

The Discovery of the Artificial and the Use of Synthetic Method between Physics and Cognitive Science

Francesco Gagliardi (fnc.research@gmail.com)

Independent Scholar

ORCID:0000-0002-4270-1636, Rome, Italy

Abstract

In this work, we outline a methodological analogy between cognitive sciences and physics regarding the use of models and the synthetic method. Beginning with brief historical remarks on “the discovery of the artificial”, as defined by Roberto Cordeschi, in early 20th century behavioral sciences and the methodological turning point in statistical physics at the same time, we demonstrate that the “envy” for the use of analytical theories in the exact sciences —often referred to as *physics envy*— which has significantly influenced the development of psychology and the sciences of human behavior, is ultimately unfounded.

Finally, we use this “overcoming” of the physics envy, along with some brief considerations on notable 20th century theoretical results related to “limitation” of computability and complexity, to demonstrate how cognitive sciences —like the natural sciences— must necessarily rely on models and simulations. This necessity arises from the inherent complexity of the systems under study, which precludes their treatment in analytical and exact terms.

Keywords: Synthetic method; Computational models; Cognitive sciences; Physics; Statistical physics; Computability, Undecidability, Complex systems; History of sciences.

Introduction

The success of physics in mathematically formulating the systems under study and in reducing certain macroscopic phenomena to microscopic theories has led to the emergence of so-called “Physics envy” (cf. Clarke, Primo, 2012), which is often perceived as a form of “inferiority complex” affecting scholars in the social and cognitive sciences. We argue that this form of envy is unwarranted, as it is based on an outdated, 19th-century conception of physics that remains stuck in the past, failing to account for later advancements in statistical physics and complex systems. In fact, beginning in the early 20th century, even within the physical sciences—particularly in statistical physics—the use of models began to emerge and gradually became widespread.

In the following, we present a methodological analogy between natural and cognitive sciences, both of which employ the synthetic method (i.e., the method of models and simulations). We highlight how the “discovery of the artificial” (Cordeschi, 1991, 2002) has played a crucial role in addressing the complexity of these systems and, in some cases, has driven the development of shared models—such as the connectionist turn in AI during the 1980s (Feldman, Ballard, 1982), which led to the development of

groundbreaking models like Hopfield Networks and Boltzmann machines.

The Discovery of the Artificial

The Discovery of the Artificial in Cognitive Sciences

The roots of cognitive science and of attempts to mechanize and reproduce the intelligent behavior in a scientific way can be traced back at least to the early twentieth century (Boden, 2006; Cordeschi, 2002). In proto-cybernetics and in the “robot approach” of the 1930s (e.g. Hull, 1930; 1943) the aim was to create models that were not merely mimetic of the functions of living organisms, but re-creations of the observed functionalities (e.g. phototropism, learning, etc.), without going as far as trying to synthesize biological systems. In such models, in fact, the biological microscopic-implementation level is ignored in favor of an intermediate level whose explanatory role is based on the equivalence (viz. fungibility) between the internal (electro-mechanical) realization of the artifact with the internal (biological) realization of the natural system.

Roberto Cordeschi has defined this methodological turning point as the “*discovery of the artificial*”, or rather the «*discovery of a methodology that has profoundly influenced the sciences of behavior and mind of the twentieth century. The main characteristic of this methodology is to appeal to a “new” conception of machine to overcome the traditional oppositions between the inorganic world and the organic world, between laws that regulate the behavior of physical systems and laws that regulate the behavior of organisms, between causal explanation and teleological explanation*» (Cordeschi, 2002).

This discovery of the artificial, and therefore of the adoption of a “synthetic method”, with its functionalism with respect to biological systems, will then be the basis of the development of cybernetics first and then of Artificial Intelligence, in which artifacts (robots, programs, etc.) are created as inorganic models of natural biological systems (cf. Simon, 1996).

All the various disciplines and methodologies that have followed one another throughout the twentieth century and up to the present day (Cybernetics, Artificial Intelligence, Neural Networks, Connectionism, Artificial Life, Robotics, Machine Learning, etc...) have always been based on the synthetic method to attempt to create mechanistic models capable of simulating the intelligence, learning and

adaptation functions of living organisms. In fact, all these approaches share the same “*culture of the artificial*”, which might be stated by referring to the background of philosophical, methodological, pragmatic assumptions characterizing the development of different artificial systems in order to re-create some aspects of considered natural systems (Cordeschi, 1991; Gagliardi, 2007; Pylyshyn, 1984).

The Discovery of the Artificial in Physics

A few years before the pioneering works of Hull briefly mentioned above, in the field of the microscopic explanation of ferromagnetic phenomena, the so-called *Ising model* was proposed (Ising, 1925; Lenz, 1920); this is a new model of statistical mechanics, a branch of physics, which captures certain aspects of the functional organization of matter, neglecting its microscopic constitution.

This approach is only partially in methodological continuity with previous microscopic research in the field of the physics of thermodynamic systems and is in a certain sense closer to the synthetic method of proto-cybernetics.

In fact, in the classical field of thermodynamics, internal theories of a microscopic type were already used to explain equations of state based on macroscopic variables. Consider for example the well-known equation of state for an ideal gas (the *ideal gas law*):

$$PV = nRT \quad (1)$$

this is a simple functional relationship that links the macroscopic variables of a physical system (Pressure, Volume, Temperature)¹ which was first stated by Émile Clapeyron in 1834 (Clapeyron, 1834; 1837).

For this macroscopic functional equation, traditional statistical mechanics is able to give a microscopic explanation thanks to the microscopic kinetic theory which supposes the gas to be made up of colliding particles whose statistical distribution of velocities is governed by the Maxwell distribution (Clausius, 1857; Krönig, 1856; Maxwell, 1867).

The Ising model is methodologically very different from the previous approach of thermodynamics and statistical mechanics which searches for the “true” internal causes by developing microscopic theories from which the macroscopic empirical laws can be derived in an exact and analytical way.

The methodological difference between the Ising model and the previous internal models developed in thermodynamics is also highlighted by a lexical distinction. The microscopic interpretation of the internal structure of gases is known as the “kinetic *theory* of gases” and, in some cases, referred to as the microscopic “constitution”, assuming that gases are truly composed of particles. In contrast, the Ising model is described as “the Ising *model* of ferromagnetism” without implying that ferromagnetic

materials are necessarily structured according to the Ising model. As Kerson Huang (1987, §14.1) states, «*The Ising model is a crude attempt to simulate the structure of a physical ferromagnetic substance*» (cf. Niss, 2005; 2009; 2011).

In fact, we could say that the equation of the statistical distribution of Maxwell particles used to explain the internal structure of gases is proposed as a true internal “model” of the gas, that is, an *ontological* theory of how gases are effectively constituted. On the other hand, the Ising model, used to explain ferromagnetic phenomena, is not proposed as a true internal model, but as a sort of “artifice”, a sort of “immaterial” model of matter that neglects many aspects of matter, just as within “the robot approach” of the 1930s non-biological models of biological systems are proposed.

In the attempt, common to both proto-cybernetics and physics, to find “internal explanations” for the observed phenomena of complex systems that cannot easily be explained in linear causal terms, one necessarily arrives at the same “discovery of the artificial”.

Overcoming Physics Envy

In the cognitive sciences, the idea that physics uses only exact or analytical theories is widespread: «*The theories with which physics explains the phenomena it studies are mathematical theories, or analytical theories, that is, theories expressed in the form of equations or systems of equations*» (Parisi, 2008).

This deeply rooted idea is at the core of the so-called ‘physics envy’, which leads us to ask methodological questions about why mathematical theories work in physics but not in the sciences that study human beings.

In a certain sense this has not been true since the first half of the Twentieth century: the “exact” physics born with Galileo entered into crisis first with thermodynamics and statistical physics and then also with the birth of modern physics (Quantum Mechanics, Relativity).

This transitional moment, moving away from a vision of the world that could be understood in an exact manner, has been described by Marcello Cini as a sort of “paradise lost” (Cini, 1999; See also the excerpt by B. C. Smith later).

Modern statistical physics, and the study of complex systems, make extensive use of models and simulations, in particular the Ising model is still widely used today and it is considered by physicists to be the “prototype” of complex physical systems (e.g. Parisi, 2002) as well as being used in cognitive science as a connectionist model (e.g. Thagard, 2000).

It has been proven (Cipra, 2000a; 2000b) that it is not possible to obtain a functional form for this model (except in trivial cases, such as 1-dimensional or 2-dimensional with no external interactions); therefore if one wants to know the configuration of the system at a given instant, given its initial configuration, one must necessarily do a computational simulation: create a model of the system,

¹ *n* is the amount of substance, and *R* is the ideal gas constant.

“run” it, and then analyze the results or, in a way, observe its behavior².

Statistical physicists throughout the twentieth century, while making extensive use of the Ising model also tried to derive a function that would “solve” the Ising model exactly, thus obtaining an analytical function. This function would allow predictions to be made without having to do any kind of simulations; Barry Cipra effectively commented on the impossibility result mentioned above by stating: «*statistical physicists phase out a dream*» (Cipra, 2000a).

These results show that the physics of complex systems cannot avoid using simulations or creating “immaterial” models of matter. The “physics envy”, which has influenced and influences research in behavioral and cognitive sciences, is therefore based on an anachronistic image of physics based on a nineteenth-century vision, rather than on an actual methodological difference; physics envy, therefore, has no real methodological foundation.

The Use of Synthetic Method

The study of physical systems or of mental phenomena, a distinction which is not mutually exclusive, is not suited to be approached with the “exact” methodologies of classical physics, but requires the use of the synthetic method: the artificial re-creations of the system studied and its observation.

Cognitive science, although it uses the synthetic method in its research, still suffers from a sort of “inferiority complex” towards the exact sciences which leads it to believe that simulations and the synthetic method are a kind of “second-rate” theories: «*the history of psychology [...] is very much a history of changing views, doctrines, images about what to emulate in the natural sciences — especially physics*» (Sigmund Koch, 1959; cited in Cordeschi, 2008; p.237).

The use of models and simulations or recreations is not methodologically “inferior” to the use of analytical or “exact” theories and on the other hand it does not even constitute a “new type of science” as some researchers claim (e.g. Wolfram, 2002). Models are the “best theories” that we can have in the case of complex systems, or for those systems for which on the epistemic-predictive level the best action is to “wait and observe”: «*In all but vanishingly few cases, in fact, waiting for the results to happen may be the metaphysically optimal — perhaps the only — way to know what will happen in detail (especially on the wonderful suggestion that the universe is running an optimal algorithm). In sum: the impossibility of accurate (epistemological) prediction is entailed by quantum indeterminacy, by computability limits, by complexity*

² Formally, it has been proven (Istrail, 2000) that the calculation of the ground state of the Ising model is computationally intractable, and therefore the “closed form” of an analytical function does not exist for the Ising Model (except that for the trivial cases mentioned above) under the assumption that the well-known computational complexity theory conjecture $P = NP$ is false.

results, *by turbulence and chaos and other aspects of non-linear dynamics, by emergent properties and emergent objects ... on and on. There is probably no more securely established result in science. But it is still difficult to get our minds around*» (Smith, 2002).

In fact, for such systems it is impossible to know a function that predicts the state of the system: the theoretical prediction of the evolution of the system must be obtained through a simulation of the model. This is very different from, for example, the predictive capabilities of the equation of falling bodies:

$$S(t)=\frac{1}{2}gt^2 \quad (2)$$

In fact, to predict the state of a falling stone there is no need to simulate the gravitational field and the falling body; it is enough to calculate the function $S(t)$ for the desired instant t ; this function becomes a sort of “computational shortcut” to predict the evolution of the system without having to observe it experimentally or observe a simulation of it.

The characteristic of “economy” of classical scientific theory is well summarized by Ernst Mach: «*All science has the aim of replacing, that is, of economizing experiences through the reproduction and anticipation of facts in thought. These reproductions are more manageable than direct experience and in some respects replace it*» (Mach, 1883)³. This characteristic of economy of theory compared to experimental observation is strongly compromised for complex systems whose best theory is a model whose predictions can be obtained through the “observation” of its simulation⁴.

Conclusions

The synthetic method with its “discovery” of the artificial, used both by the physics of complex systems and by cognitive sciences, can be considered the result of the intersection of the classical Galilean scientific method based on the observation-theory-experiment cycle with the epistemic and cognitive limits relating to computational phenomena and complexity.

Galileo Galilei proposed a foundational use of mathematics to understand nature, which he believed to be written in mathematical language: «... *this great book [of*

³ For the role of theories or simulations as instruments rather than genuine re-creations of the studied phenomena, see McClelland (2009) and Rowbottom (2019).

⁴ The observation of the physical system under study is relevant to the empirical verification phase of the scientific method, while the observation of the simulation of the system is relevant to the theory (or in this case a model) and to the deduction of some of its properties (which is more similar to the methodological practice of the *gedankenexperiment* rather than to an actual experiment). This distinction between theoretical and empirical levels, in our opinion apparently trivial, is not universally shared: some authors have gone so far as to propose simulations as substitutes for actual experiments, confusing two *toto caelo* different phases of science.

nature] which is continually open to our eyes (I mean the universe), cannot be understood unless one first learns to understand the language and to know the characters in which it is written. It is written in mathematical language [...] without which means it is humanly impossible to understand a word; without these one wanders vainly through a dark labyrinth» Galileo Galilei, (Galilei, 1623; 1957, Ch. VI).

The mathematical language in which the “great book of nature” is written, as we understand it today, encompasses not only theories such as differential equations and Hilbert spaces, but also, to name just a few relevant to cognitive sciences, the theories of computability and decidability, computational complexity, statistical physics, complex systems, automatic control, and others.

The great results of these theories have had devastating effects on the classical image of a nature intelligible in an exact and absolute way without any limitations for the human observer; it is enough to consider the “disarticulation” between truth and provability (e.g. Gödel’s incompleteness theorems), the difference between determinism and predictability (e.g. Turing’s halting problem; see also the previous excerpt by B.C. Smith), or also the link between computability and computational intractability as in the case illustrated above of the Ising model (Istrail, 2000).

This inherent “limitation” of the great theoretical results of the twentieth century necessarily positions cognitive science as a *science of the artificial* (Simon, 1996; Cordeschi, 2008, p. 237 and following): a discipline that shares methodological difficulties intrinsic to knowledge, uniting it with the natural sciences and the new “mathematical language”, which also encompasses the creation and simulation of models.

Acknowledgments

I wish to dedicate this brief paper to the memory of Roberto Cordeschi (1946–2014).

References

- Boden, M.A. (2006) *Mind as machine: A history of cognitive science*. Oxford University Press. Oxford, GB. <https://psycnet.apa.org/record/2006-12918-000>
- Cini, M. (1999) *Un paradiso perduto. Dall'universo delle leggi naturali al mondo dei processi evolutivi*. 4^a ed. Feltrinelli, Milano, I. ISBN:9788807101694.
- Cipra, B.A. (2000a) Statistical Physicists Phase Out a Dream, *Science*, 288(5471):1561–1562. DOI:10.1126/science.288.5471.1561a
- Cipra, B.A. (2000b) The Ising Model Is NP-Complete. *SIAM News*. 33(6). <https://archive.siam.org/pdf/news/654.pdf> Accessed 2025-02-03
- Clapeyron, E. (1834) Mémoire sur la puissance motrice de la chaleur. *Journal de l'École Royale Polytechnique* 23(14):153–90. <https://gallica.bnf.fr/ark:/12148/bpt6k4336791/f157> Accessed 2025-02-03.
- Clapeyron, E. (1837) Memoir on the Motive Power of Heat (translated by Taylor Richard). *Scientific Memoirs* 1:347–376. https://en.wikisource.org/wiki/Scientific_Memoirs/1/Memoir_on_the_Motive_Power_of_Heat Accessed 2025-02-03.
- Clarke K.A., Primo D.M. (2012) Overcoming ‘Physics Envy’. *New York Times*, 1 April 2012, p.9. <https://www.nytimes.com/2012/04/01/opinion/sunday/the-social-sciences-physics-envy.html>
- Clausius, R. (1857) Ueber die Art der Bewegung, welche wir Wärme nennen. *Annalen der Physik und Chemie*. 176(3):353–379. DOI:10.1002/andp.18571760302 <https://gallica.bnf.fr/ark:/12148/bpt6k15185v/f371>
- Cordeschi, R. (1991) The discovery of the artificial. Some protocybernetic developments 1930–1940. *AI & Society*, 5(3):218–238. DOI:10.1007/BF01891917
- Cordeschi, R. (2002) *The Discovery of the Artificial. Behavior, Mind and Machines Before and Beyond Cybernetics*. Kluwer Academic Publishers. Dordrecht, Netherlands. ISBN: 978-1-4020-0606-7 Url: <http://www.springer.com/978-1-4020-0606-7>
- Cordeschi, R. (2008) Steps toward the synthetic method: symbolic information processing and self-organizing systems in early Artificial Intelligence. In Husbands, P., Holland, O., Wheeler M. (Eds.) *The Mechanical Mind in History*. MIT Press, Cambridge, MA. Pp. 219–258. ISBN:978-0-262-08377-5 <http://mitpress.mit.edu/978-0-262-08377-5>
- Feldman, J. A., Ballard, D. H. (1982) Connectionist Models and Their Properties. *Cognitive Science*, 6(3):205–254. DOI:10.1207/s15516709cog0603_1
- Gagliardi, F. (2007) Some Issues About Cognitive Modelling and Functionalism. Basili, R.; Pazienza, M. T. (Eds.) *Artificial Intelligence and Human-Oriented Computing*. LNCS vol.4733. Springer, Berlin Heidelberg. pp. 60–71. DOI:10.1007/978-3-540-74782-6_7
- Galilei, G. (1623) Il Saggiatore, nel quale con bilancia esquisita e giusta si ponderano le cose contenute nella Libbra astronomica e filosofica di Lotario Sarsi Sigensano. *Accademia dei Lincei*, Roma. https://it.wikisource.org/wiki/Il_Saggiatore Accessed 2025-02-03
- Galilei, G. (1957) [1623] The Assayer. Drake, S. (ed.). *Discoveries and Opinions of Galileo*. Doubleday, Garden City, NY.
- Huang, K. (1987) *Thermodynamics and Statistical Mechanics* (2nd edn.) Wiley, Hoboken, NJ. ISBN:978-0-471-81518-1
- Hull, C. L. (1930) Knowledge and purpose as habit mechanisms. *Psychological Review*, 37(6):511–525. DOI:10.1037/h0072212
- Hull, C. L. (1943) *Principles of Behavior: An Introduction to Behavior Theory*. D.Appleton-Century Company, New York, NY.

- <https://archive.org/details/in.ernet.dli.2015.205891>
 Accessed 2025-02-03.
- Ising, E. (1925) Beitrag zur Theorie des Ferromagnetismus. *Zeitschrift für Physik*, 31(1):253–258, DOI:10.1007/BF02980577
- Istrail, S. (2000) Statistical Mechanics, Three-Dimensionality and NP-Completeness: Universality of Intractability of the Partition Functions of the Ising Model Across Non-Planar Lattices. *Proceedings of the 32nd ACM Symposium on the Theory of Computing (STOC00)*, Portland, Oregon, May 21-23, 2000, ACM Press, pp. 87–96. DOI:10.1145/335305.335316
- Krönig, A. (1856) Grundzüge einer Theorie der Gase. *Annalen der Physik und Chemie*. 99(10):315–322. DOI:10.1002/andp.18561751008
<https://gallica.bnf.fr/ark:/12148/bpt6k15184h/f327>
 Accessed 2025-02-03.
- Lenz, W. (1920) Beiträge zum Verständnis der magnetischen Eigenschaften in festen Körpern. *Physikalische Zeitschrift*, 21:613–615.
- Mach, E. (1883) *Die Mechanik in ihrer Entwicklung historisch-kritisch dargestellt*. F.A. Brockhaus, Leipzig.
https://www.deutschestextarchiv.de/book/view/mach_mechanik_1883 Accessed 2025-02-03.
- Maxwell, J. C. (1867) On the Dynamical Theory of Gases. *Philosophical Transactions of the Royal Society of London*. 157:49–88. DOI:10.1098/rstl.1867.0004
- McClelland, J. L. (2009) The Place of Modeling in Cognitive Science, *Topics in Cognitive Science*, 1(1):11–38. DOI:10.1111/j.1756-8765.2008.01003.x
- Niss, M. (2005) History of the Lenz-Ising Model 1920–1950: From Ferromagnetic to Cooperative Phenomena. *Archive for History of Exact Sciences*. 59:267–318. DOI:10.1007/s00407-004-0088-3
- Niss, M. (2009) History of the Lenz-Ising Model 1950–1965: from irrelevance to relevance. *Archive for History of Exact Sciences*. 63:243–287. DOI:10.1007/s00407-008-0039-5
- Niss, M. (2011) History of the Lenz-Ising model 1965–1971: the role of a simple model in understanding critical phenomena. *Archive for History of Exact Sciences*. 65:625–658. DOI:10.1007/s00407-011-0086-1
- Parisi, D. (2008) Two problems concerning physics. *Sistemi intelligenti. Artificial Intelligence and Cognitive Science Four-monthly Review*. 20(1):115–124. DOI:10.1422/26720
- Parisi, G. (2002) *Complex Systems: a Physicist's Viewpoint*. arXiv:cond-mat/0205297v1 DOI:10.48550/arXiv.cond-mat/0205297
- Polyshyn, Z. W. (1984) *Computation and Cognition: Toward a Foundation for Cognitive Science*. Cambridge, MA: MIT Press. ISBN:9780262281997. DOI:10.7551/mitpress/2004.001.0001
- Rowbottom, D. P. (2019) *The Instrument of Science: Scientific Anti-Realism Revitalized*. Routledge, New York, NY. ISBN:9780429022517. DOI:10.4324/9780429022517
- Simon, H. (1996) *The Sciences of the Artificial*. Cambridge, MA: MIT Press. ISBN:9780262354745. DOI:10.7551/mitpress/12107.001.0001
- Smith, B. C. (2002) God, approximately. Mark R.W., Russell R.J., Clayton P., Wegter-McNelly K. (eds.) *Science and the Spiritual Quest: New Essays by Leading Scientists*. Routledge, New York, NY, pp.207–228. ISBN:0415257662.
- Thagard, P. (2000) *Coherence in thought and action*. Cambridge, MA: MIT Press
- Wolfram, S. (2002) *A New Kind of Science*, Champaign, IL: Wolfram Media.