

Philosophy and Theory of Artificial Intelligence

A Reader

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Comments welcome!

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Contents

Preface	1
1 Introduction to AI	4
2 AI and philosophy of mind	7
3 AI and epistemology	12
4 AI and philosophy of science	16
5 AI and philosophy of language	19
6 AI and ethics	20
7 Theory of AI: Power and Limits	22
8 Reliable AI	24
Bibliography	25

Preface

This is the reader for the course “Philosophy and Theory of Artificial Intelligence” given during the winter semester 2024/25 at *LMU Munich* as part of the *Master in Logic and Philosophy of Science*. The reader is updated as the course progresses. A website with all the course material is found at

<https://levinhornischer.github.io/PhilTheoAI/>.

Comments I’m happy about any comments: spotting typos, finding mistakes, pointing out confusing parts, or simply questions triggered by the material. Just send an informal email to Levin.Hornischer@lmu.de.

Content This course provides, as its title suggests, an introduction to both the *philosophy* and the *theory of artificial intelligence*. This field researches the philosophical foundations of artificial intelligence (AI). It recently gained much prominence because of its urgent relevance. AI made astonishing but also disconcerting technological progress. For a recent example, just think of *ChatGPT*. However, we are lacking a theoretical understanding of AI. We would like to answer questions like the following. Why are neural networks—that underlie modern AI—so good at learning from data? And what kind of knowledge do they have? How do they compare to the human-interpretable symbolic AI models that have been used previously? What is even a good language to talk about AI models and the computation that they perform? What are the possibilities and limitations of AI models? We will in particular also investigate the problems of modern AI: How to deal with its ethical issues like bias or fairness. We look at the black-box problem of neural networks: that they are difficult to interpret and hard to explain. And we consider their lack of robustness: that in similar situations they unexpectedly might behave incorrectly. Answering these questions is not just an engineering task: it crucially also is a philosophical task—which we undertake in this course.

The course title was inspired by the conference series of the same name.

Objectives In terms of content, the course aims to convey an overview of the questions, methodology, and results of the philosophy and theory of AI. We cover both classic material and cutting-edge research. In terms of

skills, the course aims to teach: (1) the basic ability to program an AI model, (2) the ability to critically reflect on the many issues of AI by relating it to established theory in philosophy, and (3) the ability to apply results from the theory of AI to assess its power and limits.

Prerequisites The course does not assume any programming knowledge. It assumes basic familiarity with philosophy (first-year university level), logic (e.g., an introductory course) and mathematics (though not really beyond high-school level). None of these are strictly necessary: by far most of the reader can be understood also without, it will mostly be helpful to appreciate, e.g., remarks about connected and more advanced topics.

Schedule and organization The course is organized as a seminar. Hence, for each session, we have assigned readings. During the session, we first make sure that we all have understood the provided key AI concepts relevant for the session (by arriving at an explanation in the group), and then we critically discuss the readings. Study questions in this reader are meant to both help engagement with the readings and as starting points for discussion in class. The schedule for the readings is found on the course's website. In sum, the readings aim to provide an overview of the field of philosophy and theory of AI.

After an introduction to modern AI, the organizational principle for selecting the readings was 'question-based'. Each chapter concerns one 'big question' about the philosophy of AI. See the table of contents for a list of those chapters. As usual, there is much more possible content than time, and during the course we can still decide on which of the readings we will focus on.

Other organizational principles would be possible, too; e.g., 'method-based'.

Layout These notes are informal and partially still under construction. For example, there are margin notes to convey more casual comments that you'd rather find in a lecture but usually not in a book. Todo notes indicate, well, that something needs to be done. References are found at the end.

This is a margin note.

This is a todo note

Further study material In addition to the provided papers and further material, some helpful short explainer videos on AI are found [here](#). And on philosophy of neuroscience [here](#). References for 'classical' philosophy of AI (i.e., up to the early 1990s) are, e.g., Boden (1990) and Copeland (1993).

Notation Throughout, 'iff' abbreviates 'if and only if'. Study questions are marked by

↔ This is a study question.

Acknowledgement I have taken great inspiration in designing this course from other courses on this topic both by [Stephan Hartmann](#) and [Timo Freiesleben](#) and by [Cameron Buckner](#).

1 Introduction to AI

This chapter's big question

What actually is an AI system and, in particular, a neural network?

Key concepts

- History of AI: Ada Lovelace, Alan Turing, McCulloch & Pitts, Logic Theorist, Dartmouth workshop, division of AI into life (cybernetics, connectionism, differential equations) and mind (symbolic computing, logic), big data, deep learning revolution.
- Types of AI: classical/symbolic vs subsymbolic/neural networks/connectionism.
- Definitions of AI: Turing test (more on this in chapter 2 and figure 1.1), technological vs scientific aim of AI, virtual vs physical machines
- Types of learning tasks: Supervised learning, unsupervised learning, reinforcement learning. Machine learning pipeline (conceptualization, data, model, deployment).
- Artificial neural networks: neurons, layers, feedforward vs recurrent, weights, activation function, loss function (as your way of telling the neural network what to optimize for), back-propagation, learning rate, local/global minima (equilibrium), regularization, overfitting/underfitting.

Before one can do *philosophy of X*, one needs a good understanding of X. So we start with an introduction to AI, both practically and theoretically.

Lecture 1 For a practical introduction, we see how an AI system is actually built in practice. We consider the standard example of training a neural network to classify hand-written digits (on the MNIST dataset). Thus, we get a concrete idea of what an 'AI system' really is and this does

not remain an abstract term in future discussion. We build the system in the form of a coding exercise, which is purpose-built for this course and available on the [course website](#). But—fear not—you do not need any coding experience for this! In class, we go through the parts of the coding exercise. As a study question, you are asked to:

- ↪ Change the parameters and see how the performance of the neural network changes.
- ↪ Your challenge is to find some parameters with which the networks reaches an accuracy of 98%.

In the next lecture, we will discuss your observations.

Lecture 2 For a theoretical introduction, the readings below and also the coding exercise introduce the central concepts of modern AI, which are summarized in this chapters list of ‘key concepts’.

- ↪ Make sure that, by doing the readings, you know what these concepts mean.

We discuss them in the second lecture of the course.

The readings also mentioned the following further advanced concepts. You can skip them on a first reading and come back to them at a later stage:

- biological plausibility (backprop too global, Boden’s ‘too neat, too simple, too few, too dry’, neuromodulation like GasNet),
- Hebbian learning (fire together, wire together),
- predictive coding (Helmholtz’s ‘unconscious inference, the ‘Bayesian brain’, cognition as predicting incoming low-level sense information from higher-level neural layers),
- perceptron (XOR problem),
- localist (concepts represented by single neurons) vs distributed networks (concepts stored across the whole system)

Readings

- A very accessible overview, written at the beginning of the deep learning revolution: M. A. Boden (2016). *AI: Its nature and future*. Oxford: Oxford University Press. Chapters 1 and 4.
- Short explainer videos of central concepts in AI are found [here](#).

	<i>empiricist</i>	<i>rationalist</i>
<i>thought process</i>	thinking humanly (cognitive modeling)	thinking rationally (logic & probability)
<i>behavior</i>	acting humanely (Turing test)	acting rationally (decision theory)

Figure 1.1: The four definitions of artificial intelligence of Russell and Norvig (2021, ch. 1) according to whether an AI system should realize thought processes (first row) or behavior (second row) and whether the benchmark is human (left column) or ideal (right column) performance.

An excellent detailed mini-series explaining neural networks is found [here](#).

- The coding exercise on the [course website](#).

Further material

- A great interactive visualization of neural networks is found [here](#).
- A concise introduction to deep learning and its philosophical aspects: C. Buckner (2019). "Deep learning: A philosophical introduction." In: *Philosophy Compass* 14.10, e12625. DOI: <https://doi.org/10.1111/phc3.12625>.
- An introduction to AI from the standard textbook: Russell and Norvig (2021, ch. 1). They have a fourfold definition of AI: acting humanly (Turing test), thinking humanly (cognitive modeling), thinking rationally (logic, probability), acting rationally (rational agent; perfect vs limited rationality).
- An encyclopedia entry on AI: S. Bringsjord and N. S. Govindarajulu (2022). "Artificial Intelligence." In: *The Stanford Encyclopedia of Philosophy*. Ed. by E. N. Zalta and U. Nodelman. Fall 2022. Metaphysics Research Lab, Stanford University

2 AI and philosophy of mind

This chapter's big question

Can AI systems think? Like humans?

Key concepts

- Turing test
- Symbol grounding problem
- Octopus test/Chinese room thought experiment
- Classicist vs connectionist theories of mind
- Levels of analysis: neural, subsymbolic, symbolic; Marr's levels
- Physical symbol system hypothesis (Newell–Simon) vs Connectionist dynamical system hypothesis (Smolensky)

Lecture 3 A classic text on the question whether an AI system—or, simply, a 'machine'—can think is Turing's 1950 paper, in which he introduces what is now known as the *Turing test*. Some even take this as the very definition of artificial intelligence, i.e., when a machine should be considered intelligent (the other three are in figure 1.1). The Turing test operationalizes the intuitive question 'Can machines think?' in a behavioristic way: can you distinguish whether answers to your questions were produced by the machine or by a human?

- ↪ Can we really only test for intelligence in a purely behavioristic way (up to 'extension') and not also capture aspects of thought processes ('intentional' aspects)?
- ↪ Are response times (or computational complexity) aspects of thought processes? If the question was to multiply 793 and 868, the machine could add an artificial pause to mimic a human response; however, the machine is exposed if it is not as quick as humans in tasks they find easy (e.g., pattern recognition).

Turing is a giant of computer science. There is even a Hollywood movie (The Imitation Game, 2014) portraying Turing's eventful and also tragic life (e.g., he was prosecuted in 1952 for his sexual orientation).

↪ What is the relation between the two sentences (1) ‘This machine can think’ and (2) ‘This machine passes the Turing test’? According to Turing, we can only say something about (2), which is the extensional/observable reflection of (1). Is (2) or *rational reconstruction* of (1), serving as a good definition of AI? Or can one also ask if (2) is a *conceptual analysis* (1), i.e., is (2) sufficient and necessary for (1)? A infamous argument against necessity is the Chinese room thought experiment: A person who doesn’t speak Chinese is in a room and responds to incoming Chinese message according to a long look-up table; from the ‘outside’, this generates the correct behavior, but on the ‘inside’ there is no understanding—or so the argument goes. (For more, see Oppy and Dowe (2021).)

See Glymour (2015, p. 357) for the idea that the person in the Chinese room also has to match the computation time of a Chinese speaker, not just the input-output relation.

Fast-forward 70+ years, seeing ‘machines’ like ChatGPT, what about Turing’s test? Is it solved? The next paper discusses (and denies) whether large language models (LLMs) can, apart from producing the sensible text response, also be said to understand the meaning of this text and in this sense be intelligent.

The first author, *Emily M. Bender*, is an influential researcher in Natural Language Processing and AI Ethics, who is also well-known for the stochastic parrot paper (Bender, Gebru, et al. 2021).

We argue that, independently of whether passing the Turing test would mean a system is intelligent, a system that is trained only on form would fail a sufficiently sensitive test, because it lacks the ability to connect its utterances to the world (Bender and Koller 2020, p. 5188).

So the system cannot solve the *symbol grounding problem*, a term coined by Harnad (1990).

This reminiscent of Quine’s indeterminacy of translation (for an overview, see, e.g., [here](#) or [here](#)), so you may discuss connections.

↪ Do you find the Octopus though experiment convincing that is to establish the above cited conclusion?

Also link to discussion in chapter 5

↪ What about the concrete case of training a LLM on all available Java code but without information about compilers or input-output relations of specific programs? Is there no way to learn the meaning relation $J \subseteq E \times I$, which relates a piece e of Java code to the mathematical function i that it computes?

Lecture 4 On the question of how the symbol grounding problem can be solved, the next paper by Smolensky (1988) discusses how a neural network based approach to modeling intelligence can give rise to symbolic meaning by developing the concept of a *subsymbol*.

The background of the debate is the strong divide, especially at the time, in cognitive science between the traditional symbolic approach and the connectionist approach. Here cognitive science—or cognitive modeling—is understood as the building of formal models of how the human mind/intelligence solves various cognitive tasks like vision, language, planning, motor control, etc. As such, the goal is the same as for AI, modulo the question of whether the formal model should be operating similar to a human (cf. scientific aim of AI) or not necessarily (cf. technological aim of AI).

The symbolic approach conceptualizes a cognitive task as an input-output function and the formal model is a general algorithm of computing this function. For example, for the cognitive task of route planning, the input is a map with a current position and a desired destination and the output is a route of how to get to this destination—the algorithm would need to describe a general procedure of computing such a rule. The conviction that this is the right approach to cognitive modeling is expressed in:

“The Physical Symbol System Hypothesis. A physical symbol system has the necessary and sufficient means for general intelligent action” (Newell and Simon 1976, p. 116).

The connectionist approach, on the other hand, conceptualizes a cognitive task still as an input-output function, but at a lower level: The input is a long list of real numbers describing, e.g., some sensory input or maybe a numerical encoding of some symbolic information (e.g., a pixel image of the map) and the output similarly is a numeric encoding for the intended answer to the cognitive task. This input-output function is computed by a neural network, as we have discussed them so far.

“The connectionist dynamical system hypothesis: The state of the intuitive processor at any moment is precisely defined by a vector of numerical values (one for each unit). The dynamics of the intuitive processor are governed by a differential equation. The numerical parameters in this equation constitute the processor’s program or knowledge. In learning systems, these parameters change according to another differential equation” (Smolensky 1988, p. 6, emphasis added).

The question is then how the symbolic approach and the connectionist approach are related, i.e., how symbolic meaning may be represented and

processed in neural networks. That is discussed at length in the paper, but the key idea is:

“The entities in the intuitive processor with the semantics of conscious concepts of the task domain are complex patterns of activity over many units. Each unit participates in many such patterns” (Smolensky 1988, p. 6, emphasis added).

So a symbolic meaning (like ‘the digit 7’) is represented by a large number of subsymbols, i.e., activation patterns in the neural network (all the ways neurons can be activated to give high probability to the neuron in the output layer representing the digit 7). While the symbolic paradigm hence has a simple semantics for its symbols but allows complicated operations on these symbols, the connectionist paradigm only allows simple operations on the neurons (weighted sums plus ReLU) hence the semantics for the subsymbols must be complicated, to match the computational power of the symbolic paradigm.

- ↔ The symbolic approach operates at a higher level than the connectionist approach. But Smolensky also introduces a third, yet lower level: the neural level, i.e., the activity in an actual brain. In what way are the artificial neural networks of connectionism more high-level than the biological neural networks studied in neuroscience? How do these three levels relate to **Marr’s tri-level hypothesis**?
- ↔ In (13)(c–d), Smolensky hypothesizes when it may be possible to give a symbolic semantics to a subsymbolic system, namely according to whether or not the cognitive task involves conscious rule application or just intuition. Can you think of examples? How does this distinction line up with Kahneman’s “Thinking, Fast and Slow” (2011): System 1 (implicit, fast, parallel, instinctive, emotional) vs system 2 (explicit, slow, sequential, deliberative, logical)? For a concrete example of a (symbolic) causal abstraction of a subsymbolic neural network, see e.g. (Geiger et al. 2021).
- ↔ If the cognitive agent (or intuitive processor) is a dynamical system, which dynamical systems then are cognitive? In (19), Smolensky mentions a necessary condition: the system should be stable under a wide range of environmental conditions. Compare this to the discussion of when a dynamical system performs computation (Piccinini and Maley 2021).

Readings

- A. M. Turing (1950). "Computing Machinery and Intelligence." In: *Mind* 59.236, pp. 433–460. DOI: <https://doi.org/10.1093/mind/LIX.236.433>.
- E. M. Bender and A. Koller (2020). "Climbing towards NLU: On Meaning, Form, and Understanding in the Age of Data." In: *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pp. 5185–5198.
- P. Smolensky (1988). "On the proper treatment of connectionism." In: *Behavioral and brain sciences* 11.1, pp. 1–74. DOI: <https://doi.org/10.1017/S0140525X00052791>.

This text contains comments about race (e.g., p. 448) and gender stereotypes (e.g., p. 434) which should be reflected on critically. Given the classic status of the text, it is included in the syllabus here, but this is to flag that these comments are not silently endorsed.

This is quite a dense text: on a first reading focus on understanding the key concepts mentioned above. This is a text worth coming back to over and over again.

Further material

- For an overview of the discussion around the Turing test, see: G. Oppy and D. Dowe (2021). "The Turing Test." In: *The Stanford Encyclopedia of Philosophy*. Ed. by E. N. Zalta. Winter 2021. Metaphysics Research Lab, Stanford University.
- Further reading on the idea that cognitive agents are dynamical systems: T. van Gelder (1998). "The dynamical hypothesis in cognitive science." In: *Behavioral and Brain Sciences* 21.5, pp. 615–628. DOI: [10.1017/S0140525X98001733](https://doi.org/10.1017/S0140525X98001733).
- As mentioned above, an example of (symbolic) causal abstraction of a subsymbolic neural network: A. Geiger et al. (2021). "Causal abstractions of neural networks." In: *Advances in Neural Information Processing Systems* 34, pp. 9574–9586. URL: <https://arxiv.org/abs/2106.02997>.

3 AI and epistemology

This chapter's big question

How do AI systems gain knowledge, if any?

Key concepts

- Empiricists/nurture vs rationalists/nature
- Domain-general vs domain-specific cognitive systems
- Moderate empiricism: allow 'innate' general inductive biases to learn domain-specific knowledge.
- Control Problem: If several general modules (representing various cognitive faculties) are posited, how do they fruitfully interact?

Lecture 5 When it comes to the question what kind of knowledge deep neural networks gain, it makes sense to turn to philosophy—especially epistemology—where this question of how we gain knowledge has been discussed for millenia. There are two positions: Empiricists (like Locke) say all knowledge comes from sensory experience, while rationalists (like Leibniz) say that in getting knowledge we rely on our innate concepts about the basic structure of the world. (And Kant aimed to combine these two traditions.) Thus, it is suggestive to associate deep learning with empiricists (neural networks only learn from data) and symbolic AI with rationalists (the hard coded program of solving the task is the innate knowledge about the world). (Neuro-symbolic integration then follows Kant in combining the two approaches: see the further reading box.) However, this chapter argues for a more nuanced moderate position. It endorses the “new empiricist DoGMA [that a] (Do)main General Modular Architecture is the best hope for modeling rational cognition in AI” (p. 26).

↪ What is the main argument against the simple association of deep learning with empiricism and symbolic AI with rationalism? Can

As remarked in footnote 28 of the text, this is in reference to the famous paper of Quine (1951) “Two Dogmas of Empiricism” (here’s a lecture on it).

you think of examples (e.g., CNNs)? Relate that to the concept of *inductive bias* (we'll come back to that in chapter 7).

- ↪ Explain why “the current incarnation of the nativist-empiricist debate in artificial intelligence presents us with a similar golden opportunity, in which we might attempt one of the rarest feats of intellectual alchemy: the conversion of a timeless philosophical riddle into a testable empirical question” (p. 8)? Do you agree? How does this relate to the continuum of views between empiricism and rationalism?
- ↪ Which of the proposed theories in section 1.5 of how a (computational) model of cognition relates to the mind do you find most convincing?

Readings

- C. J. Buckner (2023). *From Deep Learning to Rational Machines: What the History of Philosophy Can Teach Us about the Future of Artificial Intelligence*. New York: Oxford University Press. DOI: <https://doi.org/10.1093/oso/9780197653302.001.0001>. Chapter 1 “Moderate Empiricism and Machine Learning”.

Further material

- Given this distinction between rationalist/symbolic and empiricist/subsymbolic approaches to AI, wouldn't it make sense to combine the two (as Kant attempted)? Especially in light of the fact that they have complementary benefits? To get the best of both worlds, rather than sharp opposition? There is a movement aiming to do precisely this: known as *neurosymbolic computation*. (Buckner cites 'cognitive' versions of this—namely ACT-R, SOAR, Sigma, and CMC—on page 39.) A recent overview is:

A. d. Garcez and L. C. Lamb (2023). "Neurosymbolic AI: the 3rd wave." In: *Artificial Intelligence Review*. DOI: <https://doi.org/10.1007/s10462-023-10448-w>

The main idea is that of neurosymbolic computation: "combine robust learning in neural networks with reasoning and explainability by offering symbolic representations for neural models" (quoted from the abstract). Ideally in a neural-symbolic cycle: compile a neural network from symbolic knowledge (in weights or semantic loss function) and decompile the neural network

into symbolic knowledge.

4 AI and philosophy of science

This chapter's big question

Is machine learning the 'end of theory'?

Key concepts

- Opacity problem
- elementwise/localist vs holistic/distributed representation
- Model audit vs scientific inference

Referring to a 2008 Wired article by Chris Anderson with the title 'The End of Theory: The Data Deluge Makes the Scientific Method Obsolete'.

Lecture 6 We have discussed how neural networks can gain knowledge about the world from the data they are trained on. This also is the goal of science—understanding the world based on observations of it. So can neural networks replace scientific theorizing, as the provocative quote above suggests? We will discuss this in this chapter.

Long before the deep learning revolution, it has been noted that there is an intriguing similarity between the fields of machine learning and philosophy of science. Philosophy of science investigates the best way of doing *scientific induction*: building a theory or model from observed data. And machine learning does something very similar: training a model (e.g., neural network) on collected data. Because of this, some even identify the two fields (Korb 2004), while others describe their relation in a more nuanced way as a *dynamic interaction* (Williamson 2004). (Some new progress in machine learning may inform philosophy of science, and at other times philosophy of science may help theorizing in machine learning.)

However, there also is a crucial difference between modern deep learning and science: the former produces opaque models that solely focus on prediction, but scientific models should also offer explanations of the phenomenon they describe. This point is forcefully made by Noam Chomsky in the discussion of ChatGPT:

Perversely, some machine learning enthusiasts seem to be

proud that their creations can generate correct “scientific” predictions (say, about the motion of physical bodies) without making use of explanations (involving, say, Newton’s laws of motion and universal gravitation). But this kind of prediction, even when successful, is pseudoscience. While scientists certainly seek theories that have a high degree of empirical corroboration, as the philosopher Karl Popper noted, “we do not seek highly probable theories but explanations; that is to say, powerful and highly improbable theories.”

The theory that apples fall to earth because that is their natural place (Aristotle’s view) is possible, but it only invites further questions. (Why is earth their natural place?) The theory that apples fall to earth because mass bends space-time (Einstein’s view) is highly improbable, but it actually tells you why they fall. True intelligence is demonstrated in the ability to think and express improbable but insightful things. (Chomsky et al. 2023)

The main reading discusses this problem that even if modern deep learning models predict the scientific phenomenon near perfectly, they are still not the *kind of* models that scientists favor. This is because these AI models are very complex (so it is hard to ‘understand’ the model) and it is unclear how the parts of the model relate to the parts of the phenomenon. This is known as the *opacity problem* (Boge 2021; Sullivan 2022). Interpretable machine learning and explainable artificial intelligence aim to make AI models more ‘understandable’. But it is not clear whether these methods can be used to draw scientific inference about the real phenomenon from the AI model. The paper discusses why and how this problem can be addressed.

- ↔ Explain the distinction between elementwise/localist representation and holistic/distributed representation. Isn’t it a problem if we do not have a compositional understanding of our model—isn’t this the hallmark of science?
- ↔ What is the differences between “auditing ML models” and “leveraging them for scientific inference”.
- ↔ How can the ‘property descriptors’ bridge this gap, intuitively speaking?

This recently turned into an online book, of which you can also read, e.g., the first part.

Readings

- T. Freiesleben, G. König, et al. (2024). “Scientific Inference with Interpretable Machine Learning: Analyzing Models to Learn About Real-World Phenomena.” In: *Minds and Machines* 34.3. DOI: <https://doi.org/10.1007/s11023-024-09691-z>

This recently turned into an online book.

Further material

- The above mentioned papers on the relation between machine learning and philosophy of science:
 - K. B. Korb (2004). “Introduction: Machine Learning as Philosophy of Science.” In: *Minds and Machines* 14, pp. 433–440. DOI: <https://doi.org/10.1023/B:MIND.0000045986.90956.7f>.
 - J. Williamson (2004). “A Dynamic Interaction Between Machine Learning and the Philosophy of Science.” In: *Minds and Machines* 14, pp. 539–549. DOI: <https://doi.org/10.1023/B:MIND.0000045990.57744.2b>.
- The book on machine learning for science:
 - T. Freiesleben and C. Molnar (2024). *Supervised Machine Learning for Science. How to stop worrying and love your black box*. URL: <https://ml-science-book.com/>.

5 AI and philosophy of language

This chapter's big question

Do Large Language Models have linguistic and cognitive competence or are they just stochastic parrots?

Key concepts

•

The term 'stochastic parrot' is from the title of the paper by Bender, Gebru, et al. (2021).

Literature

- R. Millièrè and C. Buckner (2024a). "A Philosophical Introduction to Language Models – Part I: Continuity With Classic Debates." In: arXiv: 2401.03910 [cs.CL]. URL: <https://arxiv.org/abs/2401.03910>
- R. Millièrè and C. Buckner (2024b). "A Philosophical Introduction to Language Models – Part II: The Way Forward." In: arXiv: 2405.03207 [cs.CL]. URL: <https://arxiv.org/abs/2405.03207>
- Great introductory videos to LLMs: [part 1](#), [part 2](#), and [part 3](#).

6 AI and ethics

This chapter's big question

AI systems are just objective computer models, so they must be fair, right?

There already are dedicated courses on the ethics of AI at LMU, so we focus here on some specific aspect: algorithmic fairness. We do still provide references to general overviews on ethics of AI.

Key concepts

- Policy goals as prediction tasks, and the potentially problematic modeling assumptions behind this (overarching goal, population choice, decision space).
- Bias in data: statistical and societal
- Model architecture: interpretability, perturbation, choice of features.
- Model evaluation assumptions (no interference, uniform, simultaneous)
- Identifying advantaged and disadvantaged groups: intersectionality (Crenshaw)
- Oblivious (purely probabilistic) vs non-oblivious (also including similarity metric between individuals and causality) fairness definitions.
- Oblivious: With D = decision, S = predicted score, A = sensitive variable, X = insensitive variable, Y = true outcome, (1) $D \perp A | Y = 0$, (2) $D \perp A | Y = 1$, (3) $Y \perp A | D = 0$, (4) $Y \perp A | D = 1$, (5) $D \perp A$, (6) $D \perp A | X$.
- Impossibility results: The seminal one that equalized odds and predictive parity are jointly impossible (Chouldechova 2017;

Cf. the machine learning pipeline: here we might call it the 'prediction-model construction pipeline'.

Kleinberg et al. 2016). Other ones to include a notion of counterfactual fairness using causal models (Beigang 2023).

Literature:

- An encyclopedia overview on Ethics of AI:
J.-S. Gordon and S. Nyholm (n.d.). "Ethics of Artificial Intelligence." In: *The Internet Encyclopedia of Philosophy*. Available at: <https://iep.utm.edu/ethic-ai/> (accessed: 6 Mar 2022).
- A famous paper on the ethics of Large Language Models.
E. M. Bender, T. Gebru, et al. (2021). "On the Dangers of Stochastic Parrots: Can Language Models Be Too Big?" In: *Proceedings of the 2021 ACM conference on fairness, accountability, and transparency*, pp. 610–623.
- An overview of the field of algorithmic fairness.
S. Mitchell et al. (2021). "Algorithmic Fairness: Choices, Assumptions, and Definitions." In: *Annual Review of Statistics and Its Application* 8.1, pp. 141–163. DOI: [10.1146/annurev-statistics-042720-125902](https://doi.org/10.1146/annurev-statistics-042720-125902). eprint: <https://doi.org/10.1146/annurev-statistics-042720-125902>. URL: <https://doi.org/10.1146/annurev-statistics-042720-125902>.
- A discussion of the interplay between formalized technical discourse of fairness and informal ethical discourse of fairness.
P. Schwöbel and P. Remmers (2022). "The Long Arc of Fairness: Formalisations and Ethical Discourse." In: *Proceedings of the 2022 ACM Conference on Fairness, Accountability, and Transparency*. FAccT '22. Seoul, Republic of Korea: Association for Computing Machinery, pp. 2179–2188. DOI: [10.1145/3531146.3534635](https://doi.org/10.1145/3531146.3534635). URL: <https://doi.org/10.1145/3531146.3534635>.
- A recent impossibility result showing that three plausible requirements for a predictive algorithm to be fair (equalized odds, predictive parity, and counterfactual fairness) are in fact jointly inconsistent. It can be seen as a continuation of the quite short section 5 of Mitchell et al. (2021) discussing causal reasoning in fairness definitions.
F. Beigang (2023). "Yet Another Impossibility Theorem in Algorithmic Fairness." In: *Minds and Machines*. DOI: <https://doi.org/10.1007/s11023-023-09645-x>

7 Theory of AI: Power and Limits

This chapter's big question

Is there anything AI models cannot do?

Key concepts

- Stochastic learning theory (PAC learnability, No Free Lunch theorems)
- Universal approximation theorems

We start this part of the course with a short background lecture on classic computability theory (Church–Turing thesis, Halting problem, Gödel Incompleteness, complexity theory) and a bit on extension to continuous computation (computable analysis, analog computation, Shannon–Pour-El thesis).

Maybe the two most central classical theorems from the theory of AI are the *No Free Lunch theorem* and the *Universal Approximation theorem*. Their meaning and consequences are discussed in the next two readings, respectively.

add brief take-home message of the two papers

- T. F. Sterkenburg and P. D. Grünwald (2021). “The no-free-lunch theorems of supervised learning.” In: *Synthese* 199.3-4, pp. 9979–10015. DOI: [10.1007/s11229-021-03233-1](https://doi.org/10.1007/s11229-021-03233-1)
- M. J. Colbrook et al. (2022). “The difficulty of computing stable and accurate neural networks: On the barriers of deep learning and Smale’s 18th problem.” In: *Proceedings of the National Academy of Sciences* 119.12, e2107151119. DOI: [10.1073/pnas.2107151119](https://doi.org/10.1073/pnas.2107151119). eprint: <https://www.pnas.org/doi/pdf/10.1073/pnas.2107151119>. URL: <https://www.pnas.org/doi/abs/10.1073/pnas.2107151119>

The Universal Approximation theorem shows that for every (continuous) function describing the true input-output relation in the world, there is a neural network with a weight setting that approximates this function to any desired accuracy. However, the paper asks

whether a learning algorithm (like backpropagation) can actually find this weight setting via learning from finite data about the true function. They provide a negative results: Despite the existence of a neural network

“We show that there are problems where stable and accurate NNs exist, yet no algorithm can produce such a network. Regardless of how many computational resources or data one throws at the problem, this impossibility result holds.” Colbrook 2022

Just some further readings are as follows. We will go into much more detail in the course *Advanced Topics in the Foundations of AI* that I will offer next semester.

- For some further computability-theoretic analysis of the inverse problems studied in the preceding paper, see

H. Boche et al. (2022). *Inverse Problems Are Solvable on Real Number Signal Processing Hardware*. arXiv: 2204.02066 [eess.SP].

- For a general analysis of the capabilities of analog computation, see

M. B. Pour-El (1974). “Abstract computability and its relation to the general purpose analog computer (some connections between logic, differential equations and analog computers).” In: *Transactions of the American Mathematical Society* 199, pp. 1–28. DOI: <https://doi.org/10.2307/1996870>

(For an overview of analog computation, see Bournez and Pouly 2021.)

- For the use of computability theory in the study of human intelligence (aka cognitive science :-)), see

I. Van Rooij (2008). “The Tractable Cognition Thesis.” In: *Cognitive Science* 32.6, pp. 939–984. DOI: [10.1080/03640210801897856](https://doi.org/10.1080/03640210801897856). URL: <https://onlinelibrary.wiley.com/doi/abs/10.1080/03640210801897856>

8 Reliable AI

This chapter's big question

What can we do about the black box nature of neural networks?

Key concepts

- Interpretable AI: Reasons for requiring interpretability, interpretability as transparency, interpretability as post-hoc explanation.
- Explainable AI
- Robustness in AI

Literature: Interpretable AI

- Z. C. Lipton (09/2018). "The Mythos of Model Interpretability." In: *Commun. ACM* 61.10, pp. 36–43. DOI: [10.1145/3233231](https://doi.org/10.1145/3233231). URL: <https://doi.org/10.1145/3233231>

Reasons for requiring interpretability: *trust* (that model will perform well, though hard to make precise), *causality* (infer true causal relation in the world from the correlations detected by the model), *transferability* (to new domains of application, still knowing that the model will work).

Interpretability as *transparency*: *simulatability* (a human can simulate the model at once), *decomposability* (each part of the model admits intuitive interpretation; cf. elementwise/localist representation), *algorithmic transparency* (the learning algorithm with which the model is built is understood well: provably converges to best solution, etc.). Humans aren't transparent in any of these senses. Linear models are in general only interpretable in the last sense, and the input features that they used might be processed while they are readily interpretable for neural networks.

Interpretability as *post-hoc interpretation/explanation*: Provide additional information to elucidate why the model provided a certain

output, without necessarily being faithful to the underlying mechanism producing the output (hence this can be misleading). If humans are interpretable, it is in this sense. Examples: *text explanation* (provide a verbal explanation of model output; no guarantee of correctness), *visualization* (e.g., visualize high-dimensional representations in 2D images), *local explanation* (e.g., saliency maps showing which parts of the input were most important to the output in the sense that changing them will most likely change the output; can be misleading), *explanation by example* (e.g., which datapoints are most similar/important for the model behavior).

- F. Doshi-Velez and B. Kim (2017). *Towards A Rigorous Science of Interpretable Machine Learning*. arXiv: 1702.08608 [stat.ML]
- C. Rudin (2019). "Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead." In: *Nature Machine Intelligence* 1, pp. 206–215. DOI: <https://doi.org/10.1038/s42256-019-0048-x>

Since the publication of the paper, many more local explanation methods are known: counterfactual explanation, SHAP, intergrated gradients, etc. But they also face certain impossibilities: see Bilodeau et al. (2024).

Literature: Explainable AI

- T. Miller (2019). "Explanation in artificial intelligence: Insights from the social sciences." In: *Artificial Intelligence* 267. DOI: <https://doi.org/10.1016/j.artint.2018.07.007>
- J. Woodward and L. Ross (2021). "Scientific Explanation." In: *The Stanford Encyclopedia of Philosophy*. Ed. by E. N. Zalta. Summer 2021. Metaphysics Research Lab, Stanford University
- B. Mittelstadt et al. (2019). "Explaining Explanations in AI." in: *Proceedings of the Conference on Fairness, Accountability, and Transparency*. FAT* '19. Atlanta, GA, USA: Association for Computing Machinery, pp. 279–288. DOI: [10.1145/3287560.3287574](https://doi.org/10.1145/3287560.3287574). URL: <https://doi.org/10.1145/3287560.3287574>

Literature: Robust AI

- T. Freiesleben and T. Grote (2023). "Beyond generalization: a theory of robustness in machine learning." In: *Synthese* 202.109. DOI: <https://doi.org/10.1007/s11229-023-04334-9>

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