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JOÃO PONTUAL DE ARRUDA FALCÃO

OPEN ALGORITHMS:
AN INTERDISCIPLINARY INQUIRY OF ARTIFICIAL INTELLIGENCE SYSTEMS

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Tese apresentada ao Programa de Pós-Graduação do Centro de Informática – CIn, da Universidade Federal de Pernambuco – UFPE, como requisito parcial para obtenção do título de doutor em Ciência da Computação, na área de concentração: Engenharia de Software.

Orientadores: Silvio Romero de Lemos Meira

Geber Lisboa Ramalho

Tarcísio Haroldo Cavalcante Pequeno

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João Pontual de Arruda Falcão

“OPEN ALGORITHMS: AN INTERDISCIPLINARY INQUIRY OF ARTIFICIAL INTELLIGENCE SYSTEMS”

Tese de Doutorado apresentada ao Programa de Pós-Graduação em Ciência da Computação da Universidade Federal de Pernambuco, como requisito parcial para a obtenção do título de Doutor em Ciência da Computação. Área de Concentração: Engenharia de Software e Linguagens de Programação.

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To my son, Joaquim Falcão.
He who overwhelms my life with:
joy,
love,
inspiration,
and knowledge.

A Preface, in three quotes:

The world is experiencing an outbreak of artificial intelligence algorithm systems.
(Silvio Meira)[1]

'Artificial Intelligence is not an area of Computer Science.
Artificial Intelligence is the frontier of Computer Science.
The demands of the frontier might cause changes in the body of the building itself.'
(Tarcísio Pequeno)[2]

"The term 'artificial intelligence' is problematic and misleading.
We'd better call them 'algorithm systems."
(Geber Ramalho)[3]

[1] MEIRA, Silvio. Ph.D. Professor Emeritus (UFPE/CIn and CESAR.edu) who pioneered orienting this research toward a pragmatism approach. Available at: https://silvio.meira.com/. Accessed on Dec. 12, 2024.
[2] PEQUENO, Tarcisio. Ph.D. Professor Emeritus (UFC and Unifor) mentioned this quote in a dialogue (02/01/2024). His orientation was paramount to developing our pragmatic algorithm studies approach.
[3] RAMALHO, Geber. Ph.D. Professor and Musician (UFPE/CIn – CESAR) who oriented this inquiry on 'how to apply critical algorithm studies, for real.'

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I thank Cecilia Fortes for her kind attention and warm love. And to my family – especially my mother, Carmen Pontual – for hosting my son and myself in her Olinda and Rio de Janeiro houses during part of this doctoral quest.

My deep gratitude to friends and colleagues who engaged – in one way or many – by giving precious time and knowledge to strengthen my doctoral training, namely Prof. Celso Ribeiro and Prof. Carlos Sávio from UFF-RJ and Prof. Ruben Interian from UNICAMP. Prof. Edleno Moura and Prof. Altigram Soares da Silva from UFAM. Prof. Paulo Adeodato, Prof. Fernando Castor, Prof. Fabio Queda from CIn-UFPE. It also includes some family, friends, and specialists in its area, e.g., Leo Zeba from Nazar.io. Joaquim Falcão from *Academia Brasileira de Letras – ABL,* Prof. Adriano Veloso (UFMG), and his team at Kunumi (www.kunumi.com).

Thank you to the past, present, and future members of CIn/UFPE. As an entrepreneurial academic community, we are helping Brazil advance into the Knowledge Economy and the *Phygital* World.

Lastly, I would like to thank Thaís, Bruno, and Zeza for helping me keep up with personal and professional affairs while going through this enlightening academic experience. Also, I would like to thank my close friends for the affection I have received during these doctoral (and pandemic) experiences. I sincerely appreciate all your love.

Please consider my biases: I am a Brazilian living in Rio de Janeiro with my family. I belong to a research group from the global south based at the Federal University (CIn/UFPE). We are a team deeply connected to Brazilian academia and artificial intelligence research ventures — public and private initiatives. As an alumnus of Harvard Law School, I currently serve as a board member at the Harvard University Alumni Club of Brazil.

ABSTRACT

We live in the “Age of Algorithms,” where algorithms shape human behavior and social structures, influencing power dynamics, financial growth, and how we interact amongst us. This “Algorithm Era” presents opportunities and challenges that must be addressed. Aiming to mitigate algorithms' harmful effects on society, we argue that an inquiry is necessary. Our inquiry revisits and characterizes the classical understanding of algorithms to name them ‘closed algorithms.’ Our research theoretical evidence suggests the emergence of ‘new beasts’ in the realm of algorithm studies, which we are naming ‘open algorithms.’ They require enormous energy capacity, infinite user interactions, massive data available, and cutting-edge hardware and software capabilities, playing a far more active and decisive role in society than ever. The dichotomy between ‘closed’ and ‘open’ algorithms is evident when we compare the classical algorithm system computer science studies for around 100 years with modern AI agents. Open algorithm’s behavior and outputs are challenging to control. It is hard to explain their logic and reasons solely through examining their code (as is a typical approach when dealing with ‘closed algorithms’). This doctoral research designs an inquiry based on open algorithms' epistemology, ontology, and ethics aspects. This raises the following questions: What are these new beasts in the realm of algorithms that we call open algorithms? What makes open algorithms distinct from closed algorithms? What knowledge is necessary to know, recognize, and understand open algorithms? At first, we share our rationale for choosing the terms ‘open’ and ‘closed’ algorithms. Then, we overview state-of-the-art knowledge, seeking to explore the origins and foundations of ‘open algorithms.’ We conduct exploratory dialogues and critical algorithm studies with top-notch specialists from various fields (e.g., computer science, philosophy, political science, engineering, design, sociology, and the Law). With Pragmatism Philosophy lenses, we inquiry open algorithms. The unexpected nature of the object outcomes suggests controllability, scalability, and the knowledge involved in its use are issues to be considered. Some first steps towards grasping open algorithms are understanding their ‘use’ (in loco), their ‘oneness’ (people, process, artifacts), and their constituents (energy, hardware, software, agents, data, interface, and society).

Keywords: Algorithm, Society, Philosophy, Software, Engineering, Machine, Learning, Artificial, Intelligence, LLM, Large, Language, Model, Agent, Computer, Science, Critical, Studies, Ethics, Ontology, Epistemology, Regulation, Law.

FIGURES

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LIST OF ACRONYMS AND ABBREVIATIONS

ACM	Association for Computing Machinery
AI	Artificial Intelligence
CIn/UFPE	Computer Science School, Federal University of Pernambuco (Brazil)
CRISP-DM	The Cross-Industry Standard Process for Data Mining
CS	Computer Science
DL	Deep Learning
EU	European Union
IEEE	The Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LLM	Large Language Models
LM	Language Models
ML	Machine Learning
SDLC	System Development Life Cycle
UFC	Federal University of Ceará
UFMG	Ferderal University of Minas Gerais
UFPE	Federal University of Pernambuco

SUMMARY

The greatest attribute of artificial intelligence is not malice but competence.
A superintelligent AI will be very good at achieving its goals,
And if these are not aligned with ours,
We will have problems.
Stephen Hawking,

1 AN INTRODUCTION FOR BOTH TECHNICAL AND NON-TECHNICAL READERS

This dissertation builds upon the foundational concepts introduced by Alan Turing, whose work in the 1930s was designed for modern computer science and algorithm studies. [4]

This research is focused on advancing algorithms' knowledge from a theoretical perspective. It aims to offer some steps in the direction of a "science of algorithms," an area of research that moves toward a deeper understanding of algorithms' nature, properties, behaviors, and applications.[5]

The notion of a "science of algorithms" aims to unify several disparate areas directly and indirectly related to computer science and algorithms into a cohesive body of knowledge, including human, social, and environmental studies. This will involve formalizing new constructs and establishing methodologies for interdisciplinary analysis of algorithms across different contexts and problem domains.

While this dissertation is rooted in rigorous theoretical, algorithmic analysis, it is not concerned with the philosophical implications of computation. It is a work of computer science grounded in theoretical research aimed at pushing the boundaries of pragmatically understanding algorithms in a socio-technical context.

We seek to lay some groundwork in establishing a "science of algorithms" by building on the legacy of Turing's foundational work while advancing an understanding of algorithms as socio-technical constructs. By focusing on algorithmic studies, this research aims to provide new insights directly applicable to those building algorithms in a broad range of computational fields:

[4] The Turing Institute. Available at: https://www.turing.ac.uk/ Accessed on: Abr. 2nd, 2024.
[5] 'Science of Algorithms' a concept powered by Emeritus Ph.D. Professor Tarcísio Pequeno, from the Federal University of Ceará.

Before entering the world of computers, algorithms were used in math as a step-by-step procedure for solving a problem or accomplishing some end. From a historical point-of-view, the word “algorithm” derives from the Persian mathematician Al-Khwarizmi: Algorithms—the detailed, often repetitive sequences of rules used in mathematical calculations or other problems. Greek mathematicians, for instance, used algorithms to explain their theories: Euclid's algorithm for finding the two greatest divisors of a number is famous. [6] In English, the word ‘algorithm’ was introduced in the nineteenth century and has become increasingly widespread since the 1950s due to commercial computers. [7]

While algorithms are used in different contexts, they are most widely used in computer programming. As we think in this research, algorithms belong to computer science as a field of study. The journey to Computer Science passes through the Entscheidungsproblem (German for "decision problem"), a term from mathematical logic, introduced by mathematician David Hilbert in 1928. It refers to whether an algorithm can determine whether any given mathematical statement is provable within a given formal system. Then, Turing's groundbreaking 1936 paper, "On Computable Numbers, with an Application to the Entscheidungsproblem," (Turing, 1936), introduced the concept of a universal machine (Turing Machine). A theoretical construct capable of performing any mathematical computation. The "Turing machine" became a cornerstone of computational theory, modeling the behavior of algorithms and computations. Turing posited that the Turing machine could tackle any problem solvable by mechanical means, laying the foundation for computer science as a field of study, specifically the study of algorithmic complexity.[8]

Alan Turing (1912-1954) is often regarded as the founding father of artificial intelligence as a research area. His paramount achievements led to the development of the computability theory and the study of the limits of algorithms (what algorithms can compute?). [9] Turing's contributions to computer science extend beyond algorithms' basic concepts and definitions, focusing on their practical applications in solving real-

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[6] NASA Earth Observatory. Available at: https://earthobservatory.nasa.gov/images/91544/how-algorithm-got-its-name Accessed on: Feb. 2nd, 2025.
[7] Algorithm. Definition of algorithm. Merriam-Webster. Available: https://www.merriam-webster.com/dictionary/algorithm
[8] The Church-Turing thesis (or Turing-Church thesis) is a fundamental claim in the theory of computability. It was advanced independently by Church and Turing in the mid 1930s. Available at: https://plato.stanford.edu/entries/church-turing/ Accessed on May 26th, 2024.
[9] The Turing Institute. Available at: https://www.turing.ac.uk/ Accessed on: Abr. 2nd, 2024.

world problems. He viewed algorithms as a sequence of instructions a machine executes, emphasizing their deterministic nature and lack of independent decision-making.[10]

This research title references Newell and Simon's 1976 classical article "Computer Science as Empirical Inquiry: Symbols and Search" (Newell and Simon, 1976). Their thoughts on 'fundamental knowledge' and 'laws of qualitative structure' have inspired us to think critically about the nature and consequences of what we call 'open algorithms' in the contemporary world.

As we present in this research, 'open algorithms' process vast amounts of data to extract meaningful insights and can handle unstructured data such as text, images, and audio. Open algorithms are adaptive and probabilistic, learning from new data and adapting their behavior accordingly. This adaptability contrasts sharply with the rigid, predefined nature of 'closed algorithms.'

The evolution from 'closed algorithms' to 'open algorithms' can be traced back to Alan Turing's foundational question, "Can machines think?" posed in his seminal paper "Computing Machinery and Intelligence" in 1950 (Sommaruga and Strahm, 2015). Turing's ideas set the stage for thinking about machine intelligence in the long run. This dissertation builds on Turing's foundational thoughts, suggesting first steps toward a "science of algorithms."

The early computers of the 1950s were enormous and designed to solve simple problems. As technology progressed, Gordon Moore's research observation (known as 'Moore's Law') predicted the exponential increase in transistor counts on integrated circuits, doubling approximately every 18 months. This exponential growth fueled advances in hardware, software, big data, and now users, paving the way for open algorithms to exist.

1.1 Context and motivation: the rise of algorithms in the world

We live in a New Era based on software (Andreessen, 2021; Albuquerque *et al.*, 2016; Hasselbring, 2018). This New Era is sometimes called the 'Postnormal Era' (Funtowicz, 1999), 'Surveillance Capitalism Era' (Zuboff, 2019), or 'The Knowledge Economy' (Unger, 2019). Overall, it has been widely observed that we live in the 'Age

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[10] Alan Turing. Stanford Encyclopedia of Philosophy. Available at: https://plato.stanford.edu/entries/turing/ Accessed on Mar. 10th, 2024.

of Algorithm’ (Abiteboul, 2020; Beer, 2009) and that algorithms bring to society related advantages and disadvantages that must be addressed.

These referred algorithm studies assume that algorithms can facilitate or hinder human and social progress. The ‘algorithm’ is said to provide truth for modern living and a means to shape our lives. They organize new structures and dynamics of power. Algorithms do not just want to learn what individuals do and enjoy; they also seek to define behaviors and change how we socialize and live our lives. Social media platforms, for example, shape individual behaviors, altering behavioral dynamics. Algorithms also play a central role in people's, companies’, and countries' financial growth. Algorithms exchange and participate in society – an interaction through which we become ‘algorithmic selves’ (Anderson, J. and Rainie, L., 2017). Algorithms are becoming more of a social complex (Aldoseri, Al-khalifa and Hamouda, 2023; Angée *et al*., 2018; Bhatt, Rabbat and Tat, 2020; Cormen *et al*., 2009). The more algorithms are adopted, the more challenges humanity faces (Kissinger, 2019). Algorithms are becoming competent in grasping and composing society’s everyday life in impressive ways, even programming and reprograming themselves multiple times (Turner, 2018).

The kind of algorithm we have known for the last 100 years has evolved and has been transformed into something different, mainly due to big data (Wing, 2019), ubiquitous connections, and scalability effects (Da silva, Lucas and Storozhenko, 2023). Nowadays, when dealing with an issue involving algorithm decision-making, one discovers that facts are uncertain, complexity is the norm, values are in dispute, stakes are high, decisions are urgent, and risks are running out of control (Galliah, 2019; Kitchin, 2017; Lepri *et al*., 2017; Sardar, 2021).

This perspective challenges us to critically examine the power structures underlying computational algorithms worldwide, data extraction, and its implications for social justice, equity, and human rights. Algorithm colonialism, for one, encompasses various sectors and industries, including social media, work surveillance, gig economy, Agtech, Edtech, Health Tech, logistics, and internal corporate data and AI [11], [12].

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[11] BRAZILIAN ACADEMY OF SCIENCES, Brazil. Magna Meeting: Artificial intelligence and the sciences: risks and opportunities. “AI as Myth and Colonial Landgrab”, 2024. Available: https://www.youtube.com/watch?v=zNhuyFinjGk. Accessed on May 07, 2024.

[12] MEJIAS, U. A.; COULDRY, N. Data Grab: The New Colonialism of Big Tech and How to Fight Back. Chicago: The University of Chicago Press, 2024. Available at: https://press.uchicago.edu/ucp/books/book/chicago/D/bo216184200.html. Accessed on May 24th, 2024.

1.2 The object of study: Open Algorithms [13]

In this dissertation, we seek to document the emergence of 'open algorithms' and to study their nature. We present evidence of something new involving modern algorithm systems making decisions for society, especially those systems based on ML and AI techniques.

The rise of OpenAI as a tech company with the launch of Chat-GPT in late 2022 is a milestone. Another milestone is NVIDIA's high-performance graphics processing units (GPUs). On top of that, in early 2025, a Chinese AI startup 'DeepSeek' made an open-source model that rivals updated versions of OpenAI's Chat-GPT.

This category of AI algorithm systems (which we are naming 'open algorithms') seems to differ from the traditional, more classical algorithm systems that computer science has studied for the last 100 years and that society has used for decades (which we are naming 'closed algorithms').

It seems there is a new 'animal' in the realm of algorithms, which we are naming 'open algorithm.' Some evidence and hypotheses leading us to the nature of open algorithms are: The scale of the impact of open algorithms is greater (Da silva, Lucas and Storozhenko, 2023). Open algorithms are more than math, design, and code techniques. They amalgamate energy, code, data, interface, and people (Green and Viljoen, 2020), sometimes generating 'unintended consequences' (Almeida, Filgueiras and Mendonça, 2023):

Open algorithms can benefit humankind, enabling medical, financial, and educational breakthroughs. A significant positive factor in adopting algorithms for decision-making is their capacity to process large amounts of varied data sets, pairing to infer statistical patterns directly from the data (Grady, 2016).

However, open algorithms can also be responsible for many harms (Zimmerman, 2018). They can perpetuate social injustices, be dehumanizing (Noble, 2018), and promote violent behaviors (Hoffmann, 2018).[14] Open algorithms can amplify existing biases (Angwin *et al.*, 2016), leading to discrimination (Barocas and Selbst, 2016) and unequal treatment (Harris, 2019; Harwell, 2019). They can

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[13] During the years from 2021 to 2023, the author had weekly dialogues with Ph.D. Prof. Geber Ramalho and several meetings with Prof. Tarcisio Pequeno, spent uncountable hours discussing and elaborating on what we named "The Open Algorithm."
[14] KRISHNA, 2020. "IBM CEO's Letter to Congress on Racial Justice Reform."

manipulate and control individuals and groups (O'neil, 2017; Onuha, 2022).[15] Open algorithms can exclude citizens from receiving social services (Eubanks, 2018; Obermeyer *et al*., 2019), can help spread hateful ideas (Interian and Ribeiro, 2018), and facilitate government oppression of minorities (Mozur, 2019; Rose, 2019).

Open algorithms bring society challenges on topics such as employment (as certain human occupations will disappear), privacy (citizens leave a digital track and have little control over their data), and automation of decisions (which may be unfair and incomprehensible) (Gasser and Almeida, 2017; Hvistendahl, 2017). For example, 'training data' heavily influences open algorithms: Facial recognition algorithms trained predominantly on white faces may fail to recognize people of color accurately. Similarly, biased security data can lead to racial profiling in open algorithms used by law enforcement. Inconsistent labeling data can also result in open algorithms, such as recruiting tools, unfairly excluding qualified candidates.

Open algorithms have sparked studies and discussions in multiple public[16] and private spheres – governmental, legal, economic, geopolitical, organizational, and individual (Desai and Kroll, 2017). For instance, understanding 'algorithm colonialism' within the broader framework of historical colonialism expands our understanding of algorithms' effects, impacts, and consequences on the geo-political world order. Algorithm colonialism (or 'data colonialism') extends beyond mere technological advancements or economic exploitation and may represent a new form of domination deeply rooted in the historical legacy of colonialism (Miragoli, 2024).

1.3 Research problem: mind the knowledge gap in algorithm studies

As an analogy to our research quest, we seize Marco Polo's narrative documenting the unique fauna he encountered along the Silk Road during the late 13th and early 14th centuries.[17] Polo's descriptions of animals he was seeing for the first time provide a fascinating glimpse into the perceptions of an explorer discovering a

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[15] GILLESPIE AND SEAVER, 2020. Reading list of critical algorithm studies powered by The Social Media Collective (SMC), a network of social science and humanistic researchers of the Microsoft Research labs in New England and New York, "Critical Algorithm Studies: A Reading List," Jan. 2020. Available: https://socialmediacollective.org/reading-lists/critical-algorithm-studies/#0.1. Accessed on Jun. 29th, 2024.

[16] "AI Opportunities Action Plan." Presented to UK Parliament by the Secretary of State for Science, Innovation and Technology by Command of His Majesty. January 2025.

[17] "The Travels of Marco Polo". The Complete Yule-Cordier Edition.
Including the unabridged third edition (1903) of Henry Yule's annotated translation, as revised by Henri Cordier; together with Cordier's later volume of notes and addenda (1920). Available at: https://www.gutenberg.org/files/10636/10636-h/10636-h.htm#i116 Accessed on: January 20th, 2024.

diverse variety of wildlife. He described crocodiles as loathsome creatures with big mouths. He wrote about seeing enormous, ugly specimens of pigs with a single horn.

These vivid images highlight his fascination and horror at seeing an unknown 'animal.' In his inquiry, Polo noted the natives' methods for capturing crocodiles, detailing a particularly cruel trap involving a hidden blade. This account not only illustrates the animal's physicality but also underscores the practical knowledge of the indigenous people regarding their environment.[18] Enlightened by Polo's narrative, our inquiry asks foundational questions about these 'new beasts' in the realm of algorithm studies: How could we understand, describe, and accept open algorithms?

We argue that the distinction between "open" and "closed" algorithms is not simply a matter of syntax and semantics. It has profound implications for how algorithms are built, managed, and understood. Recognizing open algorithms is crucial for developing practical solutions for society's betterment. If open algorithms do exist, we see a 'knowledge gap' in computer science related to them. Our critical perspective recognizes that computer science and algorithm studies have knowledge gaps about open algorithms: lack of language, constructs, and criteria to deal with open algorithms. For instance, the field lacks criteria to measure the success and failure of open algorithms' effects, impacts, and consequences worldwide. (Angwin and Larson, 2016; Piovesan, 2018; Unger, 2021).

If open algorithms do exist and are different from closed algorithms, computer science should be able to investigate and understand them. The knowledge gap exists in the following questions: What are open algorithms? How do you describe them? How should they be characterized? What makes it different from what we know about algorithms so far about closed algorithms?

We use interdisciplinary tools to help us frame the knowledge gap related to open algorithms. Our inquiries seek to understand the implications and challenges of studying open algorithms from a theoretical perspective. We have used our reason, our senses, the testimony and experience of others, and other knowledge resources to gather pieces of evidence that could justify such an inquiry about open algorithms. By interrogating the extent of our knowledge about open algorithms and the limitations of their use, we aim to gain a clearer understanding of them.

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[18] BRESSANIN, A. "The Travels of Marco Polo: The true story of a 14th-Century bestseller." BBC, January 2024. Available at: https://bbc.com/travel/article/20240107-the-travels-of-marco-polo-the-true-story-of-a-14th-century-bestseller Accessed on: January 20th, 2025.

When applying this research's findings into practice, we see the following possible externalities becoming true: (a) *In education* – we expect to encourage computer science schools, professors, and students (especially those who love algorithm studies) to undergo more human, social, and environmental courses. (b) *In algorithm building* – we expect more human, social, and ecological specialists to participate in creating, developing, deploying, maintaining, and evolving open algorithms. (c*) In stakeholder's responsibility* – we expect to help identify the facts (people, artifacts, and processes) involved with open algorithms and map their chain of responsibility. (d) *In risk management* – we expect to offer an approach to assess algorithms based on their use and a good understanding of their practical effects, impacts, and consequences on people, groups, and communities. (e) *In governance and compliance* – when moving open algorithms from the lab to the world, we expect to offer some guidelines to help comply with auditing and judging open algorithms. (f) *In law and regulation*, we expect to help national and international public policymakers and regulatory strategists deal with open algorithms in society.

1.4 Research method: mixed-method approach

Based on ontological, epistemological, and ethical questions, our inquiry is an analysis to break open algorithms' nature into the elements necessary to understand them. We use philosophy to help us investigate how much we know (or don't know) about open algorithms.

This research selects and integrates different methods: Historical studies helped determine where open algorithms' nature has originated. Current online media cover and dialogues with experts allow us to see what open algorithms have become today. Questions and more conversations with experts helped us explore what open algorithms can become next – without such a transforming imagination, we believe one cannot understand open algorithms as is. One is just recording and describing in retrospect.

We have structured our mixed-method approach in distinct stages to provide a clear path. The narrative builds on the previous stage to structure this theoretical interdisciplinary exploratory study (see annex 'The Journey and Research Methods').

At first, we engaged in non-structured dialogues with experts; we assessed historical facts and used philosophical tools to help us design multi-dimensional questions to open algorithms. At this stage, dynamic feedback loops were essential for creating and evolving while remaining responsive to new insights and developments. These loops allowed our research to identify and illustrate the ‘knowledge gap’ on open algorithms and to design ‘knowledge bridges’ to fill that gap. This dissertation is the result of each stage. The findings seem intellectually rigorous and socially relevant.

1.5 Research questions and hypothesis: an inquiry into open algorithms

We seek to traverse the knowledge landscape of past and present attempts to advance the nature of open algorithms. Our proposed investigation is based on three questions. Together, they represent new frontiers in critical studies of the nature of algorithms, encompassing many knowledge dimensions beyond the classical and traditional approach computer science studies usually take.

New ‘beasts’ in the realm of algorithms have become this research hypothesis (Ground Zero). From there, we design a well-structured inquiry into the nature of ‘open algorithms’ ontological (Question #1) and epistemological (Question #2) aspects.

Ground Zero – Is there evidence suggesting the emergence and existence of new algorithm systems that justify a theoretical doctoral research inquiry?

Hypothesis Zero: We see enough evidence of new knowledge frontiers related to open algorithms to justify this interdisciplinary inquiry. We found evidence suggesting that open algorithms are different from closed algorithms. Open algorithms are more uncontrollable and adaptive than closed algorithms. Open algorithms involve many more stakeholders in their production processes, and their chain of responsibility is much more complex than closed algorithms.

Question #1 – What are open algorithms?

Hypothesis #1 – Like closed algorithms, open algorithms have at least two phases and multiple stages throughout their lifecycle. First, they are created in the laboratory ‘in vitro,’ viewed as a formula inside the machine in a controlled environment. This is like in vitro fertilization, a formula in a test tube, a culture dish, or a living organism inside a controlled environment. Second, they go out into the wild world, touching the ground of reality and embracing many of society’s problems. The algorithm then makes decisions outside the lab into the real world.

Our pragmatism approach to understanding open algorithms seeks to delimit where they start and end. We may delimit the combination of all multiple systems constituting an open algorithm from the facts related to their use. Open algorithms ‘in use’ may be considered a system made from a combination of many other systems that form what we call ‘algorithms’ oneness:’ An approach to point out knowledge layers that constitute open algorithms' unity. Such knowledge layers we call: energy, hardware, software, agents, data, interfaces, and society.

Question #2 - What knowledge is needed to know and understand open algorithms?

Hypothesis #2 – We elaborate on the knowledge needed to understand open algorithms and their differences from closed algorithms. This research expands the knowledge perspective on critical algorithm studies to add knowledge from adjacent disciplines, expanding the knowledge needed to know and understand open algorithms. Our pragmatism approach assesses open algorithms while in use. Such an approach helps determine what knowledge is required to know and understand open algorithms. Knowing and understanding open algorithms depends on their use (e.g., in a hospital, bank, court, school, government, etc.) and their related facts, impacts, and consequences to society. As such, open algorithms, as a computer science subject, should expand their foundational knowledge beyond mathematics, logic, physics, statistics, engineering, and design to gain foundational knowledge from human, social, and environmental studies.

* * * *

A final remark before we dive deeper into our research. Between 2020 and 2024, we have presented, debated, and evolved this research’s ideas, arguments, and findings on myriad occasions (i.e., lectures, seminars, and panels). The moment in which this research quest gained track was on September 9, 2021, when we submitted an article explaining our thoughts on Algorithm Pragmatism to ‘IEEE ISTAS21 Technological Stewardship and Responsible Innovation’. The article was selected and presented at the end of 2021 and then published in early 2022, entitled ‘Algorithmic Pragmatism: First Steps.’

Everything you can imagine is real.
Pablo Picasso.

2 THE OBJECT OF STUDY: OPEN ALGORITHMS

This chapter identifies a new beast in the realm of algorithms. We explain the rationale that led us to choose the terminology of "closed" and "open" algorithms to represent – perhaps – a new paradigm in algorithm studies. We share below where our imagination passed through to refine support argumentation and help build the first steps towards characterizing open algorithms and their significance in today's world.[19]

2.1 Is there a new 'beast' in the realm of algorithms?

There might be new beasts in algorithm studies. Suppose we take a naturalism philosophical approach to algorithm studies. Naturalism assumes that nature is fundamentally knowable and governed by regularity, unity, and objective laws. Without these laws, scientific inquiry would be meaningless. Humanity's constant quest for concrete evidence to support its beliefs is seen as a reaffirmation of the naturalistic method. Even when one scientific theory is abandoned in favor of another, humans do not despair of knowing nature, nor do we repudiate the "natural method" in his search for truth. Theories change; methodology does not. [20]

A naturalistic observation serves as the basis for this research investigation towards essential studies of algorithms. We assume multiple views of reality are influenced by the social context and environment in which a situation is viewed.[21] Our naturalistic observation involves observing algorithm systems in their natural habitat. It is a form of qualitative research that focuses on collecting, evaluating, and describing non-numerical data. To illustrate our naturalistic approach, we draw an analogy with Marco Polo's narrative of his adventures, as well as vernacular didactic literature, of which the Middle Ages offer many examples. [22]

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[19] This chapter was elaborated based on tens of conversations between the author and myriad experts, including the two emeritus professors and one senior professor orienting this research, as well as two other professors, part of this research doctoral qualifying board.

[20] Britannica, T. Editors of Encyclopedia. "Naturalism." Encyclopedia Britannica, December 24, 2024. https://www.britannica.com/topic/naturalism-philosophy.

[21] Kent, Michael. "Naturalistic approach." In The Oxford Dictionary of Sports Science & Medicine.: Oxford University Press, 2006. Available at: https://www.oxfordreference.com/view/10.1093/acref/9780198568506.001.0001/acref-9780198568506-e-4617. Acessed on Dec. 10th, 2024.

[22] Maraini, F. and Peters, Edward. "Marco Polo." Encyclopedia Britannica, January 4, 2025. Available at: https://www.britannica.com/biography/Marco-Polo. Accessed on Dec. 12th, 2024.

Polo's journey along the Silk Road was a path that led him to encounter a rich and diverse world of animals previously unknown to Europeans. As Polo traversed through Persia, Central Asia, and China, he marveled at creatures he saw for the first time (‘new beasts’). Marco Polo’s descriptions of these animals were filled with awe and reflected his curiosity and trepidation toward what he was seeing and experiencing for the first time. Polo encountered various animals that challenged his understanding of the world. We explore the world of algorithms, and similarly, we encounter algorithms that challenge our understanding and might represent new paradigms.

One of Polo's most striking encounters was with the rhinoceros, which he described as a "monster," a giant, thick-skinned beast with a single horn. The rhinoceros was unknown and awe-inspiring to European audiences, much like the emergence of ML and AI algorithm systems (e.g., Gemini, Chat-GPT, Llama). Polo's vivid description captures the essence of encountering something fundamentally different, its physical presence imposing and mysterious. In the same way, some algorithms can appear massive, powerful, and opaque simultaneously. Society is still grappling with understanding the implications and capabilities of those algorithms (new beasts), fearing their unknown potential while being fascinated by their possibilities.

The tiger Marco Polo describes it as a powerful, ferocious creature with sharp claws capable of piercing armor, graceful in its potential, and dangerous in its power. Yet, the tiger’s power should not be underestimated. Like the tiger, some algorithms can perform complex tasks with remarkable efficiency, displaying grace in their calculations, data analysis, and problem-solving capabilities. However, algorithm systems can disrupt industries, politics, societies, war, etc. These systems can be a tool for immense progress, but their ferocity — if misused or unchecked — can also lead to uncontrollable consequences (Almeida *et al.*, 2023). Polo’s fascination with the tiger’s grace and strength might mirror society's simultaneous admiration and fear of the capabilities of modern algorithm systems, especially those based on ML and AI techniques (e.g., Chat-GPT).

Another ‘beast’ described by Marco Polo, the elephant, was a creature of intelligence and utility. Employed in warfare and labor, elephants served both practical and symbolic purposes in the Mongol Empire. Some algorithms, if we may say, are more than just powerful tools, but agents capable of executing various tasks humankind themselves cannot. The elephant’s role in battle or agriculture inspires our investigation, e.g.: how are algorithms employed in warfare and labor? Just as Polo marveled at the elephant's capacity for strength and intelligence, we are also coming to terms with algorithms expanding roles across various sectors, recognizing its potential and challenges. As elephants did in the past, algorithms can serve diverse social functions, from autonomous vehicles to medical diagnoses.

Another beast that caught Polo's admiration was the peafowl, due to its vibrant colors and symbolic importance in Eastern cultures. Just as the peafowl captivated Polo's imagination with its beauty and symbolism, some algorithms evoke a similar fascination, particularly in their applications in art, design, and entertainment. These systems generate artworks to music compositions representing a new frontier in creativity, sparking wonder and reflection.

Another beast in Polo's encounter was the baboons, described as solid and challenging to control. Just as the baboons' strength can be dangerous to those who fail to understand their behavior, some systems — particularly those involving ML and AI models — often operate in opaque and not easily controlled ways; algorithms' power can be misused. This analogy illustrates our point of view. Having Polo's narrative in mind, we ask: How can we recognize something we haven't ever seen before? How to understand it? How to describe it? Which knowledge and linguistics should be used?

2.2 Preliminary Evidence

There are new beasts in the realm of algorithms. These new beasts seem to be something we know already... but they are different. They resemble to be algorithm systems. But if they are algorithm systems, they are other kinds of them, different from what society is used to. Sometimes, these new beasts seem to be something unique; something never seen before.

Inspired by Marco Polo's narrative, we called it the 'new beast'. This research concerns the emergence of such a new beast in algorithm studies (one we call an 'open algorithm system'). Such a new beast seems fundamentally different from what computer science and algorithm studies have focused on so far…

We are used to algorithms developed, tested, and understood within controlled and somewhat isolated environments. Those algorithms' behaviors are determined by their 'closed' code without external interference. Neither the user nor the context can interfere and change the system's code. These "closed algorithms" are historically the norm in computational systems. Computer science has approximately 100 years of studies related to them. We call them simply "closed algorithms." Closed algorithms, as a term, refers to systems operating in a controlled environment where the inputs and outputs are somewhat fixed, and the code determines the system's behavior. One reads the code; one understands the system.

Closed algorithms, as we refer to, originated in mathematics, physics, logic, and statistics. Initially grounded in these areas, their evolution has progressively incorporated elements from engineering, architecture, and design techniques. Throughout this research, every time we print 'closed algorithms,' we mean 100 years of algorithm studies primarily considering systems you understand the output by simply looking at the algorithm's code. They are "closed" because their inputs, processes, and outputs are all well-defined and fixed. They operate with a more transparent and controllable input-output relationship. This makes them relatively stable, giving engineers and developers confidence in their outcomes. They behave in a theoretical or idealized environment, where every aspect is somewhat controllable and doesn't account for the complexity of on-time, onsite, real-life, human, social, and environmental influence.

Open algorithms seem different. It might represent a significant departure from the closed structure. Algorithm systems have evolved, incorporating different characteristics and diverse knowledge beyond their foundation in mathematics:

> "We now know that groups of neurons create new connections and pathways among themselves every time we acquire a new skill. Computer scientists use the term "open architecture" to describe a system that is versatile enough to change—or rearrange—to accommodate the varying demands on it. Within the constraints of our genetic legacy, our brain presents a beautiful example of open architecture." [23]

Open algorithms operate, evolve, and adapt throughout dynamic, real-world environments. Their behavior is influenced by interactions with the world (users and data), making the open algorithm less controllable and more integrated with societal contexts. The term "open" emphasizes that these algorithms are not confined to a theoretical space but operate openly, adapting to on-time, onsite, real-life, human, social, and environmental conditions. If something, open algorithms seem more adaptive than closed ones. This contextual fluidity makes these algorithms less

[23] Excerpt from: Wolf, Maryanne. Proust and the Squid: The Story and Science of the Reading Brain Unabridged., HighBridge, 2008.

controllable and more adaptive. Since the system doesn't operate in a predefined, isolated space, the term "open" effectively conveys its complexity and uncertainty.

The term "open" also signals a shift in approaching algorithm development and governance. Open algorithms making decisions in the world often have broad societal implications, especially when intersecting with human behaviors, social dynamics, and political systems. Open algorithms' behavior may vary depending on how they interact with human, social, and natural worlds. Their outcomes may provoke unintended consequences (Almeida *et al*., 2023) Open algorithms seem not to be merely mathematical constructs. They require a more interdisciplinary approach involving human, social, and environmental studies. May we wonder, for the sake of it, the following: If 'closed algorithms' are considered 'artifacts,' should we understand 'open algorithms' as a phenomenon?

The terminology helps us signal to researchers, practitioners, and policymakers that open algorithms should be approached with new strategies and interdisciplinary collaboration. Distinguishing "open" from "closed" systems underscores the need for new methodologies, tools, and processes for dealing with the 'new beast in the realm of algorithm studies.'

The social impact of open algorithms further justifies their distinction from closed systems. While closed algorithms may be confined to narrower, more controllable applications, open ones can scale and act autonomously, influencing politics, economics, and culture overnight – spreading uncontrollability across society. We emphasize that the choice of "open" and "closed" was deliberate to reflect critical differences between them. The terms were selected because they succinctly capture their key operational differences. But please remember those differences are not diametrically opposed. The closed algorithm is somewhat intertwined in the amalgam of people, processes, artifacts, and nature that open algorithms represent.

2.3 Inside the lab and in the world

We see both open and closed algorithms having at least two stages in their lifecycles: One inside the laboratory, the other in the world. Both to exist, is built inside the lab (e.g. in a University, in a garage in California, in a co-working place somewhere) and then plugged into the world.

Their lifecycle has — at least — two stages (in the lab and in the world). But their experience throughout such lifecycles seems different. The scrutiny, tests, and explanations we expect open algorithms to go through in the lab and in the world seem more intense than the classical procedures of closed algorithms have been through so far.

Experts[24] building closed algorithms, for instance, focus on specification, design, and development powered by methodologies such as the ‘Software Development Life Cycle’ (SDLC) (Ruban, 2021). Closed algorithms can be handled with relatively straightforward testing and debugging procedures within controlled environments. With Chat-GPT and other AI initiatives, we have noticed something different. Open algorithms are usually opaque systems requiring innovative development, monitoring, and ethical evaluation frameworks.

Imagine an algorithm system as a child. Imagine such a child learning physical education in high school. Let’s consider that high school is the lab, a controlled and safe environment. Such a child is exposed to a preapproved closed physical program. Now, imagine another child being physically educated to become an Olympic athlete. The child willing to become an Olympic champion must undergo a more intense, complex, and focused process. In such an analogy, both children undergo a lab stage, forged according to their mission, before entering the world. However, their building process inside and outside the lab is quite different.

In the analogy, our object of study, the open algorithm, is the child being built to become an Olympic athlete competing worldwide. Open algorithms are more powerful; they make decisions that affect society in a way that seems similar to but, in essence, differs from everything we have known so far. Perhaps, a new paradigm emerges in algorithm studies. We try to represent such a paradigm using the terminology ‘closed’ and ‘open’ algorithm systems – this dissertation explores such a dichotomy in algorithm studies.

An open algorithm lifecycle can be explained based on a general comparison with vaccines’ lifecycle. The vaccine lifecycle has a stage “in the lab” and another “in the world.” The pharmaceutical company[25] – after sequencing the DNA of the coronavirus – synthesized the vaccine in 24 hours, with “in vitro” tests. Then, it took

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[24] Stakeholders: Company Owner, Project Sponsor, Programmer, Data supplier, Database designer, Database developer, Data engineering (data preparation), Science engineer (ML modeling), Product owner, Project manager, QA, UX designer.

[25] World Health Organization. “The Moderna COVID-19 (mRNA-1273) Vaccine: What You Need to Know”. August, 2022.

much more time to start vaccinating people “in the world” because they had to do many controlled tests before releasing the product. Pharmaceutical companies spent months testing their vaccines on controlled people, groups, and communities. Only afterward was the population vaccinated for real – and still, there are many issues related to the vaccines being tested.

The question is: Why are we careful with vaccines and not with algorithms? There are numerous procedures and tests to release vaccines, whereas open algorithm, in turn, require no specific process. Our theoretical inquiry seeks to ensure that algorithms used outside the lab are technically sound, morally acceptable, and aligned with human, social, and environmental values.

Consider the ‘inside the lab’ phase necessary before launching the algorithm into society. There is no approval process for launching an open algorithm into society, regardless of its impacts and consequences on people, groups, and communities. The story goes like this: A computer programmer finishes implementing an open algorithm, tests its correctness and accuracy inside the lab, and then "plugs” the system into society – launching an open algorithm in society is as simple as that.

2.4 From the perspective of other disciplines and concepts

From Biology, Sociology, Philosophy, and other disciplines and concepts, we have discussed the existence of this paradigm in algorithm studies: One, the closed algorithm, is well known. The other, the open algorithm, is the New Beast. Below, we explore a list of terms discussed in this research investigation to explain the rationale, intellectual journey, and naming choices we made. These ideas were explored, ultimately leading us to choose ‘closed’ and ‘open’ algorithms as the most fitting terms to describe what we see as, perhaps, a new paradigm in algorithm studies:

Table 1 - Clinical Algorithm Pragmatism

A REFLECTION ON ALGORITHMS POSSIBLE TERMS	
CLOSED	**OPEN**
<u>In Vitro</u> In an artificial environment	<u>In Vivo</u> Functioning within the living, real-world environment.
<u>Controlled Environment</u> Emphasizing the setting it operates.	<u>Field-Deployed</u> Highlighting evolution in the field.
<u>Simulacrum</u> Resembling the actual environment.	<u>Clinical Trials</u> Highlighting active engagement
<u>In Fabula</u> A world that only exists in the developer's imagination	<u>In Mundo</u> Interacts with the world.
<u>Abstract</u> A conceptual model, not the real-world complexities.	<u>Pragmatic</u> The use, its practical application, and adaptation.
<u>Theoretical</u> Focusing on the conceptual aspects	<u>Empirical Algorithm</u> Meaning tries and error, engaging and experiencing conditions.

Source: Own authorship (2024).

Finally, “open algorithm” should not be confused with “open source,” as they represent distinct concepts. In short, “open source” refers to software with code available for inspection, modification, and redistribution. [26]

[26] Rodrigo Ferreira, a lawyer at Brazilian Mint (“Casa da Moeda do Brasil”), highlighted this distinction and criticized the potential misinterpretation of these terms.

Imagination is more important than knowledge.
Knowledge is limited. Imagination encircles the world.
Albert Einstein, 1929.

3 RESEARCH PROBLEM: EVIDENCE OF A KNOWLEDGE GAP

3.1 What do we know – and don't know – about the new 'beasts'?

If 'open algorithms' are our object of study, our research problem is that computer science doesn't know much about them. There lies a knowledge gap in algorithm studies. In this topic, we identify such a 'knowledge gap' by asking: How much do we know (or don't know) about open algorithms and their effects, impacts, and consequences on people, groups, and communities worldwide?

At first, we represent such a 'knowledge gap' that exists specifically in algorithm studies directly related to open algorithms with sets of ontological, epistemological and ethical questions. Together, these questions frame the referred 'knowledge gap'.

Our *ontological inquiry* investigates the ever-changing nature and relations of open algorithm. Such an ontological inquiry may provide terms, categories, and vocabulary systems for open algorithms (perhaps, limiting complexity and organizing data into knowledge).

1. What constitutes an open algorithm?
2. What objects, processes, and people are in open algorithms?
3. To what extent are open algorithms different from closed ones?
4. What constitutes one, and what constitutes the other?
5. What are the relationships involved in open algorithms?
6. Who are the stakeholders involved in an open algorithm?
7. Are open algorithms as controllable and predictable as closed ones?
8. If not, how so?
9. Are open algorithms artifacts or phenomena?

The *epistemological inquiry* seeks to expand our understanding of the open algorithm towards a new knowledge frontier. An epistemological inquiry helps us increase our knowledge of open algorithms by bringing up existing disciplines related to the subject matter (e.g., philosophy of technology, the sciences of the artificial, and linguistics).

1. What does Computer Science know about open algorithms?
2. What is the nature of open algorithms' knowledge?

3. How do you acquire knowledge from open algorithms?
4. How sure is an open algorithm about a particular understanding?
5. How much can we trust an open algorithm?
6. Which mechanisms can help understand open algorithm decisions?
7. How do closed and open algorithms differ from one another?
8. What should computer scientists know about open algorithms?
9. And how to acquire such knowledge?
10. Are some things related to open algorithms unknowable?

In this chapter, we bring real case scenarios to materialize such a ‘knowledge gap’. We pinpoint examples of: (a) society’s lack of constructs to deal with open algorithms, (b) society’s lack of successful criteria to manage open algorithms, and (c) lack of procedures to launch open algorithms in the world. We have elaborated these three scenarios to illustrate and frame the referred lack of knowledge in computer science when dealing with open algorithms making decisions in society.

3.2 Lack of constructs to deal with open algorithms

‘Constructs’ is an epistemological tool for someone in science to define things. ‘Construct,’ a common word, is used in everyday language. However, ‘construct’ needs a clear definition and an empirical basis to become a scientific construct (Asendorpf, 2004). In science, construct designates a theoretical concept that is not directly observable. A “construct” is an “ideal object” whose existence depends on a subject’s mind. Examples of constructs are designated by the sign “3” or the words “personality,” “love,” and “fear.” In contrast, biologists, foxes, philosophers, rocks, computers, and pencils, among many others, are not constructs but real objects (or real things), those whose existence is non-dependent on a subject’s mind (Bunge, 1974; Edwards, 1967).

One way to characterize this knowledge gap and frame the lack of *knowledge constructs* associated with open algorithms is the study of social polarization [27] caused by recommendation systems used by social media networks. (Interian; Ribeiro, 2018). In such a context, accuracy is measured as a technical construct related to closed algorithms. Accuracy refers to how close a measurement is to the true or accepted

[27] Polarization on Social Media. EUROCSS 2019. Available: https://gvrkiran.github.io/polarization-tutorial/. Accessed on June 15th, 2024.

value.[28] The initial intention behind this system's requirement specifications was to connect individuals with similar interests on social media platforms.

However, this well-intentioned design ultimately led to the unintended outcome of intensifying the division among people, groups, and communities in the online sphere. Although the system was initially deemed effective upon its creation, subsequent events revealed its unforeseen consequences, including the exacerbation of polarization, the formation of echo chambers, the amplification of extreme speech, and the proliferation of misinformation (Interian; Ribeiro, 2018).

The unexpected nature of these outcomes suggests that the accuracy of open algorithms' recommendation systems on social media networks needs reevaluation, especially considering the effects, impacts, and consequences of open algorithms in people, groups, and communities. It may be time to develop new 'constructs' to anticipate and address risks and responsibilities (before they materialize in society) of related negative impacts powered by open algorithms.

3.3 Lack of procedures to develop and launch open algorithms in the world

In the realm of algorithms, development procedures are limited to closed algorithms techniques. Since computer science began, scientists have created and evolved approaches to develop and launch closed algorithms worldwide. Regarding closed algorithms, software engineering has been developing ways to specify, develop, and document coding, avoid 'bugs,' reaching higher productivity, and delivering software quality. However, no specific methods exist to manage societal externalities when launching an open algorithm.

Open algorithms are designed, developed, implemented, and tested inside the lab. Then, released into the world (into society). Until the advancement of regulations in China, EU, and the USA, open algorithms were launched worldwide without a disciplined and formal procedure. The world has procedures for inserting new medicines and vaccines into society. The world has methods for building new planes and inserting them into society. (Vincent, 2016). But the world has no established procedures to launch an open algorithm. Society needs more methods and procedures when dealing with an open algorithm system going from the lab into the world.

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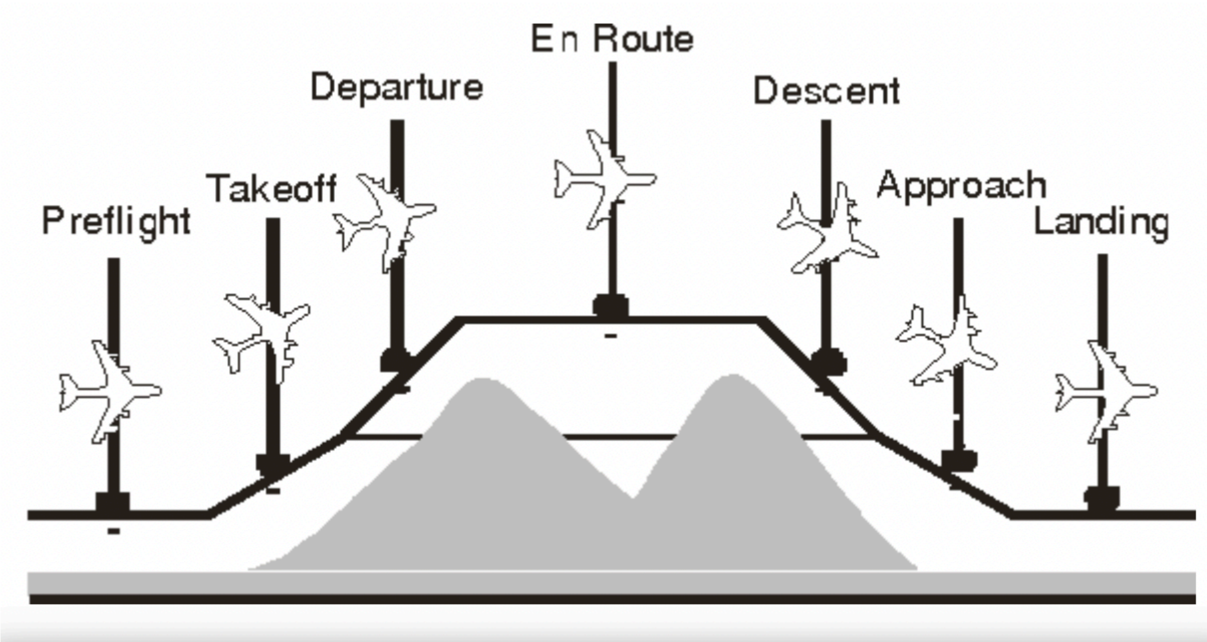
[28] Accuracy and precision. Wikipedia. Available: https://en.wikipedia.org/wiki/Accuracy_and_precision. Acessed on May 13th, 2024.

ChatGPT may be the perfect example of a need for more procedures when transitioning open algorithms from inside the lab into the world. ChatGPT was made available as a prototype without assessing potential negative externalities. Who takes responsibility for the misinformation and errors powered by ChatGPT?

Figure 1 - There are methods to get a plane safely in the air



Source: Ahmad, S. “Design of formal air traffic control system through uml.” (2011).

Another good example to demonstrate the lack of procedures to launch open algorithms in society comes from Civil Aviation. Civil aviation has developed thorough methods for air traffic control teamwork when a plane goes from the ground to the air.[29] (See Figure 1). There are methods, for instance, to authorize an aircraft's first commercial flight, and to manage take-off and landing planes to the ground.[30] That is to say, different procedures were designed to apply to different flight situations.

We inquire: What procedures could algorithm studies create and follow when moving algorithms from “in the Lab” to “in the World”? This lack of knowledge is an extensive part of this research's epistemological, ontological, and ethical quest.

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[29] Boeing Charged with 737 Max Fraud Conspiracy and Agrees to Pay over $2.5, Jan. 7, 2021, Billion. Available: https://www.justice.gov/opa/pr/boeing-charged-737-max-fraud-conspiracy-and-agrees-pay-over-25-billion. Accessed on Jul. 22th, 2022.
[30] Aircraft Evaluation Division. Federal Aviation Administration. United States Department of Transportation. Available: https://www.faa.gov/about/office_org/field_offices/aed. Accessed on Aug. 13th, 2022.

3.4 Lack of successful criteria to manage open algorithms

Algorithm studies need more criteria to account for open algorithms' complexity (success and failure) (Piovesan, 2018). A strategy to deal with that is to bring knowledge from adjacent disciplines: More human, social, and environmental studies could help design and apply successful criteria to open algorithms (Angwin and Larson, 2016).

One paramount case study helped us reflect on and illustrate the lack of human and social knowledge when dealing with open algorithms. We refer to a system called Correctional Offender Management Profiling for Alternative Sanctions (COMPAS). Judges use COMPAS to calculate jail time, which is biased and tends to lengthen prison sentences for black people in the United States (Kirkpatrick, 2017; Smith, 2016; Spielkamp, 2017). The system was created by Northpointe Inc. company to assess a person's chance of criminal recidivism.

COMPAS uses a risk assessment model that categorizes individuals as having a low, medium, or high risk of committing criminal offenses again in the future. It goes like this: Whenever a person commits a crime and is taken to a police station to register prints, they fill in a long-form (137 questions) concerning their background and personal information. This questionnaire then serves as input for COMPAS's risk assessment model. This rating carries weight in court and is used to help determine "ideal sentencing."

In 2013, the "Loomis vs. Wisconsin" case sparked media interest. Eric Loomis' COMPAS assessment considered him an individual with a high risk of recidivism and sentenced him to six years in prison. Eric's defense did not explain why he was "high-risk." In his case, the Judge corroborated the sentence by simply explaining that "you're identified, through the COMPAS assessment, as an individual who is a high risk to the community." Eric's lawyer appealed that his client's right to due process was violated and that he should be able to review COMPAS to assess its validity in the case. The appeal was denied. The company responsible for COMPAS was vehement against disclosing their system, as it is proprietary and "a core piece of our business." Eric Loomis was sent to jail, and no further explanation was provided.

Later, Pro-Publica, an independent research organization, exposed COMPAS, explaining the system was skewed and unfair.[31] Pro-Publica has investigated over 10,000 cases over two years of criminal arrests in a Florida county. The analysis showed that black defendants were twice as likely to be considered "high risk" of re-offending society when compared with white defendants. Simultaneously, almost half of white defendants regarded as "low risk" went on to commit a felony, which happened with less than a third of black defendants (Angwin, *et al.*, 2016).

The Pro-Publica investigation appointed two specific questions, out of 137 in the questionnaire, as responsible for COMPAS to act biased. Such questions causing social damage are: "How many people from your family were incarcerated?" And "How old were you when you left your parents' house?" These two questions relate to historical political and economic studies and deserve deep social reflection before becoming weighed in a recidivism formula running inside an open algorithm.

Northpointe released its report explaining that ProPublica's research was mistaken and failed to understand their system premises, among other issues.[32] The point is that COMPAS – an example of an open algorithm in use in society – lacks the knowledge to understand the consequences of its input questionnaire transformed into data and the bias involved, which leads to critical harm, such as extending someone's time in jail. The Pro-Publica investigation sparked our attention to the lack of human and social knowledge related to open algorithms.

Figure 2 - Algorithm Bias

Prediction Fails Differently for Black Defendants

	WHITE	AFRICAN AMERICAN
Labeled Higher Risk, But Didn't Re-Offend	23.5%	44.9%
Labeled Lower Risk, Yet Did Re-Offend	47.7%	28.0%

Source: ANGWIN, *et. al.,* 2016.

* * *

[31] Pro-publica research, 2016.
[32] Northpointe Inc. Research Department, 2016.

As a result of what we have presented so far, there are enough evidences suggesting that open algorithms are more uncontrollable and adaptive than closed ones. From a computer scientist's perspective, some knowledge from adjacent areas of study might be needed to bridge the ‘knowledge gap.’ For instance, open algorithms seem to require more human, social, and environmental knowledge to be understood. It appears open algorithms involve many more stakeholders in their production and evolution process. Thus, we may say open algorithm ethics and chain of responsibility are much more complex than closed algorithms. We offer the following hypothesis to our first research question:

Question Zero – Is there evidence suggesting the emergence of a new paradigm in algorithm systems that justifies an inquiry?

Hypothesis: We do see enough evidence of new knowledge frontiers that justify an inquiry into open algorithms. To bridge such a ‘knowledge gap,’ our research suggests expanding an approach exclusively based on mathematics, logic, physics, and statistics to understand open algorithms beyond the classical approach we use to identify closed algorithms.

To address such a gap effectively, we choose pragmatism philosophy as our ‘lenses’ to seek knowledge. In the next chapter, we adopt ‘pragmatism’ to organize our mindset throughout such an investigative research journey.

If I have seen further, it is by standing on the shoulders of giants.

Isaac Newton

4 A CRITICAL VIEW ON STATE-OF-THE-ART ALGORITHM STUDIES

This investigation selected state-of-the-art literature on algorithm studies' foundational. We overview (i) The Philosophy of Computer Science, (ii) The Philosophy of Technology, (iii) Alan Turing and Computational Theory, (iv) The Sciences of the Artificial, (v) Ethics in Computer Science, and (vi) Algorithmic Institutionalism, (vii) Algorithmic Realism. To provide a rigorously intellectual examination, each topic has its content organized and structured similarly. First, we explain the literature selected and its connections with computational algorithm studies. Second, we apply the literature presented towards open algorithm studies from the builders' point of view. Third, we comment on evidence that may characterize the emergence of a new paradigm in algorithm studies.

On the top of that, our cutting-edge approach considers algorithm studies from their foundational knowledge, historical origins, technical approaches, current state, present impacts, and potential future developments. Our 'pragmatism' approach to algorithms expand their traditional knowledge base to address their broader societal impacts – all to answer:

1. What is an Open Algorithm?
2. What knowledge is needed to know and understand open algorithms?

4.1 Ethics in Computer Science

Ethical issues applicable to computer science are relevant to open algorithms. Ethics, as we refer to in this dissertation, means both general and professional:

General Ethics is a guiding philosophy that governs the principles of conduct for individuals or groups. It is a discipline that distinguishes right from wrong and defines moral duty and obligation. In open algorithms, general ethics is a foundation for developing ethical frameworks and guidelines for open algorithms design, development, and deployment. [33] [34]

[33] Ethics. Britannica. Available at: https://www.britannica.com/topic/ethics-philosophy Accessed Aug. 13th, 2022.
[34] Ethics: A General Introduction. Available at: https://www.bbc.co.uk/ethics/introduction/intro_1.shtml Accessed on Jul. 7th, 2022.

Professional Ethics: in the context of open algorithms, refers to a set of moral values aimed at preventing and detecting harms that may arise from these systems. Society expects open algorithms to respect social values when making decisions. Examples of professional ethics for open algorithms include fair judgment, respect for privacy, transparency in the deliberative process, and accountability for the decisions made by the systems.[35]

In a review of 809 papers discussing ethics in computer science, Stahl, Timmermans, and Mittelstadt (2016) found that addressed the issue of privacy and data protection, which makes this the most prominent issue. However, numerous other problems are also frequently discussed, such as the autonomy of users, their agency, trust, consent, identity, inclusion, digital divides, security, harm, misuse, and deception, to name just a few (Ross, 1973).

In the contemporary discourse surrounding open algorithms, a significant debate centers on the contrast between the black box model (Bunge, 1963), characterized by their opacity (Burrell, 2016), and the fundamental principles relating to ethics, i.e., fairness, transparency, accountability, explicability, interpretability, etc. (Barocas, Hardt and Narayanan, 2021). A way to minimize such contrast is to provide concrete guidance to actors involved with open algorithms so that they can start building open algorithms "ethics by design".

There are many generic and abstract ethical concepts and principles related to computer science, software, and algorithm studies – all with little or no operational use by experts building open algorithms. (Elhalal *et al.*; Ximenes and Ramalho, 2021). More knowledge, education, and methodology are needed to implement ethics into practice. Unfortunately, with few exceptions, computer scientists have not had proper ethical formation in regular undergraduate courses until recently. In chronological order, we outline below some major initiatives proposed in the last years addressing ethical questions directly related to open algorithms:

- *General Data Protection Regulation (GDPR) (2016)* – A regulation that aims to protect EU citizens' data privacy by providing a legal framework for data protection and privacy for individuals within the European Union.[36]

[35] ACM Code of Ethics and Professional Conduct. Available at: https://www.acm.org/code-of-ethics Accessed on Set. 13th, 2024.
[36] Regulation EU 2016/679: General Data Protection Regulation. Available at: https://gdpr-info.eu/ Acessed on Apr. 18th, 2024.

- *The World Economic Forum (2016)* raised nine ethical questions about AI algorithmic systems.[37]
- *Asilomar AI Principles (2017)*: The Asilomar AI Principles were developed to promote ethical development and use of AI, with 23 principles covering areas such as transparency, safety, and social benefit.[38]
- *The ACM and the IEEE (2018)* – developed guidelines and codes to address ethical issues.[39]
- *Montreal Declaration for Responsible AI (2018)* – A set of principles for developing and deploying AI that promotes transparency, accountability, privacy, inclusiveness, and social responsibility, aiming to ensure that AI benefits humanity.[40]
- *New York City Automated Decision Systems Task Force (2018)* – A task force created by the New York City Council to review and recommend using automated decision systems by city agencies to ensure fairness, equity, transparency, and accountability.[41]
- *European Commission's High-Level Expert Group on AI (2018)* – The High-Level Expert Group provides ethical and trustworthy AI recommendations, including human agency, transparency, and fairness.[42]
- *Ethics Guidelines for Trustworthy Artificial Intelligence (2019)* – A set of guidelines developed by the European Commission outlines how to build and deploy lawful, ethical, and trustworthy AI, promoting respect for human rights, democratic values, and diversity.[43]

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[37] The World Economic Forum: Top Ethical Issues in AI. Available at: https://www.weforum.org/agenda/2016/10/top-10-ethical-issues-in-artificial-intelligence/. Acessed on Jun. 7th, 2024.

[38] Future of Life Institute. "ASILOMAR AI Principles". Available: https://futureoflife.org/ai-principles/?cn-reloaded=1 Accessed on May 29th, 2019.

[39] ACM Code of Ethics and Professional Conduct. Available at: https://www.acm.org/code-of-ethics

[40] Montreal Declaration for Responsible AI. Available at: https://monoskop.org/images/b/b2/Report_Montreal_Declaration_for_a_Responsible_Development_of_Artificial_Intelligence_2018.pdf Accessed on Jun. 24th, 2020.

[41] New York City Automated Decision Systems Task Force. Available at: https://www.nyc.gov/assets/adstaskforce/downloads/pdf/ADS-Report-11192019.pdf Accessed on Jul. 5th, 2020.

[42] European Commission's High-Level Expert Group on AI. Available at: https://digital-strategy.ec.europa.eu/en/policies/expert-group-ai Accessed on Jul. 18th, 2020.

[43] Ethics Guidelines for Trustworthy Artificial Intelligence. Available at: https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai Accessed on Set. 30th, 2020.

- *Algorithmic Accountability Act (2019)* – A bill introduced in the US Senate requires companies to conduct impact assessments on their AI systems to identify and mitigate biases and potential harm these systems may cause.
- *IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems (2019):* The IEEE Global Initiative is a collaborative effort to advance ethical considerations in the design and development of autonomous and intelligent systems by developing standards, frameworks, and guidelines.[44]
- *OECD Principles on AI (2019)* – A set of principles developed by the Organization for Economic Co-operation and Development (OECD) that promote inclusive, transparent, and accountable AI that respects human rights and democratic values.[45]
- *USA AI guidance for Federal Agencies* – Executive office of the President of the United States of America, memorandum for the heads of executive departments and agencies, with guidance for regulation of AI: Advancing Governance, Innovation, and Risk Management for Agency Use of Artificial Intelligence. [46]
- *The EU AI Act* - The AI Act is a legislative initiative with the potential to foster the development and uptake of safe and trustworthy AI across the EU's single market by private and public actors. The main idea is to regulate AI based on a 'risk-based' approach: the higher the risk, the stricter the rules (BRODKIN, 2024).

Adding to those initiatives, we now address two uppermost academic works: AI4people Framework, powered by Luciano Floridi *et al.* (2018), and the Global Landscape of AI, powered by Jobin, Ienca and Vayena (2019). To develop their general principles and abstract concepts, Floridi *et al.* have listed six guidelines,[47] while Jobin *et al.* have improved on the list, reviewing 84 policies.

Floridi's work reviewed six documents and proposed five general principles. Jobin *et al*. reviewed 84 documents and proposed 11 overarching principles. Their

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[44] IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems. Available at: https://standards.ieee.org/wp-content/uploads/import/documents/other/ead_v2.pdf
[45] OECD Principles on AI. Available at: https://www.oecd.org/digital/artificial-intelligence/
[46] Executive office of the President of the United States of America. "Memorandum for the heads of executive departments and agencies: Guidance for Regulation of Artificial Intelligence Applications," Jan. 2020. Available: https://www.whitehouse.gov/wp-content/uploads/2020/11/M-21-06.pdf
[47] Here are the sets of ethical guidelines used by Floridi et al: (1) Asilomar AI Principles; (2) The Montreal Declaration for Responsible AI; (3) IEEE Ethically Aligned Design; (4) EU Statement: Artificial Intelligence, Robotics, 'Autonomous' System; (5) AI in the UK; Tenets of the Partnership on AI.

results are incredibly close in content, as shown in “Figure 3” below. This draws a correspondence between Floridi’s and Jobin’s concepts and principles related to ethics and open algorithms, especially AI systems.

Figure 3 - Algorithm Principles 48

OVERARCHING PRINCIPLES	
Floridi et al	**Jobin et al**
Beneficence: Promoting Well-Being, Preserving Dignity, and Sustaining the Planet	Beneficence[1], Dignity[10], Sustainability[9]
Non-maleficence: Privacy, Security and "Capability Caution"	Non-maleficence[3], Privacy[5]
Autonomy: The Power to Decide (Whether to Decide)	Freedom and autonomy[7]
Justice: Promoting Prosperity and Preserving Solidarity	Justice and fairness[2], Solidarity[11]
Explicability: Enabling the Other Principles Through Intelligibility and Accountability	Transparency[1], Responsibility[4], Trust[8]

Source: Ximenes and Ramalho, 2021.

This coherence among principles happens, even when reviewing several different documents, because there is a remarkable similarity between bioethics principles and the principles being proposed globally for open algorithms. What changes from one principle to the next is the granularity at which each principle is explored and the importance the creative committee attributes to a given concept, finding it necessary to emphasize it, even though the concerns, in essence, are the same (Floridi *et al.*, 2018).

As one may see, there are many generic and abstract ethical concepts and principles related to computer science and algorithm studies – all with little or no operational use by experts building open algorithms (Elhalal *et al.*; Ximenes and Ramalho, 2021). Ximenes and Ramalho (2021) (colleagues from our research group at CIn/UFPE) surveyed computer scientists (i.e., developers and all those involved in creating open algorithms), demonstrating that although they agree with ethical concepts and good practices presented, they do not apply those concepts into practice, even when the ideas and practices are crystal clear.

[48] Ximenes and Ramalho, 2021.

Ximenes and Ramalho (2021) article "Concrete Ethical Guidelines and Best Practices in Machine Learning Development" proposes some ethical recommendations for developers (18 concrete guidelines and 24 best practices). These recommendations were formulated in a focus group and validated quantitatively in a survey of over 130 developers working in industry and academia. Their research investigates the state of adoption of such recommendations and compares what developers think they should do to achieve more ethical results versus what they do. Until now, computer scientists have not had proper ethical formation in undergraduate courses, such as auditing open algorithms. Besides, the existing computer science documents on ethics (despite being abundant) are vague and focus on governments and corporations – rather than on individual developers.

According to Ximenes and Ramalho (2021), significant work was also done by Koshiyama *et al.* (2021), which is the closest to a comprehensive, developer-focused set of ethical best practices in the literature. Koshiyama combines open algorithms' ethical, legal, and technological risks (AI and ML included) and compiles recommendations for explainability, robustness, fairness, and privacy throughout the algorithmic system workflow, from data acquisition to production. Overall, 20 specific techniques or mitigating strategies are suggested to support each pillar in each workflow phase, of which 16 are at least marginally connected to ethical aspects.

All those concepts, principles, regulations, and initiatives offer an excellent start to 'open algorithms ethics.' But they are general and abstract, leaving computer scientists and others involved in creating open algorithms without the proper knowledge to operationalize such concepts and principles into action as part of open algorithms' life journey. The gap exists, for instance, on how a computer scientist (designers, architects, programmers, etc.) should proceed to apply the idea of ethics, fairness, or justice to open algorithm creation. A way to minimize possible harm to society is to guide developers, who can build ethical systems (Lepri, 2021).

The major challenge at this point is assessing whether open algorithms comply with ethical tenets. This can only be done by establishing practical, objective measurements. This issue still needs to be solved: Just as the definitions of key concepts, e.g., justice, transparency, accountability, privacy, and fairness, the concept of 'open algorithms ethics' remains fuzzy and does not correspond to specific system requirements.

The ethical gap persists due to a lack of methods for computer scientists, engineers, designers, architects, and programmers to bear ethical concepts and principles into their practice building open algorithms. For instance, how can the principle of 'justice' be applied to the architecture of an open algorithm? How can it be done throughout the production chain of an open algorithm when it is designed, implemented, tested, and deployed to be used?

4.2 The Philosophy of Technology

‘The philosophy of technology’ helped us question (and understand) algorithms as a technology. The philosophy of technology emphasizes human and social issues related to the use of technology. It discusses significant themes, such as the relationship between technology and society, the impact of technology on the environment, and the ethics of technological development.

Significant contributors to ‘the philosophy of technology’ as a field of study come from as far back as Plato, who is known to have discussed the impact of technology on human society and its relationship to morality. Plato's insights on the nature of knowledge and reality are particularly relevant. Plato's distinction between knowledge and opinion can help us understand the role of open algorithms in shaping our perceptions of reality.[49] Open algorithms can amplify specific perspectives or biases, leading to a distorted worldview.

Plato's concerns about technology's impact on the human condition were echoed in the works of philosopher Martin Heidegger [50], who argued that technology is a mode of being that shapes our relationship to the world. Inspired by that, we bring this interdisciplinary, non-technical knowledge from social and human studies to investigate open algorithms, considering their impact on various fields, e.g., sociology, politics, economics, and the law. As an interdisciplinary field of study, the philosophy of technology explores technology's ethical, social, and cultural aspects.

The philosophy of technology offers insights into how open algorithms can be designed and used in ways that promote not only mathematical and statistical efficiency but also human flourishing and social justice in the world. For instance, the ‘ethics of technology’ emerged as a significant topic in the 20th century. Now, in the

[49] Plato. Available at: https://plato.stanford.edu/entries/plato/ Accessed on: Nov. 12th, 2024.
[50] Martin Heidegger. Available at: https://plato.stanford.edu/entries/heidegger/ Accessed on: Mar. 20th, 2024.

21st century, the ethics of technology offers us many insights into understanding the ethics of algorithms.

Ethical studies on algorithms should include cultural and political aspects (beyond engineering and specific technologies). They should focus on topics such as ‘neutrality’, ‘moral agency,’ ‘development responsibility,’ and ‘technological risks.’ When applying the ‘philosophy of technology’ to our study, open algorithms may be considered not just technical tools but social and political ones. As a technology, open algorithms are embedded in a network of social relations and power structures that shape open algorithms design, implementation, and use.[51]

If considered ‘technology’, ‘open algorithms’ could be defined as a set of instructions operating within a broader social and political context. They are not neutral or objective. According to our pragmatism point of view, they reflect their use.[52]

‘The philosophy of technology’ provides an essential framework for understanding the role of open algorithms and the ethical considerations that must be considered in its development and use. As open algorithms advance as a ‘technology’ and transform society, it is crucial to continually revisit and evolve our understanding of their impacts and implications.

The philosophy of technology fits in well with open algorithms, bringing non-technical knowledge and embracing the wilderness of the world to help us understand open algorithms as a technology. Inspired, we evolved to conceptualize open algorithms as technology. That is to say, open algorithms are conceptualized with social and human intentions. Open algorithm teams are composed of experts from different disciplines who are likely to disagree while building an open algorithm. Open algorithms are governed by severe constraints of resources (e.g., time, money, knowledge). Open algorithms impact relations to the structure of society (i.e., human culture, condition, and morality). Amongst other things…

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[51] Franssen, Maarten, Gert-Jan Lokhorst, and Ibo van de Poel, "Philosophy of Technology", The Stanford Encyclopedia of Philosophy (Fall 2024 Edition), Edward N. Zalta & Uri Nodelman (eds.) Available at: <https://plato.stanford.edu/archives/fall2024/entries/technology/>. Accessed on: Feb. 23th, 2024.

[52] Franssen, Maarten, Gert-Jan Lokhorst, and Ibo van de Poel, "Philosophy of Technology", The Stanford Encyclopedia of Philosophy (Fall 2024 Edition), Edward N. Zalta & Uri Nodelman (eds.) Available at: <https://plato.stanford.edu/archives/fall2024/entries/technology/>. Accessed on: Feb. 23th. 2024.

4.3 The Philosophy of Computer Science

‘The philosophy of computer science’ is a subfield of ‘philosophy’ that examines the fundamental knowledge, concepts, and principles underlying the practice of computer science. It explores the nature of computation, the limits of what can be computed, the relationship between computing and human cognition (Angius, Primiero and Turner, 2021). It concerns computing systems' theoretical foundations and technical structures.

Historically, the philosophy of computer science has focused on studying the machine itself and its logical, mathematical, and statistical perspectives (Aho; Ullman, 1992), blindsiding the human, social, and environmental aspects of algorithms. Stanford’s Encyclopedia presents some algorithm-related knowledge under “The Philosophy of Computer Science.” The seventy-seven-pages-long entry helped us understand the knowledge foundations of algorithms from classical, formal, and informal perspectives:

Markov (Markov, 1954) provides one of the first definitions of the algorithm as a computational process ‘determined,’ ‘applicable,’ and ‘effective’:

- *Determined* – the instructions involved are precise enough not to allow for any “arbitrary choice” in their execution. The computer must never be unsure about what step to carry out next.
- *Applicable* – they hold for classes of inputs rather than for single inputs.
- *Effective* – the tendency of the algorithm to obtain a particular result. An algorithm is effective in eventually producing the answer to the computational problem.

Following Markov’s “determinability” and strengthening “effectiveness,” Kleene (1967) specifies that instructions should be able to recognize that the solution to the computational problem has been achieved and halt the computation. Kleene adds and defines ‘finiteness’ as a further important property. Knuth (1973), in turn, deepens the analyses of Markov and Kleene by stating that an algorithm has five essential features, as presented below.

- *Finiteness* – An algorithm must always terminate after a finite number of steps.
- *Definiteness* – Each step of an algorithm must be precisely defined, and the actions to be carried out must be rigorously and unambiguously specified for each case.

- *Input* – An algorithm has zero or more inputs.
- *Output* – An algorithm has zero or more outputs.
- *Effectiveness* – Its operations must all be sufficiently basic that they can, in principle, be done precisely and in a finite time by someone using a pencil and paper.

Gurevich (2012) provides an axiomatic definition for classical sequential algorithms, saying that any sequential algorithm can be simulated by a sequential abstract state machine satisfying three axioms: the 'sequential time', the 'abstract state', and the 'bounded-exploration'. On the other hand, Gurevich (2000) says it is not possible to provide formal definitions of algorithms as the notion continues to evolve.

Moschovakis (2001) objects Gurevich, saying that abstract machines do not fully capture the intuitive notion of algorithms. He states that essential, implementation-independent properties are not captured by abstract devices but rather by a system of recursive (Rogers, 1967) equations. Moschovakis' formal analysis poses two questions: Different implementations of the same algorithm should be equivalent implementations, and yet, an equivalence relation among algorithm implementations is to be formally defined. Furthermore, it remains to be clarified what the intuitive notion of algorithm formalized by systems of recursive equations amounts to.

Vardi (2012) underlines how there is no consensus on what an algorithm is. However, Rapaport (2012) stresses that an algorithm is a procedure, i.e., a finite sequence of statements taking the form of rules or instructions. Finiteness is expressed by requiring instructions containing a limited number of symbols from a finite alphabet. Hill (2016, 2018), in turn, aims to provide an informal definition of an algorithm, starting from Rapaport's (2012): "An algorithm is a finite, abstract, effective, compound control structure, imperatively given, accomplishing a given purpose, under given provisions."

* * *

Knuth's definition is widely used and primarily concerns the algorithm's technical aspects. It has influenced computer science, particularly in analyzing algorithms and computational complexity. Indeed, Knuth's definition of an algorithm remains relevant in the technical aspects of algorithms (Knuth, 1977). However, it does not consider open algorithms (our object of study) broader human, social, and environmental impacts and consequences – such as perpetuating biases or reinforcing inequalities.

A new approach seems required to expand the definition of open algorithms and encompass concepts such as algorithms' ethics, accountability, transparency, fairness, explicability, equitability, reasoning, and reversibility.

While Knuth's definition of an algorithm is valuable in the technical aspects, it is insufficient in the context of the open algorithms' broader human and social implications (Knuth, 1974). The most recent impacts of open algorithms on society (i.e., artificial intelligence models) alerted us to raise questions about the adequacy of Knuth's definitions. The requirement of 'effectiveness' and 'definiteness' may not be sufficient to define open algorithms and ensure their ethical and responsible use, where open algorithms usually require massive amounts of computational power, and their decisions can have complex and far-reaching consequences.

The Philosophy of Computer Science helped us understand that, as a field, Computer Science has 100 years of algorithm studies foundationally connected to math, physics, logic, and statistics.

4.4 Turing and Computational Theory

Our investigation delves into computational theory's application to real-world problems, exploring the design and analysis of computational systems (Gruhn; Striemer, 2018). Computational theory applied to open algorithms goes beyond algorithms' concepts and definitions to reach their use, so we ask: How can open algorithms be applied to solve real-world problems? (Denning, 2017).

Turing explored the concept of agency in algorithms, particularly in his 1950 paper "Computing Machinery and Intelligence," where he proposed the Turing Test to assess a machine's ability to exhibit human-like intelligence.[53] Despite the complexity of tasks algorithms can perform, Turing maintained that their decisions are ultimately governed by human-set rules and parameters, highlighting algorithms' lack of inherent agency. This deterministic view aligns with closed algorithms governance, where algorithms adhere to predefined rules without autonomous or decision-making.

Turing focused on theoretical aspects, although his practical work during World War II on the Enigma Machine underscored the immediate applications of computing. Turing's work did not have time to address the broader social, political, economic,

[53] Agency. Available at: https://plato.stanford.edu/entries/agency/ Accessed on Aug. 3th, 2024.

environmental, or legal implications of algorithm impacts, as the field was in its infancy, and computers' societal impact was not fully realized.

This ongoing discourse explores the balance between algorithmic autonomy and human-centered control. Turing's theoretical framework was groundbreaking but did not consider open algorithms human, societal, and environmental implications. Bluntly put, Turing's definition needs to be revised to explain what an open algorithm is.

It wasn't until more recently, as people, computers, algorithms, and Big Data became intertwined in making societal decisions that researchers began to consider the human, social, political, and ethical implications of using algorithms to solve real-world problems. Modern perspectives recognize the need to incorporate insights from the human and social sciences, for instance, to address biases, ethical concerns, and other externalities associated with open algorithm effects. To develop a concept of open algorithms, we adopt an expanded Turing's definition of algorithms to include these considerations.

4.5 The Sciences of the Artificial

Herbert Alexander Simon, winner of the Nobel Prize in Economic Sciences in 1978 and the Turing Award in Computer Science in 1975, was a prominent figure in computer science. In his influential book The Sciences of the Artificial (Simon, 2019), Simon proposed the concept of "artificial artifact," arguing that artificial artifacts are the products of human design and reflect human intentions and purposes. Simon's work was noted for its interdisciplinary nature, spanning cognitive science, computer science, public administration, management, and political science (all relevant areas to understand open algorithms).

Simon pioneered several modern-day scientific domains, such as information processing, decision-making, problem-solving, organization theory, and complex systems. One distinctive aspect of Simon's approach to all these fields was that he set his sights on the phenomena of human thinking and problem-solving as the essential core of organization theory and economics. He argued that organizations could be understood by applying to them what you knew about human behavior generally.

Could we draw an analogy between 'open algorithms' and 'artificial artifacts'? 'The Sciences of the Artificial,' an essential economic theory powered by Herbert Simon, develops the following notion: 'Sciences of the artificial' uses the knowledge of ‘natural sciences’ to understand new artificial artifacts in the world. Simon argues that ‘artificial artifacts’ are the product of human problem-solving and represent a crucial feature of human intelligence.

Simon stated that the world we live in today is much more human-made (thus, artificial) than it is a natural world. “Artificial” meaning is produced by art rather than by nature. It's not genuine or natural. It is affected. For instance, a forest may be a natural phenomenon. A farm certainly is not. Could we then say a plowed field is no more part of nature than open algorithms and no less? Open algorithms are not apart from nature. They have no dispensation to ignore or violate natural law. At the same time, they are adapted to human goals and purposes.

Simon defines ‘artificial artifacts’ as objects intentionally created by humans to achieve a specific goal or purpose. Similarly, open algorithms are what they are to satisfy our desire to fly, eat well, or process enormous amounts of data. As our aims change, so do the open algorithms – and vice-versa.

Simon's ‘artificial artifacts’ concept provides a valuable framework for understanding ‘open algorithms’ as intentional human creations that significantly impact society. By viewing ‘open algorithms’ through this lens, we suggest understanding ‘open algorithms’ using what we know about ‘the sciences of the artificial.’ As such, if we consider ‘open algorithms’ as ‘artificial artifacts’ and apply Simon’s approach, we depict the following:

- Open algorithms cannot ignore or violate natural law – they must respect it.
- Open algorithms are human-made intentions. Not natural.
- Open algorithms are made to serve some purpose.
- Open algorithms exist to satisfy our desires.
- Open algorithms are tangible physical objects that affect the intentions of those engaged with them.
- Open algorithms do not exist in isolation.
- Open algorithms are ‘for something,’ and what they are for is called function.
- To exercise impact, open algorithms must be a system, a combination, or a composition.
- As our aims change, so do open algorithms change.

When considering open algorithms as artificial artifacts, we can see that they are intentionally designed and created by humans to solve specific problems or perform certain tasks. Simon also notes that artificial artifacts are more than passive tools humans use to achieve their goals. Instead, they are active agents that have the power to influence and shape human behavior. Research suggests this applies to open algorithms, which can significantly impact society, individuals, and organizations.[54]

4.6 Algorithmic Institutionalism

The concept of 'institution' we envision refers to a body of the social sciences known as Institutional Theory (Ostrom, 2005). In this context, an institution may be considered a relatively enduring collection of rules and organized practices embedded in structures of meaning and resources that are relatively invariant in the face of turnover of individuals and relatively resilient to individuals' idiosyncratic preferences and expectations and changing external circumstances (March and Olsen, 2005). In this context, 'institutions' promote order and stability. They build meaning, reproduce meaning, and perform discursively in the public sphere, drawing debates (Unger, 1983). Could we draw an analogy between open algorithms and institutions?

Our theoretical work believes open algorithms may be considered a component in building 'institutions'. Open algorithms now decide which children enter foster care, which patients get medical care, and which families access stable housing (Hao, 2020). Our first thoughts would be to imagine institutions as large government buildings with brass plaques proclaiming that they are the parliament or a ministry. A second thought might be of social institutions such as marriage, the Church, or the Law.[55]

We might even think of even more amorphous institutions based on norms or discourses – e.g., a social club or a sports team – that influence individual behavior because the individuals have learned and accepted the values. But can lines of computer code be considered an institution?[56] What if open algorithms were considered institutions?[57] If we see open algorithms as constituents in building institutions, how does that change our usual view? (Capoccia, 2015). What practical outcomes can we expect from the goal of applying political science to develop novel

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[54] Philosophy and AI Congress at the Federal University of Ceará.

[55] Social Institutions. Stanford Encyclopedia of Philosophy. Available: https://plato.stanford.edu/entries/social-institutions/. Accessed on May 1st, 2021.

[56] Almeida, Virgílio et al. "Algorithmic Institutionalism." In Proceedings of the 2024 ACM Conference on Fairness, Accountability, and Transparence (FAccT '24). Association for Computing Machinery, Rio de Janeiro, RJ, Brazil.

[57] Brazilian Academy of Sciences, Brazil. Webinars 37th ED. | Algorithms command society and require controls. Available: https://www.youtube.com/watch?v=poU-nbUw5j0. Accessed on May 25th, 2021.

methods for understanding open algorithms? (Almeida, Filgueiras and Mendonça, 2022).

As an institution, we may consider that open algorithms influence individuals' behavior in the community, transform social choices, and alter our capacity for collective action. They define the meanings of action in the context of the interactions that constitute society. But can insights from social and political sciences help us better understand open algorithms? What should democratic open algorithms governance look like? What are the limits of autonomous and automated decisions? How should we regulate and manage open algorithms' production and its consequences? (Almeida, Filgueiras and Mendonça, 2023).

Thinking of open algorithms as institutions requires understanding their values, how they intervene, and how they may evolve based on their effective action and consequences for the world. open algorithms as institutions of digital technologies in contemporary societies reinforce the idea that open algorithms structure people, groups, and communities' decision-making capacity.

Almeida, Filgueiras and Mendonça (2023) propose 'algorithmic institutionalism' to acknowledge algorithms as sociotechnical artifacts structuring our decision-making capacity. Based on other policy domains (e.g., environmental governance), Almeida *et al*. outline a conceptual proposal to extend institutional approaches toward open algorithms. Almeida *et al*. consider open algorithms institutions that establish boundaries for individual behaviors with collective implications. Almeida *et al*. design a global self-governance, suggesting collaborative ways involving multiple stakeholders in different forums, creating transparency and accountability mechanisms, and acting coordinated to mitigate the unintended effects of accelerated change promoted by technological innovations. Their model uses principles and practical regulatory frameworks to deal with open algorithms as institutions. Briefly, here they are: (Almeida *et al.*, 2022).

- *Purpose and impact.* Citizens and institutions must understand why the open algorithms exists, how it is used, by whom, where, and when, and what consequences it will have on individuals and society.
- *Identification of the actors*. Indicate who the open algorithms owner is and which organization is accountable, including the employees. Organizations should provide the information required to identify responsible actors.

- *Oversight*. open algorithms should have independent third-party information that reviews, tests, and audits the system before and during open algorithms decision-making operations.
- *Technical architecture*. Provide technical information about the open algorithms' broad context, critical connections with other systems, and procedures adopted for safety and security.
- *Input datasets.* Provide information on the procedures and features, steps for data collection, and the open algorithms variables used to produce outcomes.
- *Model and performance*. Provide information on how open algorithms calculate, process, and reason variables and how it does classification, prediction, and learning.
- *Output datasets*. Provide information on the results achieved by open algorithms decision systems and who, where, and when to access and use the produced results.
- *Principles.* Provide information on principles that guide the open algorithms' design, development, and operation. This includes, for example, how open algorithms address and deal with non-discrimination and inclusion of the various social actors or how open algorithms test for bias and avoid redlining open algorithms decision-making process.
- *Explainability.* Provide answers that allow citizens to understand why the open algorithms made a specific decision.
- *Human operator competencies.* Produce insights into the involvement of human operators. In addition, explain the inclusion policies adopted and the various human perspectives adopted by these operators of digital tools.
- *Citizen rights*. Provide information on how citizens can claim their right to know.
- *Privacy and data protection.* Provide information about the privacy policy adopted and how the open algorithms may affect privacy.

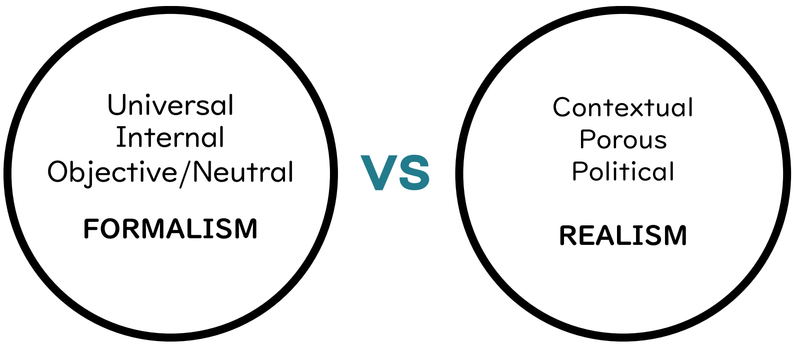
If considered an 'institution' or a constituent in building institutions, 'open algorithms' can be studied as a structural process of power and control that may produce and reproduce racialized, gendered, sexist, and ableist forms of violence, vulnerabilities, and exclusions in society.

4.7 Algorithmic Realism

Algorithm philosophy is a 'newborn' field of study, something our research group has been mapping. But one article firmly strikes us, leading our research to dive into philosophical critical studies of the algorithm. In an article titled "Algorithmic Realism: Expanding the Boundaries of Algorithmic Thought," Ben Green and Salome Viljoen find good foundations and relevant promises to discuss open algorithms systems as an 'intricate dynamic arrangement of people and code.' (Green and Viljoen, 2020).

Below, we present how the article first diagnoses and characterizes 'the problem' as computer science's tradition based on 'algorithmic formalism.' The article elaborates on 'the solution' based on American Legal History to conclude with and propose 'algorithmic realism.' The article antagonizes Formalism[58] versus Realism[59] as follows:

Figure 4 - Algorithm Formalism vs Algorithm Realism



Source: Author ownership (2025).

Algorithmic formalism: *Objective / Neutral* – algorithms are perceived as neutral tools capable of making objective decisions: "The algorithmic formalist emphasis on objectivity and neutrality occurs on two related levels. First, algorithms are perceived as neutral tools and are often argued for because they can make "objective" and "neutral" decisions. Second, computer scientists are seen by themselves and others as neutral actors following scientific principles of algorithm design from positions of objectivity." *Internal* – emphases mathematical features of algorithms, e.g., efficiency and accuracy: "(…) only considerations that are legible

58 Formalism. Definition of formalism. Merriam-Webster. Available: https://www.merriam-webster.com/dictionary/formalism.
59 Realism. Stanford Philosophy Encyclopedia. Available: https://plato.stanford.edu/entries/realism/. Accessed Aug. 13, 2022.

within the language of algorithms – e.g., efficiency and accuracy – are recognized as important design and evaluation considerations. The analysis of an algorithm primarily emphasizes its run time (or efficiency), characterizing its behaviors in terms of upper, lower, and tight bounds – all features that can be mathematically defined based on the algorithm's operations." *Universal* – one size fits all: "Algorithmic formalism emphasizes an orientation of universalism: a sense that algorithms can be applied to all situations and problems."

Algorithmic realism: *Political* – recognizes algorithmic interventions as political. "First, freed from the strict imperative to be neutral and objective, computer scientists can interrogate how their assumptions and values influence algorithm design." *Porous* – "Algorithmic realism shifts the primary focus of algorithmic interventions from the quality of an algorithmic system (in an internalist sense) to the social outcomes that the intervention produces in practice." (...) A porous approach to algorithms means formalist considerations (e.g., accuracy. efficiency, and fairness) are recognized as necessary but no longer sufficient." *Contextual* – meaning "rather than question how a situation can be modeled and acted upon algorithmically, a contextual approach questions to what extent a situation can be modeled and should be acted upon algorithmically."

Green and Viljoen's article is off to a good start, but the paper becomes quite debatable as it develops its core ideas. It brings on flawed premises and some misunderstandings, as we explain below in more detail:

The article draws an inadequate parallel between Formalism to the field and practice of American Legal History, known as "Legal Formalism," and Formalism to the realm of algorithms, naming it "Algorithmic Formalism." It seems to be a lousy premise because it treats Algorithmic Formalism the same as Legal Formalism, but they are not. Legal Formalism makes the notion of form central to the understanding of the Law and is a theory that legal rules stand alone, separate from social and political considerations. In Legal Formalism, once lawmakers produce the rules, judges are supposed to interpret and apply them to the facts of a case without much (or any) regard for social interests and political welfare. In this regard, Legal Formalism limits the interpretation and application of the Law (Schauer, 1987).

Formalism in computer science and the realm of algorithms, in turn, relates to formal computer languages, and it does not represent, at first, a limitation to the field. Criticism of a specific algorithm may be pertinent based on its inability to grasp (or model) reality. Sometimes, modeling reality through formal computer languages may be tricky – as with forecasting weather systems (Coleman, 2015). However, a priori criticism of formal computer languages as incapable of modeling reality seems too much, so it becomes an inadequate parallel. Modeling reality through formal computer languages is complicated, but it is not impossible.

Formalism in algorithms can theoretically grasp reality without limitations because formal languages may model reality (Leith, 1990). Given the power of formal programming languages, restrictions to model nuances of reality would only be valid if first proven that such modeling would amount to a non-computable function (would such a reality be non-computable?). We don't know whether this is the case: We cannot state a priori that reality cannot be modeled. Formalism in the realm of algorithms does not represent a limitation, as stated in Green and Viljoen's analogy with American Legal Formalism – *vis a vis* modern LLM models such as Chat-GPT from Open-AI, Gemini from Google, and others.

The article does not distinguish between "formal computer languages" and "computer modeling of reality." Computer languages make modeling more accessible or complicated – but the challenges and risks are in the modeling, not the language. The objectivity imposed by the formalism of computer languages does not prevent richer modeling of reality. Computational objectivity is not a limitation to capturing the subjectivity of reality (e.g., user experience, "UX"), as in Legal Formalism.

In this sense, the following article's passage: "It is impossible for an algorithm to account for every aspect of society," is quite naive because it dismisses the power of computer languages in modeling reality. Moreover, as we all know, not even a human being cannot take EVERYTHING reality presents around us into account – as Herbert A. Simon once said, 'Humans are agents of bounded rationality.' (Simon, 2019).

In short, the article designs a flawed analogy between Legal Formalism and Computer Science Formalism and needs clarification arguing what Algorithmic Formalism and its alleged flaws are. The article wrongfully diagnoses Algorithmic Formalism as a limitation, considering it an epistemological problem instead of just regarding some characteristics it might represent towards algorithms. Based on an unprecise formalistic analogy, the article creates "Algorithmic Realism" as the epistemological solution.

Considering that we would like to illustrate our ideas by bringing even more details from the article. The article argues Algorithmic Formalism and creates Algorithmic Realism to mistakenly antagonize them threefold:

First, Algorithmic Formalism perceives open algorithms as objective and neutral tools (i.e., capable of making objective decisions). As we have seen, the objectivity imposed by the formalism of computer languages does not prevent a richer modeling of reality. “Computational objectivity” is not antagonistic to capturing the subjectivity of facts (e.g., UX). Besides, mixing objectivity and neutrality can be a problem. In computing, objectivity may be a premise, but neutrality is not. Our research considers open algorithms ‘in use.’ Thus, they are never neutral. They are what humans make out of them. If algorithms are being used connected to the real world, they are not neutral. Computer scientists build open algorithms to intervene. There may be bias, and there may be errors.

Second, Algorithmic Formalism is “internal,” emphasizing algorithms' mathematical features (e.g., accuracy, correctness, efficiency) (Smith, 1985). Algorithmic Realism, instead, is designated as “porous,” i.e., shifting the primary focus from the internal quality of an algorithmic system to the social outcomes that the intervention produces in practice. From our perspective, such a porous algorithm approach makes sense but shouldn’t mean internal considerations are no longer needed. Those internal technical criteria are necessary but insufficient to address open algorithms’ social outcomes. An evolution to deal with open algorithms’ social context (beyond an internal approach), seems essential to us.

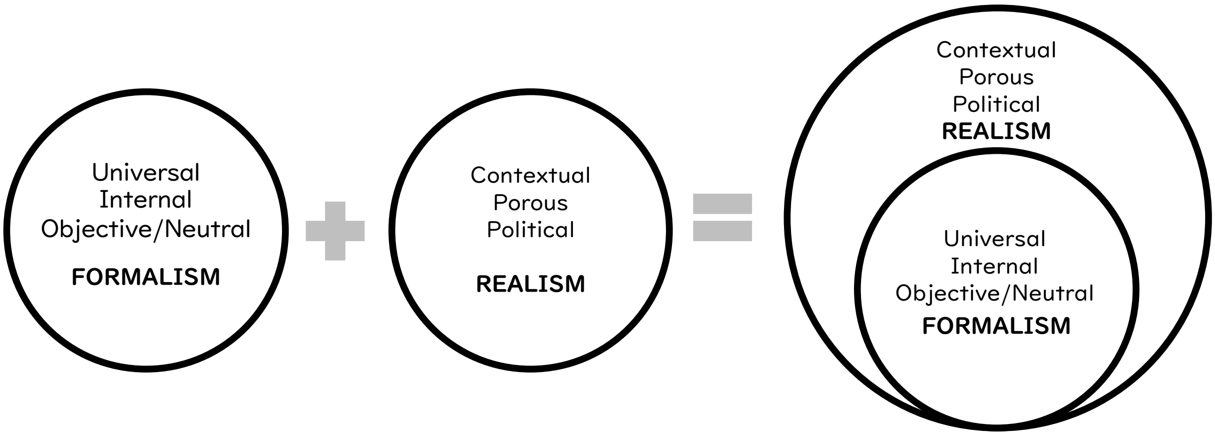
Third, the article argues that Algorithmic Formalism is “Universal” and can be applied to all situations and problems. It argues that computer scientists use algorithms for anything that can be modeled mathematically. On the other hand, we say that, though “universal,” it is always legitimate to ask when open algorithms should or should not be developed and used in society. Our sense refers to incorporating ethics and knowledge notions from other areas, notably bringing the humanities to open algorithms’ decisions.

Computing is not intended to have a deterministic impact on society. Many open algorithms (ML and AI included) are not deterministic, let alone suppose that determinism exists worldwide. Algorithmic Realism should be “Contextual,” questioning to what extent a specific situation can be modeled and should be acted upon algorithmically.

A better approach would have been to consider Algorithmic Formalism and Algorithmic Realism as complementary characteristics (Figure 5), not antagonistic. Our choice of thinking about open algorithms should not have been Formalism AGAINST Realism, but to transcend and be BOTH formalist and realist, as such amplifying one mindset:

- Objective/neutral AND political.
- Internal AND porous.
- Universal AND contextual.

Figure 5 - Algorithm Formalism subsumed by Algorithm Realism



Source: Author ownership (2025).

In addition to these flaws in its core and fundamental assumptions, the article brings some “collateral mistakes” as well:

First, it limits the epistemological gap to the phase (or mindset) of “Algorithmic Thinking.” In the article, Algorithmic Thinking is perceived as the first step in a system-development-life-cycle process that creates algorithms. But Algorithmic Thinking, as we understand it, is just one piece of the puzzle, i.e., one stage of the life cycle process (Futschek, 2006). Algorithm life cycle processes have many elements, steps, and variables – way beyond the first stages of Algorithmic Thinking.

A second collateral misunderstanding is that the article considers “computer scientists” as “one-profile-persona,” holding knowledge, mindsets, and experiences alike. There is no distinction regarding their roles in creating OPEN ALGORITHMs, e.g., cultural backgrounds, professional duties, and working contributions. The article suggests they are all the same and that one computer scientist profile fits all algorithm design functions. However, the computer scientists involved in developing algorithms are not the same. They are diverse and exercise different activities. Some are designers and software architects; others are requirement engineers, programmers, test engineers, security experts, etc. Only a few computer scientists are involved in the Algorithmic Thinking phase. This research does not doubt that the knowledge gap in algorithm studies goes beyond thinking, writing, or coding OPEN ALGORITHMs. In its realm, every computer scientist must be responsible and accountable for the consequences their actions may cause to society, respectively.

Our critical understanding described above differs from a wholesale rejection of Algorithmic Formalism or Algorithmic Realism. Opposing them is far from exhaustive and is designed only to illustrate the form such opposition can take. Our philosophical stance aims not to attack Algorithmic Formalism or Algorithmic Realism. Instead, we are here to learn and combine them pragmatically. Green and Viljoen helped us see the existence of a knowledge gap in algorithm studies – and for that, they have our gratitude. Their contribution to this research was paramount.

On the other hand, the inadequate parallel between Legal Formalism and Algorithmic Formalism misleads the article to propose Algorithmic Realism, leading this research to an in-depth work to offer another approach based on Pragmatism Philosophy instead of Legal Realism (Posner, 1990). Thus, instead of Algorithmic Realism, we propose Algorithm Pragmatism as a bridge to better deal with the Knowledge Gap in algorithm studies related to open algorithms, towards which we now turn.

Facts are good, of course. Give us lots of facts
Principles are good. Give us plenty of principles.
The world is indubitably one if you look at it in one way,
But as indubitably is it many, if you look at it in another.
William James, 1907

5 METHODOLOGICAL FOUNDATIONS

Deeply inspired by Pragmatism Philosophy, as an account of how we think and act in society, this research envisions the need to evolve reasoning related to algorithm studies, expanding its boundaries of meanings (Adornetti, 2012). In Computer Science, there are many studies on algorithms' semantics (Rapaport, 2005) and syntax (Rapaport, 2012), but those related to 'pragmatism' are just a few (Barendregt, 1985; Wall and Singh, 2017) – there lies an opportunity, we now seize:

We used Ludwig Wittgenstein's theoretical works as enlightening to evolve our pragmatism approach towards 'closed' and 'open' algorithms in the world. [60] Wittgenstein, a towering figure in 20th-century philosophy, contributed significantly to philosophy and linguistics with two paramount works: "Tractatus Logico-Philosophicus" (1921) and "Philosophical Investigations" (1953). Wittgenstein brought these two distinct and contradictory matrices of knowledge to the world.

Both theories prospered and generated great reflections and fields of study. In our theoretical investigation of algorithms, we use Wittgenstein's first work, "Tractatus Logico-Philosophicus" (1921), to help characterize 'closed algorithms' (the logical, mathematical, and statistical perspectives) and help finding answers to our research questions (see 'Introduction').

We have drawn connections between how we understand 'closed algorithms' and Wittgenstein's ideas in his first work, Tractatus Logico-Philosophicus (1921) as follows: The resemblance between closed algorithms and Wittgenstein's theory presented in his book Tractatus Logico-Philosophicus lies in their shared focus on logical systems and their limitations. In Tractatus, Wittgenstein explores the limits of language and representation, arguing that there are propositions that cannot be expressed through language. Similarly, we understand that 'closed algorithms' operate within their own controlled environment, where algorithms are designed and tested based on a simulacrum of society, predefined rules, and conditions.

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[60] Ph.D. Prof. Tarcísio Pequeno (UFC-CE) helped us 'deep-dive' into Wittgenstein's views of the world.

Just as Wittgenstein highlights the boundaries of language, closed algorithms reveal the constraints and possibilities of closed algorithms. Wittgenstein's theory in Tractatus also touches upon the idea of logical propositions and their relationship to reality. He suggests that logical propositions can only represent facts about the world if they correspond to reality. Similarly, closed algorithms aim to create algorithms that accurately represent and interact with the predefined simulated society.

Meanwhile, Wittgenstein’s later work, Philosophical Investigations (1953), a social and linguistic view of philosophical foundations, helped us characterize ‘open algorithms.’ Just as Wittgenstein critiques his first ideas of a fixed logical structure underlying language, our research argues for new modes of thinking, different from ‘closed algorithms’, to include dimensions related to algorithms’ impact on people, groups, and communities worldwide.

We connect Wittgenstein’s later work, Philosophical Investigations (1953), to open algorithms (Wittgenstein, 1953). In his work, Wittgenstein's philosophical views significantly evolved from mathematical to contextual between "Tractatus" and "Philosophical Investigations:" While "Tractatus" reflects a more rigid, logical atomist approach to language and meaning, "Philosophical Investigations" embraces a more contextual, pragmatic view. Through these works, Wittgenstein made profound contributions to the philosophy of language, logic, and the nature of philosophical inquiry, influencing generations of philosophers and scholars up until today.[61]

In this theoretical research work, we have use Wittgenstein's later philosophy to bridge some knowledge on ‘open algorithms.’ We depicted Wittgenstein’s thoughts and applied to open algorithms, as follows: (a) The importance of context and situatedness in understanding meaning and behavior of open algorithms, (b) The inherent unpredictability of human behavior, societal dynamics, and the uncertainty and ambiguity of data and society making open algorithms decisions (c) a recognition of the limitations of logical systems and the need for flexibility and adaptability in response to changing contextual circumstances, making open algorithms dependent from human behavior and its dynamic and evolving nature, and (d) open algorithms’ chains of responsibility grapple with the moral implications of their respective domains, and ethical dilemmas when innovating.

[61] BBC News Brazil. Popper contra Wittgenstein: os 10 minutos do confronto explosivo entre dois gigantes que marcaram a filosofia. BBC NEWS Brazil, 2024 Available: https://www.bbc.com/portuguese/articles/cgrwexgenxro. Accessed on May 24th, 2024.

This research seeks to expand algorithms' knowledge boundaries from mathematical, logical, and statistical to include a dynamic system of human, social, and environmental practices and activities (Wittgenstein, 1953). In our words: The meaning of open algorithms emerges from their use rather than any inherent or fixed mathematical, logical, or statistical definition of algorithms' systems. We have asked ourselves whether such use of open algorithms in a context creates what Wittgenstein named 'family resemblances.' In "Philosophical Investigations," Wittgenstein criticizes the idea of a fixed logical structure underlying language and argues that meaning is context-dependent and often involves 'family resemblances' rather than strict definitions. Could we, perhaps, ask ourselves about 'open algorithm family resemblances'? What would that mean?

Further in his short career, Wittgenstein introduces the concept of 'language games,' suggesting that language use is governed by rules and conventions learned through social interaction. Wittgenstein delves into the complexities of how language is used in everyday contexts. He delves into 'language games'.

Profoundly inspired by Wittgenstein's works, our pragmatism perspective frames 'open algorithms' as inherently contextual and contingent upon the system being played. Please, highlight the importance of considering the active broader social, political, economic, environmental, and cultural context where open algorithms are in use. Open algorithms operate in the real world, making decisions directly impacting the local individual and the collective worldwide.

5.1 Mix-Method Research

In this topic, we mention and briefly explain the techniques adopted to form this research methodological backbone. For more detailed information on this theoretical investigation, please refer to the annex 'The Journey and Research Methods.'

The mixed methods selected were adopted to deepen our critical studies on open algorithms and to explore their role in society. These methods were used combined to facilitate interdisciplinary research of open algorithms. They helped us create a robust structure for analyzing open algorithms from historical perspectives, knowledge foundations, and the current state of affairs.

Naturalism Observation involves observing algorithm systems in its natural habitat. It is a form of qualitative research that focuses on collecting, evaluating, and describing non-numerical data. To illustrate our naturalistic approach, we draw an analogy with Marco Polo's narrative of his adventures.

Historical Analysis helped us frame algorithms' historical evolution and to profoundly understand them, tracing their effects, impacts, and consequences to society throughout time. As part of this initial research efforts, we have published an article focusing on Brazil's Legal System, building up a chronological evolution of Machine Learning and Artificial Intelligence systems.

Textual, Interpretative and Thematic Analysis: We have developed detailed interpretations of primary texts and expert discussions to refine state-of-the-art conceptual understanding of open algorithms. Such an approach helped identify and analyze recurring themes in qualitative data (e.g., expert dialogues), which informed and supported our efforts to create conceptual frameworks for open algorithms.

Qualitative and Dialectic Research were adopted in expert dialogues and case studies to explore the meanings and impacts of open algorithms in society. It helped us engage experts from diverse fields in open-ended, non-structured conversations to generate insights for understanding algorithms between ideas.

Philosophical Analysis, we use the philosophical reasoning of pragmatism to help frame our algorithm investigation based on three aspects: ontology, epistemology, and ethics.

Peer Review and Validation: We have subjected our midterm research work to expert feedback and external validation (e.g., peer review) to ensure rigor, originality, and scholarly contribution. Our midterm paper was selected to be presented and published as part of The IEEE International Symposium on Technology and Society (ISTAS), the flagship conference of the IEEE's Society on Social Implications of Technology (SSIT), held from 28-31 in October 2021, in Waterloo, Ontario, Canada.

Narrative Synthesis and Writing Techniques: Without a transforming imagination, one merely records and describes algorithms retrospectively, failing to grasp their true essence in today's world. We have carefully designed this doctoral dissertation into clear, structured chapters, to sustain our methodological approach and theoretical findings.

We now highlight our research 'lenses' to this open algorithms inquiry.

5.2 Pragmatism Philosophy Lenses

In this topic, we explain how we have used philosophy (i.e., 'the science of knowledge') to help us deal with the lack of knowledge related to open algorithms. Philosophy, as we adopt in this research, uses everyday experience but, by definition, is a non-empirical discipline. In this research, philosophy is the science of fact, which does not generate facts but uses everyday life before us.

In this context, philosophy helps us investigate fundamental questions of open algorithms' existence, values, reason, mind, and language. We take Pragmatism Philosophy (in all its forms) as superior to other philosophies in helping investigate open algorithms. In Philosophy, Pragmatism represents surpassing positivism, realism, or any other mode of thinking that is not flexible or rooted in its use and the dirt of facts, context, and social justice. Pragmatism considered a way of thinking that focuses on practical problem-solving and experimentation rather than fixed doctrines or abstract theories.

Pragmatism is a philosophy emphasizing the use and practical consequences of ideas and actions in a context. Everything we do and think is engaged with matters of actual daily importance. Nothing is true or false; it either works or does not. Action and experience are considered the only ways we learn. In this sense, pragmatism is created through examples rather than a detailed analysis of what it involves.[62]

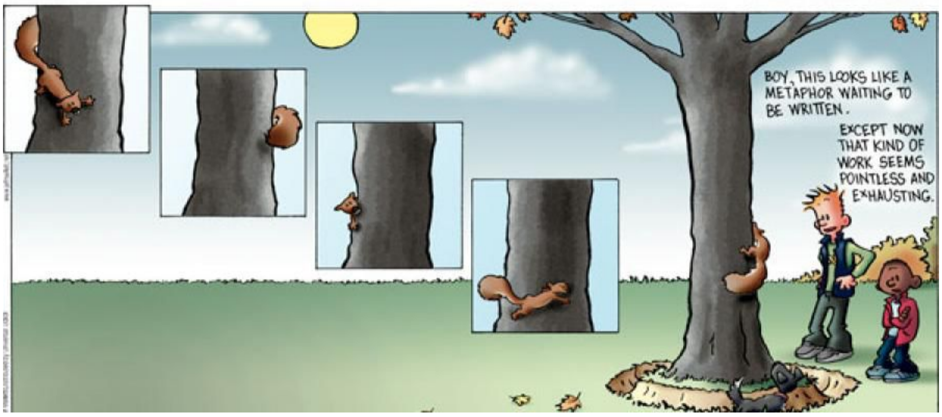
Classical Pragmatism primarily began in the meetings of the so-called Metaphysical Club at Harvard University during the 1870s (Hookway and Legg, 2021). It was powered by Charles Sanders Peirce (Campbell, 2011; Peirce, 1878, 1905). William James (James, 1907) and John Dewey (Dewey, 1938, 2021). For instance, Darwin's Evolution Theory (Darwin, 2003) (disciplined by laboratory experience) inspired members of the Metaphysical Club to demonstrate their work rigorously.

Back in the days of the Harvard Metaphysical Club, pragmatists described pragmatism through the following story tale: 'The tree, the squirrel, and pragmatism philosophy explained': "On a visit to the mountains, founders of Pragmatism engage in a 'ferocious metaphysical dispute' about a squirrel hanging on one side of a tree trunk while a human observer was standing on the other side. This human witness tries to get sight of the squirrel by moving rapidly around the tree, but no matter how fast he goes, the squirrel moves as fast in the opposite direction, and always keeps the tree

[62] BBC Podcasts on "Pragmatism (In our times). [Online]. Available at: https://www.youtube.com/watch?v=fn7WtXkI0sI. Accessed on Aug. 13th, 2022.

between himself and the man, so that never a glimpse of him is caught. The resultant metaphysical problem is this: Does the man go round the squirrel or not?” [63]

Figure 6 - A story tale: ‘The tree, the squirrel, and pragmatism philosophy’



Source: Philosophytalk[64]

In the above example, the correct answer depends on what you practically mean by ‘going around.’ If you mean passing from north of the squirrel, east, south, or west, then the answer to the question is ’yes.’ If, on the other hand, you mean in front of him, to his right, behind him, to his left, and in front of him again, then the answer is “no.” Philosophically, when pragmatic clarification disambiguates the question, all dispute comes to an end (Chang, 2017, 2019).

Fifty years later, Classical Pragmatism was reenergized by Richard Rorty *et al*. (Rorty, 1982), giving birth to a movement called “Neopragmatism.” Neopragmatism moves away from traditional philosophical concerns with objective truth and metaphysical grounding. Central to Neopragmatism is the rejection of foundationalism (the idea that knowledge must be based on an unshakeable foundation). Neopragmatism emphasizes pluralism, rejects traditional metaphysical debates, and highlights the adaptability and context-dependence of meaning. It advocates for a problem-solving approach to philosophy that engages with real-world issues rather than abstract theoretical disputes (Rorty, 1979; Putnam, 1981; Brandom, 1984).

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[63] Entry “Pragmatism”, in Plato: The Stanford Encyclopedia of Philosophy. Available at: https://plato.stanford.edu/entries/pragmatism/. Accessed on May 25th, 2022.

[64] A story tale: ‘The tree, the squirrel, and pragmatism philosophy.’ Available at: https://www.philosophytalk.org/blog/william-james-and-squirrel-example. Accessed on January 12th, 2025.

Above all, our pragmatism lenses are considered a practical approach, suggesting practicality precedes dogma (even though Pragmatism is itself a dogma). As a dogma, the Pragmatism doctrine argues that every conception is a conception of potential practical effects that allows any flight of imagination – provided this imagination ultimately alights upon a possible practical consequence, whereas consequence matters. Practical matters affect the questions people should ask and the answers they should seek.

Applying such ideas and concepts of Pragmatism Philosophy to investigate open algorithms leads us to see the open algorithm's meaning in its use and practical consequences. Pragmatism is empiricist in its adherence to facts yet finds room for faith – in one way or many. The world is one or many, and if its ‘'manyness” were so irremediable as to permit no union of its parts, not even our minds could ‘'mean” the whole of it at once. Could we apply such an approach to study open algorithms?

For instance, consider we all are made of star particles (Gleiser, 2012). As such, we are part of the universe. Nonetheless, as human beings, we know where our shape, body, and system begin and where we end. Each of us knows (or should know) where our bodies start and where they finish themselves. Our individuality is a manyness of subsystems belonging to a whole system, our body. So, instead of considering open algorithms a ‘black box’ or an ‘opaque system,’ could we consider their unity and wholeness as being made of as many computational, social, and environmental subsystems forming one specific open algorithm system?

This concept of ‘the one and the many’ comes from William James and his emblematic "Lecture 4: The One and the Many" (James, 2014), rejecting all absolute philosophies that create closed (obscured) systems. James argues: Is the world one or many? The oneness and the manyness of the world are thus obtained concerning what can be separately named – as open algorithms should be. They are neither a universe pure and simple nor a multiverse pure and simple. They are one and many.

* * *

For the records: We first presented this research methodological approach at the 2021 IEEE International Symposium on Technology and Society (ISTAS), the flagship conference of the IEEE’s Society on Social Implications of Technology (SSIT). Influenced by pragmatism, we elaborated the following conceptual framework as the first steps toward understanding open algorithms (Falcão, Meira, and Ramalho, 2021).

Every new concept first comes to the mind in a judgment.

Charles Sanders Peirce, 1907.

6 PRELIMINARY ANSWERS: ALGORITHMIC PRAGMATISM FIRST STEPS

We have discussed open algorithms' historical perspective and classical definitions up to a contemporary and modern understanding. This chapter seeks answers to questions directly related to the knowledge dimensions of these open algorithms. Through pragmatism *lenses*, this chapter presents an in-depth analysis of open algorithms – our object of study – based on an ontological and epistemological inquiry.

6.1 Ontological Inquiry: What are open algorithms?

Ontology is traditionally defined as the 'theory of what exists.'[65] [66] As a branch of philosophy, it deals with the nature of being, existence, and reality, examining the categories and relationships that constitute the world. (Breitman, Casanova and Truszkowski, 2007). In ontological terms, 'being' encompasses both objective (factual) and subjective (experiential) aspects of existence, dealing with everything from physical entities to abstract concepts (Gruber, 1993). Ontology seeks to identify the essence of what is real, exploring questions about existence, change, and the interconnections between things.[67]

However, this research does not refer to the technical usage of "ontology" in computer science (which deals with domain-specific knowledge structures) (Salatino *et al.*, 2018) but rather applies a broader ontological perspective to open algorithms. This inquiry considers the nature of open algorithms as entities that transcend specific knowledge domains and embody a more holistic, evolving system. We aim to understand open algorithms by exploring their components—hardware, software, data, and the people and processes that interact with them—not as static constructs, but as dynamic, ever-evolving entities.

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[65] Ontology. Britannica. Available: https://www.britannica.com/topic/ontology-metaphysics Accessed on Nov. 23th, 2023.
[66] Ontology. Merriam-Webster. Available: https://www.merriam-webster.com/dictionary/ontology Accessed on Dec. 15th, 2023.
[67] Being and Becoming in Modern Physics. Stanford Encyclopedia of Philosophy. Available at: https://plato.stanford.edu/entries/spacetime-bebecome/ Accessed on Set. 20th, 2024.

What is the ontological examination of open algorithms? In other words: How ontology can help us understand the nature of open algorithms and its relationship to reality? Are open algorithms artifacts, representing objective facts; or are they phenomena, shaped by nature (environmental, social, and technological forces)? Our inquiry delves into how open algorithms exist in the world; basically, asking: What are open algorithms?

Three primary metaphysical perspectives on ontology offer contrasting ways to approach such a question: (a) *Ontology as Immutable Deep Structure*: In this view, the world is composed of essential, unchanging components governed by immutable laws. (b) *Ontology as Timeless Unitary Being*: Here, distinctions and changes in the world are illusory; beneath everything, there exists a singular, timeless essence. (c) *Ontology as Ever-Changing Temporal Naturalism*: This perspective emphasizes change as fundamental. It holds that everything in the world, including the processes of change, is in flux. "Time is the transformation of transformation, and even change itself changes."[68]

This research adopts Temporal Naturalism to explore the ontology of open algorithms. We view open algorithms as dynamic entities that evolve, adapt, and transform over time, shaped by the interplay between energy, hardware, software, data, interfaces and human interaction. This approach challenges static models, urging us to examine the processes of creation, deployment, and transformation of open algorithms in real-world settings.

* * *

<u>Stack system</u>: Consider algorithms a "stack system," a hierarchical arrangement of different layers that work together to enable computing tasks (Brozek, Olszewski and Urbanczyk, 2014). "Stack system" as a multi-layered architecture where each layer builds upon the one ‘below’ it, contributing to the overall functionality and performance of the system. This layered approach is critical for understanding the opportunities and risks of open algorithms. Such a structured approach allows for efficient development, deployment, and management while providing a framework for addressing their associated risks.

Professor Margaret Martonosi, from Princeton University, compared ‘closed’ and ‘open’ algorithms stacks, highlighting the significant differences and implications

[68] Semi-structured dialogues with Philosopher Roberto Mangabeira Unger (Harvard University) and Political Science Prof. Carlos Sávio (UFF-RJ). Rio de Janeiro, 2022-2023.

of each. Prof. Martonosi underscores that layer after layer, each layer in the stack has a role in the performance and functionality of the systems. Improvements in hardware efficiency can lead to more powerful and energy-efficient open algorithms. Similarly, robust operating systems and software are needed to manage open algorithms' increased complexity and data demands. She emphasizes that understanding the interactions between these layers is crucial for addressing the risks associated with open algorithms, including data privacy, security, and ethical concerns. The middleware and frameworks layer can incorporate data encryption and access control mechanisms to protect sensitive information. This ontological examination is crucial in knowing open algorithms.

Closed, or classical computing stacks, are fundamentally hardware-centric. These architectures revolve around central processing units (CPUs), memory, input/output (I/O) devices, and system buses. The traditional model is based on von Neumann architecture[69], where the CPU executes instructions sequentially from memory, leading to deterministic and predictable outcomes. Closed algorithms in classical computing follows explicit instructions coded by developers, and these systems excel at processing structured data using predefined algorithms.

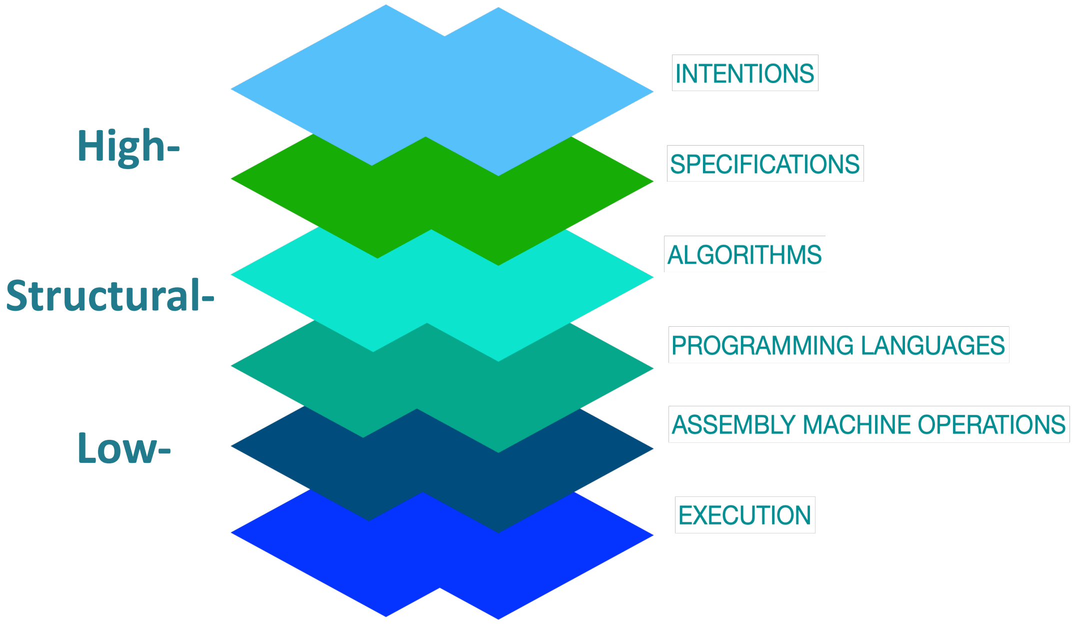
* * *

Levels of Abstraction: We now mention Giuseppe Primiero's framework of what an algorithm is (Primiero, 2020). Primiero is an Italian computer science theorist at the University of Milan. His research draws insights (i) from the philosophy of science to develop formal methods for analyzing algorithms and systems and (ii) from the philosophy of logic, to develop rigorous frameworks for reasoning about computational systems.

Primiero's methodology refers to three different stages an algorithm can be understood based on six levels of detail and implementation. We have designed our own perspective over Primiero's LoA.

[69] The von Neumann architecture is a computer architecture based on the First Draft of a Report on the EDVAC, written by John von Neumann in 1945, describing designs discussed with John Mauchly and J. Presper Eckert at the University of Pennsylvania's Moore School of Electrical Engineering.

Figure 7 - Algorithm Levels of Abstraction (LoA)



Source: Author ownership (2025).

- *At the highest LoA*, algorithms can be seen as abstract concepts that describe a procedure without specifying how the procedure is executed. This high LoA is useful for understanding an algorithm's general structure and purpose and for communicating its functionality to stakeholders.
- *At a structural LoA*, algorithms become more specific and define the instructions needed to solve a given computational problem. In this context, algorithms are seen as procedures that provide a step-by-step process for solving a particular problem. At this level of abstraction, algorithms are used by programmers to create software, and by computer, scientists to analyze their computational complexity and efficiency.
- *At the low LoA*, algorithms are seen as implementable abstract machines. In this context, algorithms are defined as sets of machine-level instructions that a computer processor can execute. This level of abstraction is useful for understanding how algorithms are implemented in hardware and optimizing their performance.

Those three different stages of abstraction serve different purposes and, within them, exist different levels of the algorithm.

- *The intention level* is where the user or stakeholder formulates and defines the computational problem. In other words, the cognitive act defines a computational problem to be solved. It formulates the requests usually provided by customers, users, and other stakeholders.
- *The requirements* are elicited and translated into rules or procedures at the specification level. That is to say: It is the formulation of the requirements necessary for solving the computational problem at hand through requirements elicitation.
- *The algorithm level* expresses the procedure providing a solution to the proposed computational problem, which must meet the specification requirements.
- *The high-level programming language level* is where the algorithm is implemented (source code) in a specific programming language (such as C, Java, or Python).
- *The assembly machine operations level* is where the high-level language is compiled into assembly code and then in machine code executable by a processor translated into machine code.
- *The execution level* is the physical level of the running software, i.e., of the computer architecture executing the instructions. It is where the computer hardware executes the algorithm.

Are the concepts explained above satisfactory for describing what open algorithms are? Not exactly, there are other concepts we can use as well.[70] To answer, "What are open algorithms?", we applied 'Linguistics Pragmatics' to our investigation. Here is how we did it: [71]

* * *

Linguistics Pragmatics: 'Linguistics,' the scientific study of language, is an entire area of study that scholars have explored for centuries. The field has a long history and has contributed to many fields, including psychology, philosophy, anthropology, and computer science – particularly in artificial intelligence, natural language processing, and computational linguistics (Silverstein, 1972).

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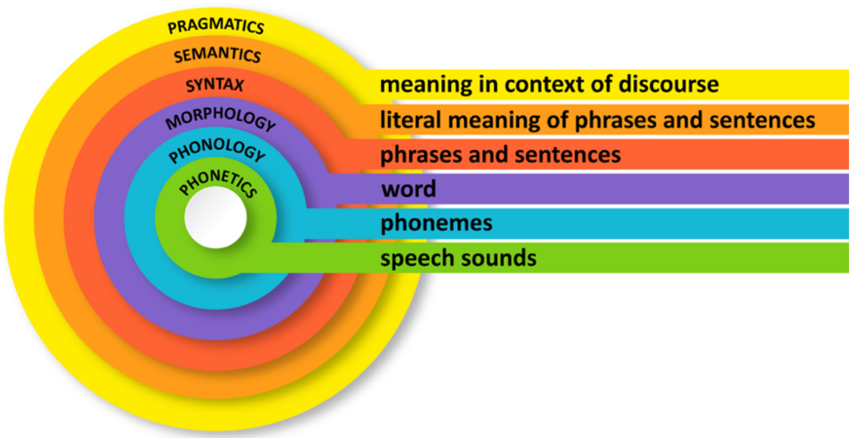
[70] NASA: Technology Readiness Levels. Available at: https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/ Accessed on February 18th, 2025.
[71] Ph.D Professor Geber Ramalho (UFPE/CIn – CESAR) oriented our investigation of algorithms based on linguistics.

‘Linguistics’ aims to understand how languages are constructed, function, change over time, and are used in communication (Finch, 2000). As a field of study, linguistics involves analyzing the properties of language, including its sounds, grammar, meaning, structure, development, and use in social contexts (Moyne, 1975).

As presented in ‘Figure 8 – Major Levels of Linguistics Structure,’ Linguistics encompasses a wide range of subfields that examine various aspects of language, including phonetics (the study of speech sounds), phonology (the study of sound systems), morphology (the study of word formation), syntax (the study of sentence structure), semantics (the study of meaning), and pragmatics (the study of language in context).

Figure 8 - Major Levels of Linguistics Structure



Source: James & Cook (2005) [72]

As a subfield of linguistics, pragmatics focuses explicitly on how context contributes to the meaning of language. As such, ‘Linguistics Pragmatics’ (Legg, Hookway; 2021) investigates how speakers' intentions, the specific utterances [73] they make, and the implicatures they convey contribute to the overall meaning of language in a given context. This includes analyzing how contextual cues like tone, facial expressions, and social norms influence language interpretation (Cummings, 2017).

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[72] Thomas, James J. & Cook, Kristin A., ed. (2005). “Illuminating the Path: The Research and Development Agenda for Visual Analytics, National Visualization and Analytics Center,” p. 110 (ISBN: 0-7695-2323-4).

[73] Utterance. Oxford Learner's Dictionaries. Available at: https://www.oxfordlearnersdictionaries.com/us/definition/english/utterance. Accessed on May 1st, 2021.

For instance, consider the sentence, "Can you pass the salt?" Semantically, this question inquiries about the listener's ability to pass the salt.[74] Pragmatically, however, it is understood as a polite request for the listener to pass the salt (Leech, 1983). This shift from a literal question to a request demonstrates the influence of context on meaning, a primary concern of pragmatics (Nordquist, 2019, 2020).

While linguistics is the broader study of language systems and structures, pragmatics zeroes in on how context shapes the use and interpretation of language. This distinction is crucial for understanding what language means and how it operates in real-world interactions. To further illustrate, let's analyze a different example. The sentence "It's cold in here" could serve multiple pragmatic functions depending on the context. As such, possible meanings are: *Statement of fact*: Simply stating that the temperature is low; *Request*: Implicitly asking someone to close a window; *Complaint*: Expressing dissatisfaction with the temperature (Ball; Damico, 2019).

Thus, we suggest a new look towards open algorithms. A look beyond ‘stack systems,’ ‘levels of abstraction,’ and ‘linguistics pragmatics,’ We propose two new constructs to answer “What are open algorithms?” One is called ‘algorithm oneness.’ The other, ‘algorithms constituents.

* * *

<u>Algorithm Oneness:</u> As articulated by classical pragmatist philosopher William James (1907), in his famous lecture: "The One and the Many." James argues that the world is neither a simple, unified whole (a "universe"), nor a chaotic multiplicity (a "multiverse").[75] Instead, he proposes that both unity and diversity coexist, where oneness is not a fixed, absolute concept but one that is practical, fluid, and context-dependent.

In the context of open algorithms, oneness refers to the collective integration of various artifacts, actors, and processes that shape the algorithm’s development and deployment. The "oneness" of an open algorithm is not an inherent property but emerges through the interactions and responsibilities of those who create, use, and maintain it. As open algorithms evolve, their oneness is continuously negotiated across multiple dimensions, e.g., technical, ethical, social, and legal.

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[74] Pragmatics. Stanford Encyclopedia of Philosophy, 2019. Available at: https://plato.stanford.edu/entries/pragmatics/#Intro Accessed on Aug. 13th, 2022

[75] JAMES, W. "The One and The Many", in Pragmatism: A New Name for Some Old Ways of Thinking. Cambridge University Press, 2014.

Pragmatically, an ontological inquiry over open algorithms' oneness involves answering some of the following questions: How are open algorithms thought, brought into being, and put to work? Who (one or many) is responsible for the open algorithm wholeness? How are open algorithms' decisions imagined, designed, developed, trained, and deployed? How is an open algorithm made? Who make open algorithms? What constitutes an open algorithm? Who chooses the dataset that trains the open algorithms? Who designs its interfaces and features? Who distributes, sells, and profits from it? How are open algorithms' calculations done, tested, and experienced?

Our pragmatic approach to understanding open algorithms, then, involves looking at their ontological wholeness in terms of 'The Sciences of the Artificial' (people, processes, and artifacts), each contributing to the evolving nature of the system (Simon, 2019). Whenever we ask "What is an open algorithm?" we must also ask, "Who is involved in building it?", "Which context bears it?" and "What are the boundaries of its effects?"

This proposed concept of 'open algorithm oneness' calls for recognizing the algorithm not as a discrete entity, but as part of a broader socio-technical assemblage that includes technical systems, human agency, and social practices. Computer scientists building open algorithms should engage in interdisciplinary studies to fully understand what they are building up.

Granting 'open algorithms oneness' to exist as a new construct to studying algorithms' ontology, we pass from the abstract to the concrete. Granting the 'one' and the 'many' to exist, what facts differs in consequence? Open algorithms, though one, should always be perceived as a collective experience. They are not a monolith. Nor are they infinite. They are a collective of other systems.

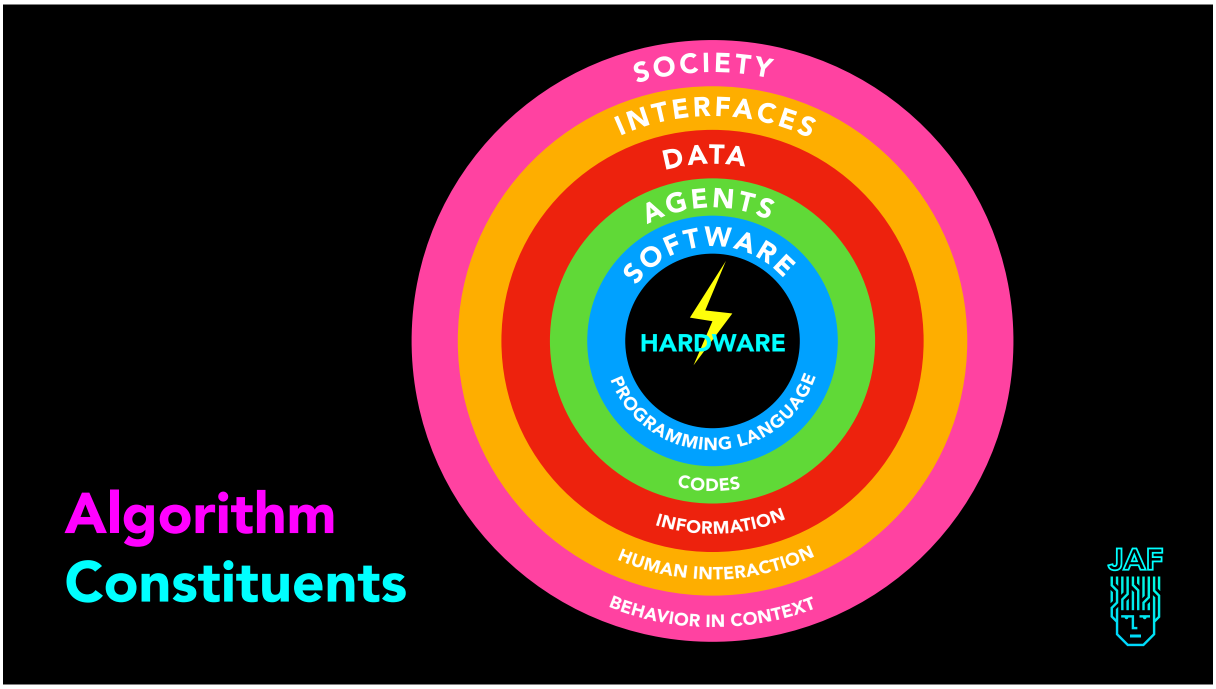
Oneness is a concept that identifies the existence of an open algorithm, distinguishing it from other intertwined dynamic systems, delimiting the boundaries, and setting responsibilities to facilitate future updates and maintenance. To understand the open algorithms' actions and consequences, one must understand where the open algorithms' fingertips start and where it ends.

'Open algorithms oneness' as an ontological dimension of algorithms studies help identify all actors, processes, and artifacts involved, their respective duties and responsibilities in creation, deployment, testing, maintenance, and upgrading open algorithms stages. In this context, open algorithms' actors should have had to explain (periodically) and justify the actions and social effects generated by their open algorithms. Actors should have had to explain how their open algorithms truly work and impacts society. Open algorithms actors should be capable of justifying the existence of their open algorithms to society, seeking to maximize their benefits and reduce their potential risk to those less favored.

As we continue, we sustain that open algorithms have evolved from closed algorithms and are not simply mathematical equations or instructions for computers to follow. Here are our perspectives on another new construct called 'algorithms constituents.'

Algorithm constituents: We propose that open algorithms have at least seven constituents, each playing a crucial role in our understanding of open algorithms. Finally, we elaborate on the following seven constituents to help us understand and describe what open algorithms are made of. We have drawn an image to represent the constituents of open algorithms. 'Figure 9 – Open Algorithms Constituents' presents knowledge layers we see constitute open algorithms' oneness:

Figure 9 - Open Algorithms Constituents



Source: Author ownership (2025)

Energy (represented in the image by a 'lightning') refers to the computational energy required to train and run algorithms, particularly in deep learning models. As these models become more complex and require massive datasets, the energy consumption for training and inference grows significantly. This has critical implications for both environmental sustainability and the scalability of open algorithms. Optimizing energy power in open algorithms is thus essential not only for reducing operational costs but also for addressing the ecological impact of resource-intensive computations. Researchers are increasingly focused on designing energy-efficient architectures, algorithms, and hardware to ensure that open algorithms can continue to advance without imposing unsustainable environmental and economic burdens.

Hardware encompasses the mineral materials, electrical and physical infrastructure on which the system operates. It includes the computational devices, processors, memory, storage, and other peripheral devices necessary to process and manipulate data and other hardware components that enable open algorithms' execution. Understanding the hardware aspects of open algorithms is essential for optimizing performance and efficiency.[76]

Software refers to the set of instructions written in a programming language that defines the behavior of open algorithms. It encompasses the algorithms, data structures, and implementation details – consisting of instructions that specify the steps to be executed by the hardware. Software comprises algorithms, data structures, control flow, and other programmatic elements (Berger and Zorn, 2023; Hunt *et al.*, 1999).

Agents are adaptive entities that solve problems or perform tasks by implementing algorithmic logic to transform input data into outputs. These agents, for instance, can be instantiated as Large Language Models (LLMs) like GPT, enabling them to comprehend complex contexts and nuances across various domains. However, while LLMs enhance an agent's understanding of problems, they often remain overly general and sometimes superficial. Multiple agents can be specifically organized and coordinated to collaborate and evolve, allowing them to improve their performance over time.[77]

Data plays a vital role in open algorithms, serving as input for processing and generating meaningful output. Data became a fundamental component of open algorithms, as open algorithms often depend on data to perform, train the system, and

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[76] Brazilian Academy of Sciences, Brazil. Magna Meeting: Artificial intelligence and the sciences: risks and opportunities. In https://www.abc.org.br/evento/rmagna24/ Accessed on May 25th, 2024

[77] The definition of 'Agents' presented relates to Professor Adriano Veloso (Computer Science/UFMG) great academic and entrepreneurial work. Since July 2024, the author joined Kunumi, a AI tech company led by Professor Adriano.

extract insights. Data selection, collection, processing, and storage significantly affect the system's functionality and impact. Data can be structured, unstructured, or semi-structured; open algorithms must be designed to handle and interpret different data types effectively.

Interfaces are bridges between users and the system. The points of interaction between open algorithms and its users, other systems, or the external environment. They define how users or external systems can communicate with and receive outputs from open algorithms. They enable communication, data exchange, and control flow. Designing user-friendly interfaces and ensuring interoperability with other systems are critical aspects of open algorithms component. "The Design of Everyday Things" by Donald A. Norman explores user-centered design and usability principles, including interface design considerations. Jenifer Tidwell's book "Designing Interfaces" is valuable for understanding interface design principles and best practices.

Society means active people, groups, and communities –both the individual level of society, its citizens, and the collectivity of us all as part of the universe. The societal component refers to humanity's participation in open algorithms, individually and as a group. Society kicks in with the database chosen to train open algorithms. Society interacts with the system's features. Society uses the system, training and retraining it. As open algorithms' component, society encompasses political, ethical, legal, economic, and social considerations, impacts, and consequences associated with the deployment and use of open algorithms.

What are open algorithms made of? To grasp the research's ontological perspective firmly, one must consider open algorithms as an intricate, dynamic assemblage of systems, comprising a unity of energy, hardware, software, agents, data, interfaces, and society.

* * *

<u>The Everyday Life of an Algorithm</u>: To illustrate and explore the ontological aspects of open algorithms' constituents, we draw on ethnographic research conducted by Professor Daniel Neyland, whose case study offers valuable insights into the everyday life of open algorithms.

Prof. Neyland, in his book The Everyday Life of an Algorithm, examines the development and deployment of an open algorithm (an algorithmic video surveillance system in European transport hubs). Through three years of ethnographic fieldwork, Neyland presents a comprehensive view of how open algorithms operate in real-world contexts, where they are not merely technological tools, but complex socio-technical systems involving multiple actors, decisions, and values (Neyland, 2019).

Neyland’s research reveals that open algorithms are far from neutral or objective. They are shaped by the social, political, and economic forces that influence their design, development, and use. His ethnographic approach—gathering data through observations, interviews, and document analysis—reveals how algorithms are continually transformed by their interactions with people, organizations, and society at large.

Neyland’s work highlights that open algorithms are not standalone entities but are part of a broader network of actors, processes, and systems that together shape their development and implementation. By mapping this network, Neyland is able to trace the ontological boundaries of open algorithms, identifying where they begin and end, who is responsible for them, and how they evolve over time. Furthermore, we could also have used such an ethinographical approach to map effects, impacts and consequences of algorithms to society.

Neyland’s ethnographic study offers several key lessons that resonate with our investigation, as such, a *clinical approach* (Lam *et al*., 2024; Terzis, Veale and Gaumann, 2024) to open algorithm’s contituents and oneness:

Continuous Testing and Evaluation: Open algorithms must be recurrently tested against real-world outcomes, as their behavior can change over time due to evolving inputs, contexts, or user preferences. This ongoing assessment is crucial to ensuring that algorithms remain fair, unbiased, and ethical.

Ethical Oversight: Neyland advocates for an independent ethics board that evaluates the broader societal impacts of open algorithms. Such a body can ensure that algorithms are developed with the right expertise and are monitored for ethical implications throughout their lifecycle.

Inside and Outside Perspectives: Neyland’s approach emphasizes the importance of moving between the "inside" (those directly involved in algorithm development) and the "outside" (external experts, stakeholders, and societal actors) to gain a holistic understanding of the algorithm’s effects. This dual perspective enables a more thorough and transparent assessment of open algorithms.

Social and Political Dimensions: Open algorithms must be understood within their broader social, economic, and political contexts. Neyland’s research illustrates how the algorithmic decision-making process cannot be isolated from the power structures and societal values that influence it.

As a result of our inquiry, knowledge from adjacent areas of study appears to be necessary to bridge the ‘knowledge gap’ related to open algorithms, specifically in human and social studies. We were inspired by Neyland's ethnographic approach to help map, identify, and explain the seven constituents of open algorithms. Through his work, Neyland shows that open algorithms ontology is not straightforward but involves multiple actors, diverse processes, and complex relationships.

6.2 Epistemological Inquiry: What knowledge is needed to know open algorithms?

Epistemology is one of the central branches of philosophy concerned with the nature, scope, and sources of knowledge. Epistemology delves into the fundamental questions of what knowledge is, how we acquire it, and how we justify our beliefs about the world (Krasmann, 2020).

Traditionally, knowledge has been defined as justified true belief. This formulation, primarily attributed to Plato[78], suggests that for someone to know something, three conditions must be met to form the foundation of traditional epistemological theories: (a) *Belief*, the individual must believe in the proposition or fact. (b) *Truth*, the proposition must be true. (c) *Justification* - there must be a rational basis or justification for believing it. These definitions emphasize the interplay of belief, truth, and justification. For example, if I believe that the sky is blue, and this belief corresponds to the actual color of the sky, my belief can be justified by my perception of the world. The knowledge is, in this sense, true and justified.[79]

Epistemology also investigates the *scope* of knowledge, e.g., what kinds of things can we know about open algorithms? What is the knowledge needed to understand open algorithms? And how do we gain such knowledge about open algorithms?

Historically defined by pioneers like Knuth and Markov, algorithms were not initially conceptualized considering their human, social, and environmental effects,

[78] Plato, Theaetetus (ca. 369 BCE). In this dialogue, Plato presents the foundational ideas of knowledge as justified true belief.
[79] Epistemology Cambridge Dictionary. Available: dictionary.cambridge.org/pt/dicionario/ingles/epistemology. Accessed May 1, 2021.

impacts, and consequences on people, groups, and communities worldwide (see Topic 4.3). However, this epistemological stance seeks to offer a new approach grounded in pragmatism. If any, we hope to provide bridges to deal with the referred knowledge gap in open algorithms.

For the last 100 years, computer science's epistemological studies of algorithms have primarily focused on mathematical, physical, logical, and statistical knowledge.[80] Computer science's focus on such knowledge foundations has blindsided a more human, social, environmental, and pragmatic knowledge perspective of open algorithms. Not surprisingly, today's algorithm studies need new concepts, methods, and modes of thinking.

* * *

Pragmatism, particularly as developed by classical philosophers like Charles Sanders Peirce, William James, and John Dewey, offers us an epistemological framework in shaping open algorithms foundational knowledge. Emphasizing 'use', 'experience' and 'practice', classical pragmatist approach inspires us to ask a basic question, whether open algorithms work or do not work in society. As such:

Charles Sanders Peirce taught that knowledge is inherently tied to the process of inquiry: A dynamic, open-ended process of problem-solving that is shaped by use and experience. According to Peirce, knowledge arises from our interactions with the world and is always provisional, evolving as we test our hypotheses and revise our beliefs based on experience.

William James, in his theory of pragmatic truth, James suggested that the truth of a belief is not merely whether it corresponds to an objective reality but whether it proves to be useful and effective in practical terms. In his famous dictum, "truth is what works," James framed knowledge as something that is validated through its practical consequences, through the outcomes it produces when applied in the world.

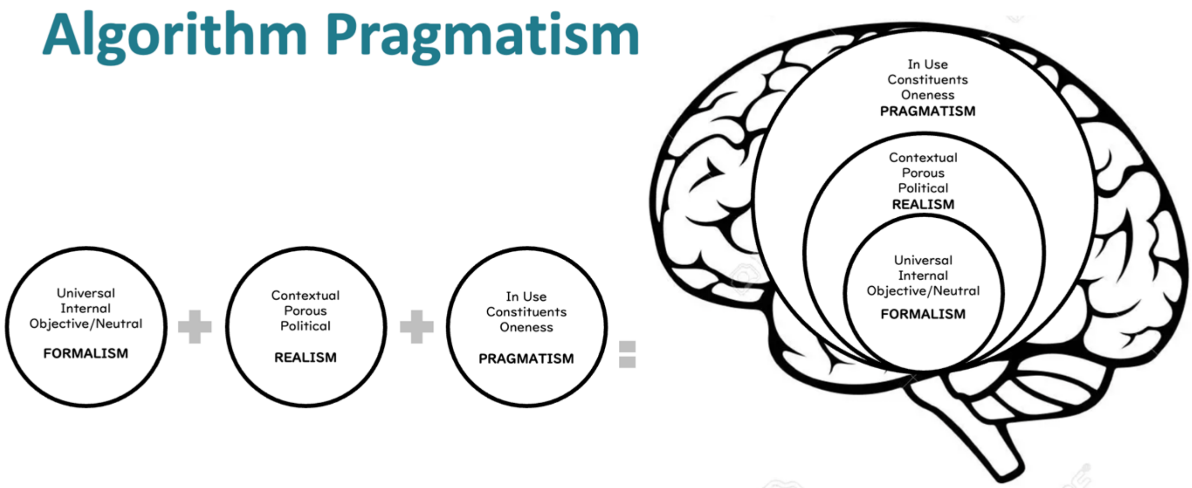
John Dewey extended pragmatism into the realm of education and democracy, emphasizing that knowledge is not static but is shaped by our collective experiences and social interactions. He believed that inquiry is not an individual pursuit but a social process in which communities test ideas through shared action and collaboration.[81]

[80] "The Epistemological Status of Computer Science." Stanford Encyclopedia of Philosophy, Jan. 19, 2021. Available at: https://plato.stanford.edu/entries/computer-science/#EpisStatCompScie.
[81] Colther, Cristian & Doussoulin, Jean-Pierre. (2024). Artificial intelligence: Driving force in the evolution of human knowledge. Journal of Innovation & Knowledge. 9. 100625. 10.1016/j.jik.2024.100625.

Open algorithms evolve over time – from closed algorithms, to natural language processes, machine learning, deep neural networks and artificial intelligence (Falcão and Cirillo, 2020). Through collective learning processes, open algorithms' knowledge is continuously tested and updated based on new data and contexts (Cormen *et al*., 2009). Such a continuous learning process aligns with the pragmatic idea that knowledge is never final or absolute but always subject to revision through use and practice.

This research suggests complementing formalism and realism, as presented, with pragmatist approaches to understanding open algorithms in the world. Formalism, realism, and pragmatism, together, take us to a more contemporary, interdisciplinary, and complementary mindset.

Figure 10 - Formalism and Realism Subsumed by Pragmatism



Source: Author ownership (2025).

You never really know if open algorithms have a positive or harmful effect on society because, for that, you need to know, in advance, what and who their decisions will affect. It depends on the use. Trials, tests, and constant experiments are the way to deal with open algorithms' dynamic use. When open algorithms are in use, deciding, it can happen in different places and times depending on its context. For example, open algorithms used in a self-driving car might make real-time decisions based on data from sensors and cameras. However, open algorithms used in financial credit scoring might make decisions based on historical data and current information when a loan application is submitted (Yuan, 2021).

Open algorithms experience the world based on their use. While in use, they can present information and carry out actions. Their use fills in the details to allow a complete understanding of open algorithms. Without action, open algorithms are unable to experience the world. It is the use that provides the meaning.

* * *

Linguistics Pragmatics: A first version of this research approach can be found in an article titled 'Algorithmic Pragmatism First Steps' (Falcão, Meira, and Ramalho, 2021). This article was selected to participate in IEEE-ISTAS21, held by the University of Waterloo and the University of Guelph, Canada.[82] Based on a clinical pragmatics approach, we propose a conceptual framework for understanding how open algorithms work and interact with society and how they convey knowledge. From linguistics, we seize two concepts – utterance and implicature – to understand open algorithm.

'Utterance', meaning expressing something in words. Utterances are the units of sound one makes when one talks. Linguistics Pragmatics investigates how context affects the meaning of utterances (Haye and larraín, 2011). The pragmatic signs accompanying those utterances give syntax and semantics their true meaning (Unger, 2007). "Utterance" is the smallest unit of speech and the object of study in linguistics pragmatics analysis. Could we draw an analogy between utterance and open algorithms? Could we say open algorithms are digital utterances? [83]

'Implicature', refer to conveying or suggesting a meaning indirectly through speech or to the meaning implied by that act. It can arise from either the specific words used in a sentence or the context of the conversation and take conventional or unconventional forms. Could we learn from 'implicature' and apply it to the context of open algorithms? [84]

Examples of implicature in linguistics include figures of speech like metaphors and irony and subtle forms of communication such as loose language and

[82] The IEEE International Symposium on Technology and Society (ISTAS) is the flagship conference of the IEEE's Society on Social Implications of Technology (SSIT). ISTAS is a multi/inter/trans-disciplinary forum for engineers, policy makers, entrepreneurs, philosophers, researchers, social scientists, technologists, and polymaths to collaborate, exchange experiences, and discuss the social implications of technology.
[83] Oxford Learner's Dictionaries.
[84] IMPLICATURE. The Stanford Encyclopedia of Philosophy. Available at: https://plato.stanford.edu/entries/implicature/. Accessed on Aug. 13th, 2022.

understatement (Grice, 1975). Take, for example, the following exchange: A (to passerby): I am out of gas. B: There is a gas station 'round the corner. Here, B does not say but conversationally implicates that the gas station is open – otherwise, his utterance would not be relevant in the context. Conversational implicatures have become a central focus in linguistics pragmatics. A key challenge is distinguishing between words and phrases' specific meanings and logical entailments versus the more generalized conversational implicatures that arise during communication. Additionally, there is an ongoing debate about the extent to which the meaning of a sentence directly determines what is explicitly communicated. [85]

In Linguistics, while semantics concerns the inherent meaning of words and sentences, pragmatics examines how those meanings can be influenced by various factors, such as the speaker's intention, the relationship between the interlocutors, the physical and social context, and the conventions of language use. One of the central insights from pragmatism presented in ‘Frame 1 - Algorithmic Pragmatism Conceptual Framework’ is that the meaning of any given statement depends heavily on its pragmatic use: The same words or phrases can take on different meanings depending on who is speaking, to whom, and in what circumstances. To fully understand an open algorithms’ output, we must know where and how it is being used. Open algorithms that operate in financial or educational contexts might generate different interpretations of "risk" than those operating in healthcare – e.g., whether the algorithm's decision-making is valid and justifiable. Understanding these sensitivities is key to an epistemology inquiry of open algorithms.

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[85] IMPLICATURE. The Stanford Encyclopedia of Philosophy. Available at: https://plato.stanford.edu/entries/implicature/. Accessed on Aug. 13th, 2022.

Table 2 - Algorithmic Pragmatism Conceptual Framework

	Field of Study	
	Linguistics *How to use language in a context in particular ways*	***Algorithms*** *How to use algorithms in a context under justified ways*
Object of Study	**Utterance**: Linguistic information produced by the sender	**Effects**: The computer system output produced by the algorithm
Source Sender	Humans who encode messages, data and transmit information (Written / Orally)	Of what intention does the algorithm consist? Where it starts, and where it ends? To what extent does it change?
Receiver Observer	The one who receives decoded information from the sender.	The one who receives the algorithmic effects from the sender.
Context Space-time	Physical background in which the utterance is going on; where the conversation takes place.	Physical and digital background in which the computer system is going on, where the algorithmic intervention occurs.
Purpose	The relationship between the source and the information.	If algorithms make decisions, who takes care of the algorithms?
Social background	The relationship between interlocutors.	The relationship between humans, computer machines, and algorithms.
Background	A set of extra-linguistic factors that conditionate both the production and the meaning of the utterance.	A set of extra-algorithmic-intervention factors that conditionate both the production and the meaning of its effects.
Bias	Belong to a specific social group is understood by that group (set of speakers and hearers).	Belong to a specific set of data training and is understood by that data training.
Situational	It can be understood only by the source and the observer – here and now.	It should be understood by whoever is affected – here and now.
Metaverse	It is the linguistic environment where a word can be found (utterances previous to the utterance).	It is the digital system environment where algorithms are found (intervention previous to the intervention).
Epistemic	Knowledge shared by speakers and hearers	Knowledge shared by algorithms' stakeholders and scientists.
Pragmatic information	A set of knowledge, beliefs, opinions, and feelings of a person.	Algorithmic interventions' intentions when designing the world's composition.

Source: Falcão, Meira and Ramalho (2021)

* * *

Unintended Consequences: From our pragmatism approach, ‘belief’, 'truth', ‘justification’, ‘scope’, and ‘sources’ of open algorithms lie in their ability to fit within their respective use, ensuring that their decisions are meaningful to society, justified, and ethically sound. From this research epistemic perspective, open algorithms reveal themselves when connecting to their respective social use.

As algorithms become more integrated into the fabric of society, they must be evaluated not only for their technical accuracy but also for their broader societal impacts. For example, an algorithm used in the financial sector has very different implications than one used in a healthcare system. In the financial sector, understanding algorithms involves knowledge of the monetary system, economic policies, and financial regulations. In healthcare, the focus shifts to patient care protocols, medical ethics, and legal frameworks.

One paramount case study helped us reflect on how use, experience and practice play significant roles in open algorithms. We refer to the Correctional Offender Management Profiling for Alternative Sanctions (COMPAS) algorithmic system. Pro-Publica, an independent research organization, exposed COMPAS, explaining the system was skewed and unfair.[86]

The investigation identified that because of two specific questions, out of 137 in the questionnaire, COMPAS is acting biased. The questions causing such social damage are: “How many people from your family were incarcerated?” And “How old were you when you left your parents' house?” These two questions relate to Human and Social Sciences and deserve deep reflection (and public policies) before becoming weighed in a recidivism formula. The point is that COMPAS lacks human and social knowledge to understand the consequences of its input questionnaire being transformed into data and the bias involved, which can lead to critical harm, such as extending someone’s time in jail.

Open algorithms are making consequential decisions that affect society, with impacts and consequences that impact us all. They produce knowledge by analyzing data and offering insights, patterns, and predictions. This data-driven nature often gives open algorithms an appearance of objectivity. But they are shaped by human choices (e.g., in model design, data selection, and contextual use). This means that

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[86] Pro-publica research, 2016.

the authority of open algorithms is influenced by biases and assumptions embedded in human and social processes. Furthermore, danger seems to stem from the adaptability, uncontrollable characteristics, and unintended consequences of open algorithms (Eubanks, 2018).

* * *

Karl Popper: In this context, it is worth mentioning Karl Raimund Popper (1902–1994): An Austrian-British philosopher and academic, widely regarded as one of the most influential philosophers of science in the 20th century, founder of the Department of Philosophy at the London School of Economics (LSE), developed critical rationalism, an approach to knowledge that emphasizes continuous criticism over foundational certainty.

Popper's "Three Worlds Theory," introduced in works like Objective Knowledge (1972) and The Self and Its Brain (1977), offers a framework for understanding reality through three interacting realms. These realms –World 1, World 2, and World 3– are not isolated but emerge sequentially as distinct yet interrelated dimensions of existence.

"World 1" represents the material realm, encompassing physical states and processes studied by the natural sciences, including physics, chemistry, and biology. Initially, the universe consisted solely of World 1 in a lifeless state. Over time, through evolutionary processes, biological life emerged, introducing a new level of complexity within the material world.

"World 2" is the realm of mental states, ideas, and processes, including conscious and unconscious experiences such as sensations and thoughts. This realm arose from biological evolution, dependent on nervous systems and brain functions, yet distinct from purely physical processes. While the biological structures of World 1 shape World 2, World 2 represents a qualitatively different form of existence that allows for subjective experience and cognition.

"World 3" consists of the cultural realm, which includes human intellectual products such as scientific theories, works of art, laws, and institutions. Although these entities originate from human thought within World 2, they gain an independent existence, influencing cognition and shaping human behavior. The development of World 3 marks a significant distinction between humans and other animals, as only humans engage with and expand this realm by treating mental constructs as independent entities.

Popper’s theory challenges reductionist perspectives that attempt to explain later developments solely in terms of prior states. Instead, he argues that the emergence of each world represents a creative, non-reducible evolutionary process. World 2 arose from the increasing complexity of biological systems, while World 3 developed through the expansion of human cognition and cultural production.

A key aspect of Popper’s argument is that World 3 does not directly affect World 1 but influences it through human cognition and action. For example, a scientific theory about nuclear reactions does not lead to the construction of a nuclear reactor. Instead, its impact is mediated through human understanding, decision-making, and physical implementation. This dynamic interaction between the three worlds underscores an emergent, evolving reality where knowledge, culture, and material existence continuously shape one another.

As we transition to more recent views on the knowledge needed to understand open algorithms and their role in the world, the ideas of two avant-garde pragmatists: Computer Scientist Silvio Meira and Philosopher Roberto Unger. Together, their thoughts provide a compelling bridge between the epistemology of open algorithms and the modern complexities of their existence.

* * *

Silvio Meira, a pragmatist Brazilian scholar, introduced the concept of ‘fí.gi.tal world’ (see figure 11). In english, "phi.gi.tal" world, which blends the physical, digital, and social realms into a seamless, interconnected experience (Meira, 2021).

Figure 11 - Figital

Source: Meira 2021 [87]

In Meira’s view, the traditional boundaries between physical objects, digital technologies, and social systems are increasingly blurred, creating a new, hybrid world

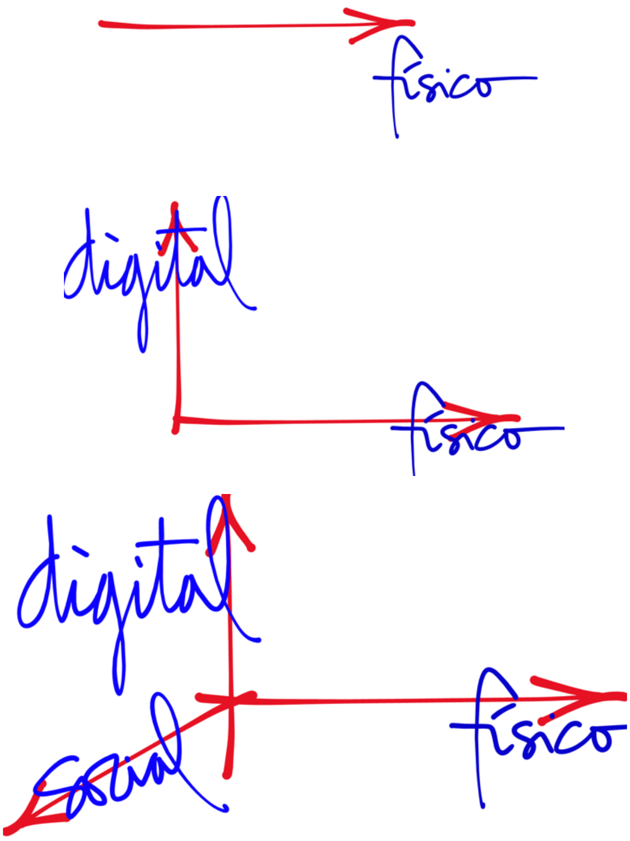
[87] https://silvio.meira.com/ Accessed on March 5th 2025.

in which the interactions between people, technologies, and environments shape knowledge in complex and unpredictable ways. For Meira, open algorithms force us to reconsider traditional epistemological boundaries. Just as classical pragmatism emphasized the contextuality of knowledge, Meira's phi.gi.tal concept underscores the interdependence of knowledge across physical, digital, and social domains.

The knowledge we create today, particularly through open algorithms, is not isolated in any one domain but exists as part of an integrated system that influences and is influenced by the world around it. In this "phi.gi.tal" world, knowledge is no longer something static or abstract; it emerges in real-time through continuous interaction and adaptation across diverse contexts involving energy, hardware, software, algorithms, data, interfaces, and society.

The *phi.gi.tal* concept raises important questions about privacy, security, and ethics that affect all of us – in one way or another. As more devices and objects become connected to the Internet, there is a growing risk of cyber-attacks and data breaches.

Figure 12 - ‘Fígital’: Physical, Digital and Social Dimensions



Source: Meira 2021 [88]

The lines between the physical, digital, and social worlds are becoming increasingly blurred as people and objects are increasingly connected to the Internet. We would even add another dimension to the three proposed by Prof. Meira – a fourth layer representing an environmental dimension. In this scenario, we must learn to create a *phigital* experience to meet our evolving global needs and expectations toward open algorithms. For instance, when moving an open algorithm from 'in the lab' to be used 'in the world,' human, social, and environmental context makes all the difference. Open algorithms then become not only an epistemological blend of mathematics, physics, logic, statistics, engineering, and design but also an amalgam with human, social, and environmental knowledge. Open algorithms, in this sense, is continuously evolving, adapting to new phi.gi.tal contexts.

[88] https://silvio.meira.com/ Accessed on March 5th 2025.

Another perspective of the broader context in which open algorithms operate comes from Harvard Professor Roberto Mangabeira Unger, a prominent social theorist and philosopher (Unger, 2024).

* * *

Roberto Mangabeira Unger: situates open algorithms under the knowledge economy (Unger, 2019). Unger argues that we are undergoing a profound transition from the industrial economy—an economy grounded in physical resources and production—to the knowledge economy, where information, creativity, and innovation are the primary drivers of economic and social progress. For Unger, the knowledge economy is not merely a technological transformation; it represents a fundamental shift in how value is created.

As part of the Knowledge Economy, open algorithms are no longer just about scientific truths or technical expertise. It is intricately tied to social systems, cultural values, and political structures. This perspective echoes classical pragmatism, which posited that knowledge is shaped by practical consequences and contextual factors. Similarly, Unger emphasizes that the value of knowledge today hinges on its ability to address complex societal problems and its potential to reshape economic and social structures.

The knowledge economy presents an economic framework that moves away from traditional, resource-based sectors like oil and minerals, instead prioritizing knowledge and innovation as the key drivers of productivity and growth. This shift provides a relevant context for understanding open algorithms. In this research, we position the knowledge economy as the broader framework within which open algorithms must be understood.

The knowledge economy fundamentally diverges from the industrial economy. Whereas the industrial era was centered on tangible inputs—such as raw materials and labor—the knowledge economy thrives on the creation and manipulation of information. Open algorithms, as a paramount manifestation of this new economic order, are deeply intertwined with issues of wealth distribution and societal structure. While they can foster innovation, open algorithms also contribute to significant inequality, particularly when those who control valuable knowledge use open algorithms to extract substantial economic rents.

The knowledge economy marks a profound shift in both productivity and growth, powered in large part by open algorithms. It reflects a new economic order in which generating and disseminating knowledge takes center stage. This economy is increasingly defined by the role of knowledge in production processes, and by the growing global significance of open algorithms. As a result, the knowledge economy provides a compelling lens for examining the impacts of open algorithms, with far-reaching societal and economic consequences.

Interconnectivity and interdependence are key features of the knowledge economy. Open algorithms, in this context, thrive through networks of knowledge and experience, with collaboration emerging as a critical success factor. In this economy, entrepreneurship plays a crucial role, with successful companies often marked by a combination of investment funds, specialized knowledge, risk-taking, and experimentation.

However, the rise of the knowledge economy also brings new challenges, particularly in terms of social organization. Traditional institutions, such as labor unions and political parties, must adapt to address the complex issues arising from open algorithms and technological innovation. Additionally, the boundaries between work and leisure are becoming increasingly blurred. To navigate these challenges, governments must invest in education and infrastructure, foster innovation and creativity, and promote new forms of social organization—efforts that align with the imperatives of the open algorithms in the knowledge economy.

* * *

By connecting classical pragmatism of Peirce, James and Dewey with the contemporary perspectives of Meira and Unger, we see how the pragmatic tradition offers a powerful lens through which we can understand the evolving role of knowledge in open algorithms. Like the pragmatists, Meira and Unger emphasize that knowledge is context-dependent, adaptive, and socially constructed. The phi.gi.tal world and the knowledge economy they describe highlight the increasing complexity and interconnectedness of open algorithms. These systems are no longer confined to specialized domains but exist at the intersection of the physical, digital, and social realms, continuously shaped by the actions and decisions of individuals and societies.

In this new knowledge dimensions (i.e., Fígital) and new economic landscape (i.e., The Knowledge Economy) the pragmatist's emphasis on use and context remains more relevant than ever. Without use, open algorithms cannot experience or engage with the world – they are purely abstract models. Open algorithms derive their meaning and purpose from their specific use – do they work or not? To understand the value of open algorithms in the 21st century, we must look at its capacity to address social interactions.

In ‘fí.gi.tal.’ and ‘the knowledge economy’, open algorithms derive authority from the institutions that deploy them, such as governments, universities, NGO’s and tech companies. While this institutional trust boosts their credibility, it also raises concerns about how power is distributed, as algorithms may serve the interests of a few and reinforce societal inequalities (Barocas, Hardt and Narayanan, 2021). Here is a real example: Nexa Technologies' involvement with the authoritarian regimes in Libya and Egypt (Fussell, 2021). The company has had four former executives indicted over accusations of supplying these countries with algorithms eventually used for the invasive surveillance and sometimes kidnap, murder, and torture, of activists and dissidents.

The authority of open algorithms is also linked to the expertise of the professionals who create and maintain them. Computer scientists, data scientists, software engineers and self-taught tech-geniuses are often seen as credible sources. The knowledge required to understand these algorithms is inaccessible to most people, raising concerns about whose interests are represented in their use.

Their use delimits context and defines their scope. To know open algorithms is to understand their use and context (i.e., oneness – see Topic 6.1). What appears as complexity in open algorithms are, to a considerable extent, the complexity of their use and context, in which open algorithms are expected to respect and adapt – in ‘fí.gi.tal’ dimensions of ‘the knowledge economy.’ Open algorithms are not neutral; they reflect the values of those who create them. Together, *creators and creatures* can perpetuate societal biases. In decision-making areas like criminal justice and healthcare, biased algorithms can reinforce inequalities – making open algorithms epistemic authority contested.

The epistemological aspects of open algorithms are multifaceted and interdisciplinary, as they are powerful tools for knowledge generation, offering insights based on real-time interaction, large-scale data, and robust analysis. The knowledge needed to know open algorithms is shaped by interdisciplinary studies, highly technical expertise, and the broader social context in which they operate.

Inside me, everything is in a state of ferment.
Ludwig Wittgenstein, 1913.

7 FINAL REMARKS ON OPEN ALGORITHMS TOWARDS A SCIENCE OF ALGORITHMS

In this dissertation, our object of study is understanding the nature of open algorithms in the world. Our research theoretical work dives into the nature and foundational knowledge of open algorithms. From a naturalistic approach, open algorithms appear to be “new beasts” in the realm of algorithms. Based on ontology, epistemology, and ethics, our work conceptualizes and tries to identify, describe, characterize, and know the nature of open algorithms.

This research suggests we use pragmatists ‘lenses.’ Through pragmatism, we consider a new approach to understanding and differentiating “open algorithms” – our object of study – from “closed algorithms,” artifacts that computer science has studied for the last 100 years or more.

The pragmatism philosophical framework used in our interdisciplinary inquiry suggests new knowledge layers are needed to grasp open algorithms and understand their use, context, effects, impacts, and consequences to people, groups, and communities. Pragmatically, we strive to provide society (i.e., developers, scientists, regulators, policymakers, judges, lawyers, politicians, financial and business professionals) with the ability to utilize open algorithms for the betterment of society.

This doctoral research on open algorithms has led us to consider the need for a broader conceptual framework—what we refer to as a science of algorithms. This emerging perspective goes beyond the traditional boundaries of computer science, calling for a multidisciplinary approach to the study of algorithms. Like any science, it would rely on systematic methods of inquiry, empirical analysis, theoretical grounding, and critical scrutiny. Such a science would examine algorithms not only as technical artifacts but also as social, ethical, legal, and epistemological constructs. In particular, the study of open algorithms highlights the importance of fields such as philosophy, law, sociology, economics, and political science. We envision a science of algorithms as a truly interdisciplinary field, grounded in both empirical rigor and theoretical reflection, to address the complex role algorithms play in our societies.

As part of this research’s strategy to achieve its purpose and goals, we have tested our ideas and findings on myriad occasions (i.e., lectures, panels, and two academic publications). Typically, we presented a set of slides to spark a dialogue on open algorithms. In chronological order, here are the highlights of such a thrilling journey that contributed so much to this research's present maturity:

On September 9th, 2021, we submitted an article explaining our thoughts on Algorithmic Pragmatism to 'IEEE ISTAS21 Technological Stewardship and Responsible Innovation'. The article was selected and presented at the end of 2021 and then published in early 2022, entitled 'Algorithmic Pragmatism: First Steps'. (Falcão, Meira and Ramalho, 2021). This publication is a landmark in our research, giving us protagonism when the subject is pragmatism philosophy and algorithm critical studies.

During the "42nd Congress of the Brazilian Computing Society" at the Fluminense Federal University (UFF/Brazil), in August 2022, we presented our pragmatism approach in a panel about the "Influence of large corporations in making Internet legislation more flexible." [89]

In January 2024, at a World Innovation, Technology, and Services Alliance – WITSA seminar, we presented our ideas in a panel with two specialists, one former white house staff and one OCDE director, responsible for global AI regulation monitoring. The panel was called: "Regulation and the Future of AI in Business."[90]

In April 2024, we co-chair the inauguration of an AI center for strategic studies in Brazil in a dialogue with Brazilian Senator Eduardo Gomes, rapporteur of the Brazilian AI Bill. We conducted a panel called: "High-Level Dialogue on AI Ethics & Regulation."[91]

"Rio2C," the Latin America conference on creativity, in June 2024, discussed how AI can radically transform education. We presented this research perspective in a panel called: "The world of AI and AI in the world – a Pragmatism."[92]

In June 2024, as part of the "LED Festival," a major Brazilian conference on Education powered by Grupo Globo Communication was held in the Museum of Tomorrow, Rio de Janeiro. In a roundtable with other specialists, we explained our views of open algorithms pragmatism and towards educational challenges. As part of

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[89] https://youtu.be/FAFpj_vhLmg Accessed on Aug. 24th, 2024.
[90] https://www.youtube.com/watch?v=caeSP6h_GQo Accessed on Set. 5th, 2024.
[91] https://www.instagram.com/p/C6G2q18ul3T/?igsh=ZGNnZTZyeGs4djRi&img_index=1 Accessed on Set. 10th, 2024.
[92] https://content.rio2c.com/programacao_rio2c/como-a-inteligencia-artificial-pode-transformar-radicalmente-a-educacao/ Accessed on Set. 29th, 2024.

a panel that later became a broadcast TV Program, we discussed the following subject: “Navigating artificial intelligence: how education can guide us.” [93]

In July 2024, the Technology and Society Institute (ITS/Rio), in partnership with the Humboldt Institute for Internet and Society (HIIG) and the German Center for Research and Innovation in São Paulo (DWIH São Paulo), featuring Brazilian and international experts, invited us as panelists in the “IA20: Artificial Intelligence in the Global Context”, as part of the G20 Summit in Brazil, to debate, pragmatically, challenges and opportunities of AI in different sectors. [94]

In October 2024, Futura, a broadcast TV channel focused on education in Brazil, produced a series of lengthy interviews with experts in AI, innovation, and its impacts on society. Our interview theme was: “AI in Practice: Entrepreneurship, Universities, and The Market.” [95] During G20 Summit Brazil, we also participated as panelists in the “MIT Technology Review – G20 Summit,” in a panel called: “AI and the context of Global geopolitics: how the new tool and context influence the geopolitical future?” [96]

In November 2024, we lectured at the “National Congress of Philosophy, AI, and Information” at the Federal University of Ceará (UFC/Brazil) with the theme “Computer Science as Theoretical Inquiry: Open Algorithms Pragmatism.” [97]

Throughout this 5-year doctoral journey, we have actively and vigorously been part of multidisciplinary research and collaborations. This academic journey aimed to generate knowledge and understanding about open algorithms –as said, the ‘new beasts’ in the wild world of algorithms and society. With an eye on the future, this research calls for continued critical engagement, urging scientists and practitioners to consider a broader perspective in the fundamental studies of open algorithms, encompassing human, social, and environmental knowledge.

* * *

Open Algorithms: From the standpoint of algorithmic pragmatism provided in this research, open algorithms are not merely lines of code or computational models—they are living, evolving socio-technical systems. They exist not only in servers and

[93] https://somos.globo.com/movimento-led-luz-na-educacao/festival-led-luz-na-educacao/noticia/festival-led-chega-a-terceira-edicao-cheio-de-novidades-inscreva-se.ghtml Accessed on Oct. 2nd, 2024.
[94] https://itsrio.org/wp-content/uploads/2016/12/relatorio_IA-20_FINAL.pdf Accessed on Oct. 4th, 2024.
[95] https://globoplay.globo.com/v/12991249/ Accessed on Oct. 11th, 2024.
[96] https://www.instagram.com/reel/DCyygpWRfxy/?igsh=eHAxaTVtY3F2YWt0 Accessed on Oct. 27th, 2024.
[97] https://www.youtube.com/@CongressoIatlee/playlists Accessed on Nov. 1st, 2024.

data centers but in the world, continuously shaped and reshaped by their interactions with people, institutions, data flows, material infrastructures, and social expectations.

Unlike closed algorithms, which are somewhat controlled, open algorithms are ontologically dynamic, adaptive and more uncontrollable. Open algorithms are temporal entities whose meaning, function, and consequences evolve (over time) through use and in various contexts. This view draws from temporal naturalism, a philosophical orientation that rejects timeless abstractions in favor of a world always in the making. Open algorithms cannot be fully known in abstraction; they are understood only through their practical effects in the world.

We emphasize use as the condition for understanding open algorithms. For example, in a self-driving car, the algorithm must process sensor data in real time to make decisions that impact human life. In a financial system, the same algorithm might evaluate credit risk based on historical and behavioral data. The context of use delimits the scope, meaning, and consequences of the algorithm. Therefore, open algorithms are not judged solely by internal metrics or performance benchmarks—they are evaluated by how they behave in the real world, in interaction with actual people, systems, and environments.

Drawing on William James' idea of "the One and the Many," we understand open algorithms as neither a seamless whole nor a chaotic patchwork. Their "oneness" is pragmatic, shaped by real-world constraints and interactions. This means an open algorithm does not possess unity by design. Its unity must be justified, continually explained, and socially legitimated by those who build, deploy, use, and maintain an open algorithm.

So far, our pragmatism perspective defines open algorithms as a composite system, made up of at least seven interacting constituents:

1. Energy – The physical power required for computation and infrastructure.
2. Hardware – The physical devices on which computation runs.
3. Software – The codebase and logic implementing the system.
4. Agents – Automated entities that interact with or affect the system.
5. Data – Both input and feedback, shaping decisions and performance.
6. Interfaces – Points of access, control, or understanding for users.
7. Society – The broader social context in which the system is embedded.

Understanding open algorithms through the lens of pragmatism forces us to abandon the myth of the neutral machine. Instead, we recognize them as adaptive and socially embedded entities—artifacts of human culture and responsibility. They require continuous testing, ethical oversight, and cross-disciplinary dialogue. Importantly, those who work with open algorithms must be prepared to justify their existence, not just how they work, but why they matter, what harms they may cause, and how their benefits are distributed—to say the least. These are the first steps towards responsibly developing a 'science of algorithms' in a world that, like them, is always in flux. Nonetheless, what 'open algorithms' are may remain unresolved as a concept to be defined, just as some definitions of critical concepts for humankind (e.g., justice, democracy, love).

Alan Turing concluded his famous paper on 'Computing Machinery and Intelligence' (TURING, 1950) with the words: 'We can only see a short distance ahead, but we can see plenty there that needs to be done.' May this research serve as a vanguard approach in algorithm studies, to help computer scientists see the distance ahead, but also to decipher practical intricacies that need to be done.

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THE JOURNEY AND RESEARCH METHODS

The methodology employed at each stage is appropriate to our inquiry's journey's specific objectives and evolution. Each stage reflects a progression from conceptual exploration to theoretical formulation. Eventually, we critically examine and formalize our research findings and some preliminary answers.

* * *

Reflection on experience: Theory and practice

[Stage #1, from 2019 to 2021]

The primary goal during this stage was to reflect on and build a profound understanding of algorithm systems. We aimed to discover different ideas and concepts of 'algorithms' that could guide us forward – a paramount stage that later helped us conduct state-of-the-art literature overview related to open algorithms.

This initial stage began with algorithm studies historical facts and foundational concepts literature (e.g., online articles, books, lectures, case studies, movies). Such a journey involved: (a) historical studies of algorithm development and the history of computational systems, (b) analysis of foundational works on technology and society, (c) overview of media coverage and case studies examining algorithms' impact on society.

The key finding of this first stage was characterized as the 'knowledge gap' in algorithm studies related to open algorithms. This marks the distinction between classical, traditional, 'closed' algorithms and more contemporary 'open' ones. This distinction (i.e., closed and open algorithms) sets the next stage, helping us design and conduct semi-structured dialogues with experts.

* * *

Exploratory non-structured dialogues

[Stage #2, from 2020 to 2023]

We were modeling a well-structured intellectual approach to identify and investigate the 'knowledge gap' in 'open algorithms.' Please notice that, at this stage, we haven't had adopted yet a philosophical framework to inquiry open algorithms. Our primary research method in this stage involved non-structured dialogues and open conversations with experts in multidisciplinary areas.

The goal was to engage in exploratory conversations with experts in algorithms and try to find key knowledge dimensions that we could relate to open algorithms.

Experts were selected based on their top-notch expertise amongst computer scientists, philosophers, economists, lawyers, art curators, politicians, entrepreneurs, and university professors). Through open conversations, we have conducted qualitative research based on exploratory interviews. This approach allowed for flexibility in conversation while maintaining a clear focus on the knowledge gap related to open algorithms. This approach also left open space to foster organic discussions.

These exploratory dialogues were guided by thematic prompts based on updated versions of research, carrying the evolution of our inquiry (see annex 'The Journey and Research Methods') Sets of slides with the evolution of our intellectual research work). A thematic analysis technique of expert dialogues was used in our research, identifying recurring subjects and insights to guide our inquiry. For each dialogue, this research used a set of 20-30 slides as basis for presenting an updated version of our research evolution.

The interview preparation involved detailed analysis of primary texts and experts' discussions. This preparation and the interviews themselves were used to fine-tune and validate knowledge about and related to open algorithms.

We started a well-structured analysis of key texts on classical pragmatism, particularly those that deal with context, meaning, truth, and use. We aimed to present a comprehensive and grounded framework for understanding open algorithms, with clear contributions in expanding algorithm studies.

As a result of this stage, our research was subject to external validation, selected through peer review and expert feedback. This helped ensure that the research was rigorous, original, and impactful. Our research was selected and published by IEEE-ISTAS21, held by the University of Waterloo and the University of Guelph, Canada.

* * *

State-of-the-art literature overview

[Stage #3, from 2022 to 2023]

This investigation selected state-of-the-art literature on algorithm studies. This topic explains our approach towards state-of-the-art specialized literature related to open algorithms foundational knowledge, historical origins, technical approaches, current state of affairs, and future developments.

In this context, we have selected state of the art literature related to computer science and algorithm studies.

We have conducted our overview of topics bearing in mind the referred three philosophical aspects – ontology, epistemology, and ethics of open algorithms. Our journey delved deeper into crafting questions based on ontology, epistemology and ethics aspects to analyze open algorithms, this research object of study. As a result of this stage, we were able to design the research questions:

- Ontological inquiry: What are open algorithms?
- Epistemological inquiry: What is needed to understand open algorithms?

* * *

Philosophical Analysis

[Stage #4, from 2023 to 2024]

Adopting pragmatism philosophy helped our research work going forward. From such a ‘pragmatism’ perspective, this research engages with Wittgenstein's theory of ‘language games’ to understand how algorithms (in general) and open algorithms (in particular), how they function in various contexts.

Our findings, at this stage, suggests first steps towards an algorithm pragmatism critical analysis, based in the following key knowledge dimensions related to open algorithms: (1) Algorithm in Use: Understanding algorithms in the context of real-world applications (2) Algorithm Oneness: A concept that explores the interdependence of algorithms in society.

These three first steps towards an algorithm pragmatism approach to open algorithms becomes our theoretical backbone for further research work.

* * *

Tests and Validations

[Stage #5, from 2021 to 2024]

On September 9, 2021, we submitted an article explaining our thoughts on Algorithmic Pragmatism to ‘IEEE ISTAS21 Technological Stewardship and Responsible Innovation’. The article was selected and presented at the end of year 2021 and then published in early 2022, entitled ‘Algorithmic Pragmatism: First Steps’.[98]

During the “42nd Congress of the Brazilian Computing Society” at the Federal University Fluminense (UFF/Brazil), in August 2022, we presented our pragmatism

[98] Falcão, Meira and Ramalho, 2021.

approach in a panel about the "Influence of large corporations in making Internet legislation more flexible."[99]

In January 2024, at a World Innovation, Technology, and Services Alliance – WITSA seminar, we presented our ideas to two specialists, one former white house staff and one current OCDE director responsible for monitoring AI regulation globally. The panel was called: “Regulation and the Future of AI in Business.”[100]

In April 2024, we co-chair the inauguration of an AI center for strategic studies in Brazil, in a dialogue with Brazilian Senator Eduardo Gomes, rapporteur of the Brazilian AI Bill. We conducted a panel called: “High-Level Dialogue on AI Ethics & Regulation.”[101]

“Rio2C,” the Latin America conference on creativity, in June 2024, discussed how AI can radically transform education. We presented this research perspective in a panel called: “The world of AI and AI in the world – a pragmatism and pragmatic approach.”[102]

In June 2024, as part of the “LED Festival,” a major Brazilian conference on Education powered by Grupo Globo Communication was held in the Museum of Tomorrow, Rio de Janeiro. In a roundtable with other specialists, we explained our views of open algorithms pragmatism towards educational challenges. As part of a panel that later became a broadcast TV Program, we discussed the following subject: “Navigating artificial intelligence: how education can guide us.” [103]

In July 2024, the Technology and Society Institute (ITS/Rio), in partnership with the Humboldt Institute for Internet and Society (HIIG) and the German Center for Research and Innovation São Paulo (DWIH São Paulo), featuring Brazilian and international experts, invited us as panelists in the “IA20: Artificial Intelligence in the Global Context”, as part of the G20 Summit in Brazil, to debate, pragmatically, challenges and opportunities of AI in different sectors.[104]

In October 2024, Futura, a broadcast TV channel focused on education in Brazil, produced a series of lengthy interviews with experts in AI, innovation, and its

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[99] https://youtu.be/FAFpj_vhLmg
[100] https://www.youtube.com/watch?v=caeSP6h_GQo
[101] https://www.instagram.com/p/C6G2q18ul3T/?igsh=ZGNnZTZyeGs4djRi&img_index=1
[102] https://content.rio2c.com/programacao_rio2c/como-a-inteligencia-artificial-pode-transformar-radicalmente-a-educacao/
[103] https://somos.globo.com/movimento-led-luz-na-educacao/festival-led-luz-na-educacao/noticia/festival-led-chega-a-terceira-edicao-cheio-de-novidades-inscreva-se.ghtml
[104] https://itsrio.org/wp-content/uploads/2016/12/relatorio_IA-20_FINAL.pdf

impacts on society. Our interview theme was: “AI in Practice: Entrepreneurship, Universities, and The Market.”[105] During G20 Summit Brazil, we also participated as panelists in the “MIT Technology Review – G20 Summit,” in a panel called: “AI and the context of Global geopolitics: how the new tool and context influence the geopolitical future?”[106]

In November 2024, we lectured at the “National Congress of Philosophy, AI and Information” at the Federal University of Ceará (UFC/Brazil). We are currently submitting an article with the same title as the lecture, “Open Algorithms Pragmatism,” to be published as part of the Congress initiatives.[107]

* * *

Synthesis and Writing

[Stage #6, from 2024 to 2025]

The final stage of the research involved synthesizing all previous work into an academic narrative explaining our inquiry of open algorithms. This stage objective was to write a coherent doctoral dissertation that critically explains the foundations, evolution, nature, and implications of open algorithms in today’s world.

The research was organized into clear chapters based on academic writing techniques, each addressing different aspects of our academic journey. The final work includes new terminologies (closed and open algorithms) and a research approach (algorithm pragmatism).

Last, we mention a critical reflection on the study’s limitations, other gaps in the existing literature, and suggestions for future research directions.

* * *

ETHICS NOTE: The entirety of this text was written by the author with artificial intelligence models, such as Grammarly, ChatGPT, Perplexity.ai, Gemini, Claude, and several other online assistants.[108]

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105 https://globoplay.globo.com/v/12991249/
106 https://www.instagram.com/reel/DCyygpWRfxy/?igsh=eHAxaTVtY3F2YWt0
107 https://www.youtube.com/@CongressoIatlee/playlists
108

Exploratory Research

Method: Open dialogues with experts conducted between 2021/2022

Objective: To structure theoretical research

*List of Experts:

Silvio Meira Professor Emeritus CIn/UFPE

Geber Rabalho Professor of Computing & Ethics CIn/UFPE

Tarcisio Pequeno Professor Emeritus Computing & Philosophy UFC

Celso Ribeiro Professor on Algorithm UFF-RJ

Ruben Interian Professor on Algorithm UNICAMP

Roberto Mangabeira Unger Philosopher Harvard Law School

Paulo Daflon Professor of Law Boston College

Fabio Silva Professor on Research Methodology CIn/UFPE

Pedro Fortes Professor on Philosophy, Law & Technology UERJ

Edleno da Silva Professor Algorithm & Entrepreneurship UFAM

Nivio Ziviani Professor Emeritus Computer Science UFMG

Paulo Adeodato Professor Computer Science CIn/UFPE

Lincoln Tempest Tech-entrepreneur and VC investor

Nina Gaul Designer and Philosophy Student.

Diogo Souto Professor International Relations FGV/SP

Caio Sávio Professor Political Science UFF-RJ

Joaquim Falcão Professor Constitutional Law FGV-Direito/RJ

Fabio Scarano Professor Biology UFRJ

Caio Rodriguez Professor of Law & Philosophy INSPER

Ivar Hartmann Professor of Law & Technology INSPER

Carina Frota Alves Professor Software Engineering CIn/UFPE

Walter Sá Cavalcante Green Economy Investor & Entrepreneur

Cecilia Fortes Curator Art, Philosophy & Technology

Fabio Scarano Professor Ecology UFRJ, Curator Museu do Amanhã

Virgilio Almeida, Professor Emeritus UFMG, author of “Algorithm Institutionalism”

Modeling Research Concepts

Method: Semi-structured dialogues with experts conducted between 2023/2025

Objective: To Adjust and Validate Theoretical Research

* List of Experts:

Silvio Meira Professor Emeritus CIn/UFPE

Geber Rabalho Professor of Computing & Ethics CIn/UFPE

Tarcisio Pequeno Professor Emeritus Computing & Philosophy UFC

Celso Ribeiro Professor on Algorithm UFF-RJ

Roberto Mangabeira Unger Philosopher Harvard Law School

Fabio Silva Professor on Research Methodology CIn/UFPE

Ben Green Professor of Mathematics Michigan University

Nivio Ziviani Professor Emeritus Computer Science UFMG, AI entrepreneur

Nina Gaul Designer and Researcher at NYU.

Fabio Scarano Professor Biology UFRJ, Curator Museum of Tomorrow - Rio

Cecilia Fortes Curator Art, Philosophy & Technology

Alberto Colares, Designer and AI-Tech Entrepreneur

Isabella Ferrari, Federal Judge in Brazil and Technology Savvy

Adriano Veloso, Prof. Computer Science UFMG, AI specialist and entrepreneur

Mauricio Zuardi, Designer and AI-Tech Entrepreneur

Nina da Hora, Master’s in Computer Science (UniCamp/SP)

Rodrigo Ferreira, Lawyer at Brazil’s Mint

Virgilio Almeida, Professor Emeritus UFMG, author of “Algorithm Institutionalism”