of intelligence such as learning, attention, and memory.

A dialogue between neuroscience and AI research seems to be largely welcomed within the AGI community. A survey conducted by Muller and Bostrom [13] highlights how, according to many researchers, a human-level AI will likely be achieved by means of research approaches tying AI to neuroscience—e.g., Integrated Cognitive Architectures, Computational Neuroscience, and Whole Brain Emulation. Of course, the commitment to the simulation of psychological, cognitive, and biological aspects of human intelligence is exerted in many ways. Let us see some examples.

Some projects belonging to BICA and AGI's agendas (e.g., SyNAPSE, HTM, SAL, ACT-R, ICARUS, LIDA, the ANNs, the Human Brain Project, and the Large-Scale Brain Simulator) are interested in various aspects of the human general intelligence and accept, though to different degree, that simulating the human brain's structure can be promising for AI research [3, 14-20].

Further, various researchers are inspired by the ontogenetic and phylogenetic aspects of human intelligence and suggest that we should simulate the same facilities for learning that human infants have or the evolutionary trajectory of intelligence [9, 21, 22].

Lastly, Wang [6] suggests that an AGI system may require a single mechanism capable of reproducing the general-purpose, flexibility, and integration of human intelligence. Accordingly, a general intelligent system should comprise both domain-specific and domain-general subsystems: while the existing domain-specific AI techniques are considered tools for solving specific problems, the integrating component is general, flexible, and can run the various domain-specific programs. In the proposed architecture, i.e., the NARS, reasoning, learning, and categorisation represent different aspects of the same processes. This approach, highlighting the relationship between general intelligence and a

[4] For instance, since mind and brain are strictly related, the LIDA's theoretical model proposed by the authors seeks to reproduce it *in silico*.

hypothetic domain-general mechanism, is particularly interesting to us. Indeed, as we shall explain shortly, the psychometric theory of human intelligence draws on similar intuitions.

Is human intelligence related to a single, general cognitive mechanism? How can general intelligence emerge from the complexity of the human brain? To the extent that AGI researchers aim to reproduce human intelligence on a mechanistic and processing level, they should care about these questions, which are typically addressed by empirical research on human intelligence. In the next two sections, we briefly review the psychometric theory of general intelligence and ask whether AGI and BICA projects can safely rely on it.

3. THE THEORY OF HUMAN GENERAL INTELLIGENCE

The concept of general intelligence was born in the early twentieth century, in parallel with the rise of the psychometric tradition. The central aim of psychometricians is to develop methodologies capable of assessing and quantifying intellectual differences among people, i.e., IQ tests. Over the last century, these tests served a variety of purposes, ranging from educational to clinical ones, but they played a central role in empirical research as well (e.g., in behavioural genetics and neuroscience).

The concept of intelligence is generally related to a wide range of psychological aspects and adaptive capabilities (e.g., learning, knowledge, social skills, and creativity; see [23]). By contrast, psychometricians have mainly focused on the cognitive abilities mostly involved in the solutions of the problems included in IQ tests (e.g., mathematical, linguistic, logic, and visual-spatial abilities). Thus, general intelligence represents a theoretical construct related to these cognitive domains.

In order to clarify the nature of general intelligence, psychometricians generally refer to what Charles Spearman [24] called the general factor of intelligence or *g* factor. Remarkably, there are two different ways of understanding *g*: on the one hand, the psychometric *g*; on the other hand, the neurocognitive *g*. Let us see them one by one.

From a psychometric point of view, the *g* factor is related to the so-called positive manifold: individuals who show good performance on a given task will tend to show good performance also in other tasks. In other words, intelligence measurements are positively intercorrelated both in different cognitive domains and different individuals. Spearman understood that scores of a battery of tests tend to load on one major factor regardless of their domain. He employed factor analysis to identify this factor. The *g* factor, as Spearman called it, is a latent variable which summarises the typical correlation matrix of intelligence test scores.

What is the meaning of the psychometric *g*? Factor analysis can be understood as a procedure of "distillation" capable of identifying a factor reflecting the *variance* that different intellectual measures have in common. In this sense, the *g* factor explains ~40 percent of tests' variance. Thus, it reflects *individual differences* in performance in intellectual tasks [7, 25]. This interpretation of *g* can hardly find room in neuroscientific research: indeed, the psychometric *g* does not represent a concrete neurocognitive mechanism in the strict sense, but rather an abstract entity or a property of a population of individuals (see [26] for similar concerns].

From a neurocognitive point of view, the story is different. In neuroscience, the *g* factor is understood as a domain-general cognitive ability that characterises human beings [27]. In this respect, it represents the fundamental mechanism underlying general intelligence. However, the meaning of the neurocognitive *g* is still unclear. When Spearman tried to clarify the nature of intelligence, he described *g* as a form of mental energy. Successive researchers have tried to reduce *g* to some neurocognitive properties of the human brain, e.g., working memory, processing speed, and neural efficiency (see Section 4 for details).

The reliability of the psychometric *g* is generally accepted as the positive manifold represents a stable empirical phenomenon. By contrast, several concerns have been raised on the neurocognitive interpretation of *g*. In recent decades, many neuroscientists have come to represent the central detractors of the concept of general intelligence. Most of them have developed non-generalist conceptions of human intelligence; others have interpreted *g* as a mere statistical artefact. In the next section, we analyse the controversial role of the general factor of intelligence in neuroscientific research.

4. A NEUROSCIENTIFIC VIEW ON THE *g* FACTOR

Is there any evidence of the existence of *g* in the human brain? Is human intelligence general or not? Since psychometrics and cognitive science met a few decades ago, these questions divide scholars for both empirical and theoretical reasons.

From an empirical point of view, the pro-*g* scholars have tried to reduce *g* to neurocognitive constructs, often assumed as reliable and, hence, suitable to make sense of *g* in neuroscientific terms. Associations have been found, for instance, between IQ and processing speed, working memory, problem-solving, meta-cognition, attention, associative learning, glucose metabolic rates, electrocortical activity, and brain size [28-30]. However, to find reliable associations between *g* and these variables has not been easy at all: replicability rates are often low and spurious correlations ubiquitous. Moreover, the associations between *g* and other aspects of the human brain are often considered to be theoretically inconsistent or, at best, weak [31, 32].

From a theoretical point of view, the pro-*g* scholars have developed theories of intelligence aimed at reconciling neuroscientific and psychometric approaches. For instance, the Minimal Cognitive Architecture Theory [33] aims to match the psychometric view with developmental theories of intelligence and with the modular theory of mind. The Parieto-Frontal Integration Theory [30, 34], in turn, aims to locate the *g* factor into the human brain, i.e., in the parietal and frontal regions.

Although these models represent interesting attempts, many scholars believe there is no room for general intelligence in contemporary neuroscience. Indeed, most contemporary theories of intelligence do not include the *g* factor within the human cognitive architecture and do not identify a single general mechanism capable of summarising individual performances as a global test-score such as IQ. Rather, several aspects of biology and cognition are invoked. Renowned examples are the theory of Multiple Intelligences [35], the PASS model [36], and the Multiple Cognitive Mechanisms approach [37]. All these theories appeal to the role of several distinct cognitive processes to explain the human intelligent behaviour.

If there is no a general mechanism such as *g* in the human brain, why then the positive manifold? Some scholars have recently provided valuable explanations of the empirical correlations among IQ-tests performance without invoking a general underlying mechanism. According to these proposals, the psychometric *g* is supported by multiple, interacting mechanisms that become associated with each other throughout the course of development. For instance, the mutualist model, proposed by Van der Maas and colleagues [37], recognises that the positive manifold is a robust empirical phenomenon, but advances an explanation based on a developmental model involving the relationships between cognitive processes. The mutual influence between these processes gives rise to the positive manifold but rules out *g* as a single, latent variable. According to the architects of this model, there is nothing wrong with using the *g* factor as a summary index as long as we do not assume that this variable relates to a single underlying process.[5]

To summarise, cognitive neuroscientists often deny the existence of the neurocognitive *g* and, thus, suggest that general intelligence does not represent a valuable posit for understanding human cognition (see also [38]). The disagreement about the existence of the *g* factor can be clarified by considering the theoretical gap between psychometrics and cognitive science. Since the birth of cognitive psychology, cognitive scientists have focused on the functional-structural segmentation of the human mind. Thus, in a neurocognitive perspective, mental abilities and cognitive processes cannot be considered properties of the brain taken as a whole: rather, they are implemented by specific brain-areas and populations of neurons (for instance, the modularity of mind hypothesis relies on this assumption). This conclusion is sometimes agreed by researchers in AGI as well. For instance, Goertzel [4] has contrasted the conception of general intelligence with approaches looking at the various competencies humans display (see the list of competences assembled at the 2009 AGI Roadmap Workshop [2]).

In the last section, we explore some implications for research in AI.

5. CONCLUSIONS: IMPLICATIONS FOR AI RESEARCH

The quest for the nature of human intelligence, involving its generality and its architecture, remains open. However, it stands to reason that general intelligence cannot be safely understood as a real biological entity. Rather, we can describe it as a behavioural, emergent phenomenon due to the causal interaction between many aspects of the neurocognitive development. Accordingly, intelligence seems to be a term imported by everyday life that clusters together distinct cognitive processes, autonomous to a certain extent both in developmental and evolutionary terms.

What does this imply for AI researchers who adopt a generalist view of intelligence? Two things, at least. First, the generalist conception of intelligence, if adopted in AGI and BICA, threatens to inherit the weaknesses of its relative in the human domain, the psychometric one. Artificial systems inspired by such a theory can well turn out to be less human-oriented than other, classical ones, such as the so-called narrow AI systems. Second, implementing some sort of general-purpose mechanism in artificial systems to emulate the human intelligent behaviour—as Wang [6], among others, suggests—may not be the right strategy.

It is worth noting that, in general, a psychometric-like view of intelligence does not play a central role in AI. Indeed, most contemporary artificial architectures do not assume that a human-level intelligence necessarily requires a single generative mechanism. Rather, intelligence is understood as emerging from many underlying aspects—an interpretation with which, as we have shown, many cognitive neuroscientists agree. At the same time, almost any scholar would agree that the classical narrow approach to AI is unsuccessful in shifting towards a human-level intelligence.

So, what there is between specialised artificial systems and a single domain-general mechanism? Is there any intermediate level to work on? Essentially, these are the questions AGI researchers aim to address (see [14, 39]). In other words, AGI researchers are asked to develop lower-level, specific-purposed systems capable of generating higher-level networks of processes and interactions. These networks would arguably realise general intelligence on the behavioural level. Indeed, intelligence represents a systemic and dynamical property of complex systems.

Unfortunately, even complex cognitive architectures, such as SOAR and ACT-R, are characterised by both technical and epistemological problems (see e.g., [14, 40, 41]). Neurosci-

[5] See [2] for developmental approaches in AGI.

entific theories of intelligence can help AI by providing a meaningful explanation of human neurocognitive development. Nevertheless, taking up the challenge ultimately depends on the ability of AI researchers to pick up the relevant conceptions of what an intelligent system is. In this sense, a discussion on general intelligence in AI seems to us, at present, inevitable.

Can the *g* factor play a role in AGI research, after all? In light of our discussion, the answer can be either positive or negative. Roughly, the answer depends on what the aims of AGI are. A weak or instrumental notion of *g*, like the psychometric *g*, can play a role in AGI projects characterised by an emulative approach, where the goal is reproducing a human-level intelligence regardless of details about its neurocognitive or biological architecture. Here, the psychometric *g*, as assessed by IQ tests, might help to evaluate the intelligent behaviour of artificial systems besides other behavioural tests—e.g., Turing and Nilsson's tests.

By contrast, a strong, neurocognitive notion of *g* is involved in the discussion about the composition of human intelligent systems, the causal interactions among parts, and how to artificially reproduce these aspects. In this respect, the possible role of the *g* factor in AGI research depends on empirical data in neuroscience. As we have argued in this paper, this role of *g* in AI is dubious.

As we noticed, AGI research encompasses different viewpoints on what intelligence is and on what the purposes of a human-level AI are. While many authors in AGI are cautious about their assumptions, others believe it is not enough to merely emulate the intelligent behaviour. Rather, in this view, artificial systems should simulate the mechanisms and processes that make humans intelligent the way they are. For these approaches, where theories and data adopted by cognitive neuroscientists play an important role, we invite cautious about the commitment to the concept of general intelligence. As Goertzel [4] notices, brain sciences are advancing rapidly, but our knowledge about the brain is extremely incomplete. Seemingly, relying on a controversial theory of human intelligence, such as the psychometric one, can be perilous for AI research.

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