From algorithmic thinking to thinking machines

Four theses on the position of artificial intelligence in the history of technoscience

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1. AI and the historical epistemology of science and technology

When analysing the impact of AI on science it would additionally be important to clarify the position of AI in the history of science and technology. Rather than seeing it as a recent phenomenon, this paper aims in fact to contextualise AI as part of the large history of technoscience. It further intends to shed light on the relation of AI to the making of modern science and, in particular, to the paradigms of mechanical, statistical and algorithmic thinking. Right here, at the beginning, we should add an observation that is obvious to historians of science and philosophy, but not as widely supported by computer scientists, namely that the definition of intelligence is always historical: a universal definition of intelligence does not exist and this should be the perspective in which AI should be regarded. For this reason, the intention of writing the history of AI very quickly also turns into the project of a *historical epistemology of intelligence*, in which AI is not only a technical artifact, but also a project based on and affecting the definition and formalisation of human intelligence and knowledge.

In fact this paper would like to suggest to the field of AI studies, the incorporation of the method of *historical epistemology of science and technology*, which has been propagated, in different ways, by Boris Hessen, Henryk Grossmann, George Canguilhem and Gaston Bachelard and more recently by the work of the Max Planck Institute for the History of Science in Berlin and other institutions.[1] What is the approach of the historical epistemology of science and tech-

1 About the historical epistemology of AI, see Pasquinelli 2023; for a critique of social constructivism in technology studies, see Winner 1993; for an overview of historical and

nology? By way of introduction, we could say that while science and technology studies in general emphasize the influence of external factors on science and technology (unfolding different variants of *social constructivism*), historical epistemology on the other hand follows the dialectical interweaving of practice, knowledge and tools within a broader economic and historical dynamic. To paraphrase Boris Hessen's famous study of Newton's mechanics (Hessen 2009 [1931]), it could be said that historical epistemology is concerned with the investigation of the 'economic and social roots' of technoscience.

It should be noted that the method of the historical epistemology of science and technology has been pursued by a large number of historians without using this label. Feminist theorists such as Hilary Rose, Sandra Harding, Evelyn Fox Keller and Silvia Federici, for instance, have contributed to explaining the rise of modern rationality and mechanical thinking (to which AI also belongs) in relation to the transformation of women's bodies and the collective body in general into a productive and docile machine (see e.g., Rose/Rose 1976; Harding 1986; Keller 1985; Federici 2004). This paper attempts to illustrate the paradigm of *algorithmic thinking* at the core of AI in the same way (yet more modestly) in which the different schools of historical, critical, feminist and political epistemology have studied the rise of *mechanical thinking* in the modern age and, more in general, the social and economic genesis of the *abstractions of thought*, such as number, time, and space in the history of human civilisations.[2]

The following paper explores four theses:

I. *AI as the denial of epistemology.* In AI, the identification of machine output with human intelligence has to be questioned: algorithmic thinking has to be separated from material algorithms. In the history of science and technology, usually, the mental model of an artefact is distinguished from the material model, from the technical artefact that implements it.
II. *AI as symbolic representation vs. modelling.* The history of AI is not based on a single definition of intelligence being mechanised, but on competing models of intelligence and competing algorithms. AI algorithms are distinguished, for example, in those that aim at the direct implementation of

political epistemology see Omodeo 2019; Renn 2020; MPIWG 2012; Omodeo/Ienna/Badino 2021; Schmidgen 2011.

2 For mechanical thinking, see Damerow et al. 2004 [1991]; for the notion of number, see chapter 1 in this book and Damerow 2013 [1996]; for the notion of space, see Schemmel 2015.

logic (so-called GOFAI) and those that implement modelling techniques (i.e., artificial neural network, machine learning, etc.).

III. *AI as an experimental artefact.* AI algorithms did not emerge from the top-down application of mathematical ideas but through experimentation. Specifically, machine learning took shape at the confluence of two lineages of technoscience: electro-mechanical engineering and statistics.

IV. *AI as an epistemic scaffolding and meta-paradigm.* Rather than a project to automate intelligence in the abstract, AI should be considered a complex epistemic scaffolding and meta-paradigm in which social, technical, logical and ideological factors have to be constantly analysed in their historical imbrication and unfolding.

2. AI as the denial of epistemology

In the history of human civilization, tools have always emerged together with a system of explicit or less explicit technical knowledge associated with them, which is distinguished from the tools themselves. This aspect seems very confused in the artefacts of AI that are said to directly automate human intelligence. This epistemological dimension (or 'epistemic gap'), that is the obvious *distinction between technical knowledge and tools* exists, of course, also in the recent variant of AI, machine learning, as the distinction between the know-how to program an artificial neural network (e.g., in Python language) and their application (e.g., in image recognition). Yet this distinction seems to be continuously removed from the debate on AI that is fixated on an equation unique to the history of epistemology: machine output = intelligence. The faith in the direct implementation of human reasoning into a machine or an algorithm specifically belongs to the tradition of symbolic AI that has been canonically established in Alan Turing's essay 'Computing Machinery and Intelligence' and the Dartmouth workshop in 1956 in preparation of which McCarthy coined the term 'artificial intelligence' (Turing 1950; McCarthy et al. 2006 [1955]).

Traditionally, epistemology is a meta-reflection on the conditions of intelligent behaviour and knowledge making. It is based on the assumption that thinking is not immediate but *mediated* – by practices, tools, cultural techniques, language, physical properties of the brain, cognitive maps inside and outside the brain, etc. Epistemology is the self-awareness of the hiatus between reason and the medium of reason. When this canonical lesson is brought to the case of AI, an obstacle is perceived, as the main assumption is that AI is the straightforward implementation of intelligence. I would like to define provisionally as 'folk AI' (after the known expression 'folk psychology') the superficial identification of the output of a machine with intelligent behaviour and advance the hypothesis that such denial of the epistemological questions (and epistemology in general as a meta-discourse) has affected not only the scientific definition of AI but also its historiography since the 1950 and even earlier.

Ultimately, it should be noted that the propositional knowledge that symbolic AI aims at automating is not equivalent to scientific and experimental knowledge, that is a full process of knowledge making which is conventionally based on the progressive stages of observation, hypothesis, and testing. In short, back in the 1950s symbolic AI (as most of cybernetics) already represented a *reductionism of scientific mentality* and obliteration of the experimental method, whose consequences are yet to be studied.

Interestingly, it has not been the work of philosophers of mind but the industrial and commercial successes of deep learning in the automation of manual and mental labour which have forced scholars to look back at the history of computation, cybernetics and AI with a different perspective, prompting everyone to rediscover the fundamental difference between symbolic and connectionist AI. Even at this stage of widespread celebration of the powers of AI, the confusion remains: today we call 'artificial intelligence' what was actually the rival paradigm of artificial intelligence in the 1950s, namely artificial neural networks research, or connectionism. This terminological confusion and the current lack of a proper AI historiography is not related to the fact that AI is a novel field (it is at least half a century old), but to the cultural and philosophical hegemony of symbolic AI, which has obscured other readings and interpretations, especially regarding connectionism, statistics and modelling techniques.

3. AI as symbolic representation vs. modelling

Connectionism developed on the basis of different postulates than symbolic AI and it is actually even older. Connectionism was initiated by two historical papers by Warren McCulloch and Walter Pitts ('A Logical Calculus of the Ideas Immanent in Nervous Activity' from 1943 and 'How we know universals the perception of auditory and visual forms' from 1947). The term 'connectionist' itself was introduced by Donald Hebb to describe the organisation of neurons in his

1949 book *The Organization of Behavior*. This book was also crucial for introducing the so-called Hebbian rule of neuroplasticity 'Neurons that fire together, wire together', which would have a deep influence on the history of connectionism and cognitive science. Frank Rosenblatt adopted the term in 1958 to define his theory of artificial neural networks.

In which way is connectionism different from symbolic AI? According to symbolic AI, human thought can be formalised into mathematical or propositional logic, which can be then implemented into a deductive algorithm and successfully mechanised. Connectionism, on the other hand, is not concerned with human thinking per se rather the material processes of the brain that make thinking possible – in particular the functioning of neural networks, which were then seen and formalised as computing networks. According to connectionism, the brain thinks by building models of the world through the self-organisation of its neural networks and this process can be emulated by inductive algorithms and differential equations that describe the parameters of such models.

Folk AI and its specific form of epistemic reductionism should be understood in the background of the confrontation of these two paradigms of intelligence and computing. However, folk AI is not only based on the assumption (inherited from early symbolic AI) that a mechanism can fully implement and automate an act of reasoning, an inference, or rule, but also that a mechanism can implement the *interpretation* of the rule, as Wittgenstein already pointed out in his critique of Turing Machines (Wittgenstein 1958 [1953]: §§ 74, 77–81, 185, 193, 194, 199). According to Wittgenstein, there is a difference between 'mechanically following a rule' and 'following a mechanical rule', while according to symbolic AI, there is none (cf. Shanker 1998: 27–30). The fallacy derives also from the wrong expectation that the externalisation of a model of the mind can *exhaust* the act of modelling itself, while the principle of thinking implies the impossibility of the full identification of mind and world, of internal mental models and external technical models, such as tools, machines and algorithms.

The distinction between a direct logico-symbolic representation of the world and techniques of world modelling always existed in the AI debate, but has never properly come to the fore due to the cultural and academic hegemony of symbolic AI. A key essay from 1988 by Hubert and Stuart Dreyfus elucidated the development of AI according to the two paradigms of 'making the mind' (i.e., symbolic AI) vs. 'modelling the brain' (i.e., connectionism) (Dreyfus/Dreyfus 1988). As known, the project of symbolic AI (together with expert systems and knowledge databases) failed and machine learning gradually emerged from statistical techniques of data modelling pioneered by artificial neural networks. It should be noted that the power of machine learning derives precisely from its capacity to *automate statistical modelling* rather than logico-symbolic intelligence, as the early developers of AI argued.

The key moment in this history and confrontation of paradigms is the invention of the artificial neural network perceptron by Frank Rosenblatt in 1957, which attempted to perform pattern recognition through the automation of statistical tools of multivariable analysis rather than deductive logic (Rosenblatt 1957: 4; Rosenblatt 1958: 405; Rosenblatt 1961; cf. Pasquinelli 2023). The perceptron is considered, by convention, the first artificial neural network, prototype of deep learning and first algorithm of machine learning, yet an epistemological study of its foundation is still missing.[3] Although proceeding from quite different traditions and employing different techniques, both connectionism and statistics represent in fact paradigms and techniques of *modelling*. Avoiding to seek causal explanation, both statistical techniques and artificial neural networks compute models of world data based correlations and factor analysis. Machine learning gradually emerged as a spin-off of the tradition of statistics. Already in 2001, Leo Breiman distinguished the traditional technique of data modelling in statistics from *algorithmic modelling*, calling them the two cultures of statistics.

4. AI as an experimental artefact

The paradigm of connectionism, prototype of the current deep neural networks and large language models, did not emerge from the top-down application of mathematical ideas, but through experimentation, more precisely through building *experimental machines*. Connectionism took shape through the confluence of two lineages of technoscience: the tradition of *electro-mechanical engineering* and statistics. On the one hand, it belongs to the tradition that unfolded from modern mechanics into electro-mechanical engineering and

3 Rosenblatt, for example, was also influenced by the neoliberal economist Friedrich Hayek who published a tractate on connectionism, 'The Sensory Order', in 1952, which was already far more advanced than the definitions of AI that emerged from the 1956 Dartmouth workshop. Following the Austrian philosopher Ernst Mach and Gestalt theory, Hayek sketched the idea that the mind is made by material structures that model the world, rather than ideas that represent the world through propositional knowledge (Pasquinelli 2021).

digital computation (Babbage 1832; Turing 1936; Shannon 1938; von Neumann 1993 [1945]). On the other, it belongs to the controversial tradition of statistics that evolved from eugenics and the biometrics of intelligence (see the history of the IQ test) into the *analysis of multidimensional data* (as Stephen Jay Gould illustrated in his magisterial book *The Mismeasure of Man* from 1981). These two lineages merged together in a precise moment that the history of AI rarely acknowledges, which is Rosenblatt's invention of the artificial neural network perceptron.

The invention of the perceptron demonstrates (once again) the innovation proceeds by the continuous scaffolding of technical and logical paradigms on top of the previous ones, rather than by abrupt breaks and intuitions of solitary geniuses. Neither of these two lineages originated from the *top-down* application of pure mathematics, rather often *bottom-up* on the initiative of engineers, sociologists, psychologists, criminologists, cyberneticians responding to state and industrial drives for social control, information processing, and labour automation.

As just mentioned, multivariable analysis, for instance, originated from psychometric techniques that were part of eugenic and racist campaigns of class discrimination in Europe and North America. On the other hand, automated computation started with the Hollerith machine used to tabulate the punched card of the US census well before the Turing machine (which is perceived as the cornerstone of the information revolution) was conceptualised. Moreover, Thomas Haigh and Mark Priestley (2020) have clarified that the Turing machine did not help the actual design of the digital computer whose implementation von Neumann resolved in a different way.

The history of computation demonstrates once again that technological development drives scientific paradigms, rather than the other way around – also in the case of machine learning *invention predates theorisation*. This history also shows that the evolution of knowledge, techniques and technologies is a gradual implementation, stratification and scaffolding of *mental and technical models* on top of the previous ones. In this respect, AI can be truly illustrated as an *epistemic scaffolding* of social, technological, logical, and ideological forms. In such scaffolding, which is typical for the development of technoscience, (1) economic processes trigger (2) technological experiments and the invention of new machines that require (3) the formalisation of scientific paradigms, which all together influence also (4) mythologies and ideologies (see the cult of thinking automata). There is no deterministic development between levels, rather *each level models and is modelled back by the contiguous levels* in different ways.

5. AI as an epistemic scaffolding and meta-paradigm

The making of AI should be considered part of the general development of modern technoscience: this evolution shows no breaks or phenomena of 'singularity' as folk AI professes. Although it may appear highly 'abstract', 'artificial' and 'autonomous' to some, AI has gradually developed, just like other cultural techniques of humankind. The myth of machine autonomy shows an interesting parallel with intuitionism in mathematics and philosophy of mind and it would be interesting to discover how historians of science have already dealt with this problem. For instance, to contrast the illusion of *a priori* ideas in mathematics and to demonstrate their historical and material origins, the historian of mathematics Peter Damerow (2013 [1996]) proposed to frame the mind's activity as a continuous cycle of internalisation of actions with tools and externalisation of mental models, which is an intuition that this paper attempted to apply to the making of AI.

To explain the formation of the concept of number, then, Damerow suggested a scaffolding of technical and mental models that progressively unfold from *practices of counting* (e.g., reckoning with fingers) to *systems of numeration* (e.g., positional decimal system) to *techniques of computation* (e.g., algorithms) and eventually to *number theory* (e.g., arithmetic as a formal discipline). This process is not linear, but follows alternate movements of *representation* (the use of objects and signs a referent of other objects, signs and ideas) and *abstraction* (problem solving). This process of *reflective abstraction* (inspired by both Piaget's genetic epistemology and Hegel's dialectical logic) constitutes progressive stages of symbolic representation in which the passage from one order of representation to the following occurs via a new abstraction. In this reading, thought starts with labour that invents tools and technologies in order to solve problems mostly of economic and social nature and transform the world accordingly. Subsequently, these tools project new knowledge forms and scientific paradigms. In the Damerow scaffolding, technical and mental models evolved together and stimulated each other in a dialectical way. Tools, machines and algorithms are all forms of *material abstraction*.

The cycle of internalization and externalization of technical and mental models crosses the whole history of human civilisations and also includes advanced technology of automation, such as machine learning. As the historian of science Jürgen Renn has noted:

> After all, machine learning algorithms [..] are simply a new form of the externalization of human thinking, even if they are a particularly intelligent form. As did other external representations before them, such as calculating machines, for example, they partly take over – in a different modality – functions of the human brain. (Renn 2020: 398)

The Damerow scaffolding maintains together, in a consistent and historical way, material actions and mental models, praxis and abstraction and it can be useful to articulate the epistemic scaffolding of AI.

6. Conclusion

At the crossroads of different techniques and disciplines, AI has become one of the most crucial and complex paradigms of the present – a global meta-paradigm (such as the Anthropocene in other respects). Within the global economy, machine learning has become a key paradigm for data analytics, information processing, planning, forecasting and labour automation as much as management automation. Its production pipeline extends from the Global North to the South, involving multitudes of precarious gig workers and also 'ghost workers' (Gray/Suri 2019; Atanasoski/Kalindi 2019). A consistent analysis of contemporary AI requires the political understanding of its global scale and of the complex imbrication of social, technical, logical and ideological forms.

AI has been studied so far by a wide spectrum of AI Studies, which include Computer Science, Science and Technology Studies, Social History, Sociology of Labour and Automation, Semiotics, Philosophy of Mind and Language, Neuroscience, Media Theory, Visual Studies, etc. and in advancing a new methodology of research, we also have to consider the contributions and legacy of all these disciplines. It was in the search for a more comprehensive approach that the contribution of the historical, critical and political epistemology of science and technology has been advanced.

The approach of historical epistemology, however, can be received as a general methodology to syndicate the fields of AI studies and cover the numerous epistemic troubles that haunt AI. In conclusion, we could say that a basic historical epistemology of AI should be pursued according to three lines of inquiry: firstly, the investigation of the social and economic roots of AI (its relation to the current global economy and international division of labour); secondly, the comparison of AI to other knowledge models and forms of mental labour (learning, writing, design, scientific work, etc.) and thirdly, the positioning of AI in the long evolution of knowledge systems (extending the previous cultural techniques, 'information societies' and technologies of civilisation).

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