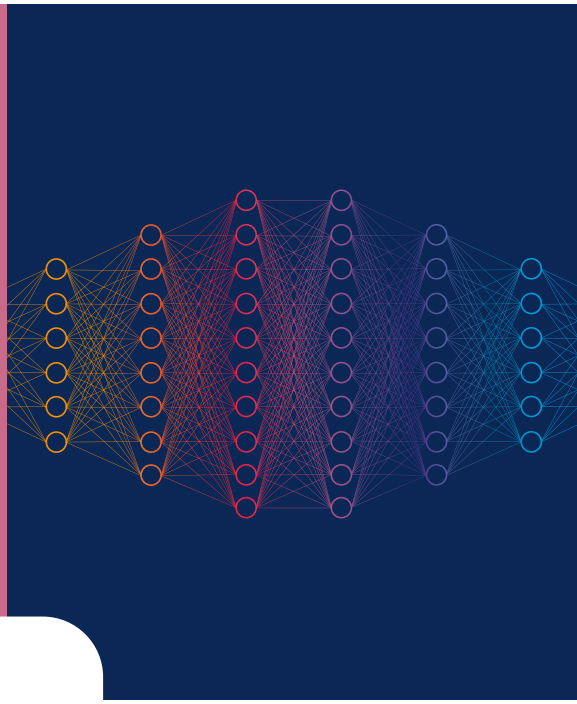
Lernende Systeme

GERMANY'S PLATFORM FOR ARTIFICIAL INTELLIGENCE

Machine Learning and Deep Learning



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Executive Summary

We are living in the golden age of Artificial Intelligence[1] (AI). Continuing progress in algorithm development, particularly in Machine Learning[2] (ML) and Deep Learning (DL), combined with the availability of huge data sets and advances in rapid, parallel computing have helped deliver breakthroughs in diverse fields of use. Applications that just a few years ago seemed to be plucked from the realms of science fiction are now already – or are soon to become – part of our daily lives. Knowledge of unimaginable breadth and astonishing depth is becoming accessible at the click of a mouse, voice-controlled assistance systems are helping us in many aspects of life, image recognition systems have achieved near-human performance levels, autonomous vehicles are increasingly becoming a reality, business models are changing rapidly and personalised medicine is supporting optimum and personalised treatment.

Artificial Intelligence can help enhance our standard of living in a whole range of ways. The challenge for society is to shape the future with Artificial Intelligence, a process that will involve seizing opportunities but also analysing risks and offering solution approaches. The various social actors must work together to shape a future with Artificial Intelligence. The following text focuses primarily on the technical challenges and the establishment of capabilities. What are the issues for which AI competence needs to be built up nationally, and which research issues should we be investing in, both now and in the future?

1 According to J. McCarthy, Artificial Intelligence is "the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable" (McCarthy 2007).

2 T. Mitchell defines Machine Learning as the science "that is concerned with the question of how to construct computer programs that automatically improve with experience" (Mitchell 1997: 15).

Machine Learning and Deep Learning: The engine for current AI breakthroughs

At present, smart solutions are predominantly programmed manually. A smartphone, for instance, contains more than 10 million lines of code. However, the latest developments in Artificial Intelligence mark a paradigm shift – instead of manually coding processing steps, it is the ability to learn that is being programmed. With the aid of Machine Learning, agents can take a large volume of example situations, identify patterns and transfer them to new, similar situations. The biggest successes in AI are currently based on deep neural networks (Deep Learning), which involve a large number of artificial neurons processing input data in multiple layers and outputting the result.

Humans still have to carry out programming for Machine Learning, but instead of programming finished solutions, they are developing programs that learn how to solve the problem at hand based on training data. Deep Learning, which is a sub-discipline of Machine Learning, has recently helped deliver notable breakthroughs in many areas. These advances form the basis for most successes in the fields of application mentioned. For example, state-of-the-art translation and image recognition systems would be inconceivable without Deep Learning. Neural networks feature a high level of expressiveness, which, in simple terms, is the ability to approximate any continuous function as accurately as required. Consequently, training these networks is often a very data and time-intensive process. At the same time, a network that has been painstakingly trained for a specific task can usually be adapted fairly easily for a new task.

In some cases, understanding of the theoretical principles of Deep Learning is still patchy – unlike earlier approaches such as support-vector machines. Optimum solutions are created through a process of trial and error based on practical knowledge and heuristics. Formulating the theoretical principles of Deep Learning is currently an important focal point for research.

Frequently, the terms Artificial Intelligence, Machine Learning and Deep Learning are not used selectively. Artificial Intelligence defines challenges that need to be met and develops solution approaches. Machine Learning centres primarily on the process of learning solutions. Deep Learning, for its part, is currently providing some of the most high-performance approaches to Machine Learning.

AI expertise for “AI made in Germany”

Without Deep Learning, it is inconceivable that the spectacular and currently much-discussed breakthroughs in Artificial Intelligence could have been achieved. To ensure “AI made in Germany” is successful, it is essential that expertise in Machine Learning and Deep Learning is reinforced in Germany. Indeed, if data is considered the “oil of the 21st century”, gathering it in large or small volumes remains useless without a high-performance “refinement” process in the form of Machine Learning or Deep Learning – it would stay exactly as it is: crude oil that is unable to power any (economic) engine.

The following points identify the competences that are pivotal to rolling out "AI made in Germany" and ought to be addressed in universities, research programs and competence centres. They also indicate the infrastructure requirements that need addressing through dialogue between the worlds of science, business and politics. They are listed in order of their current importance for technological development.

- **Reinforce expertise in the basics and processes of Machine Learning.** Examples include (un)supervised learning, reinforcement learning, density estimation, boosting and ensemble methods, maximum margin models, online and data stream learning methods, relational learning and other processes. The basics also include comprehensive expertise in model selection, data cleansing, feature selection, mathematical optimisation, statistics, the interpretation of models and their results, and the execution of empirical evaluation in general.

- **Reinforce expertise in Deep Learning**, particularly in the subsections of neural networks, convolutional neural networks, recurrent neural networks, autoencoders, neural variational inference, generative adversarial networks, self-supervised deep networks, deep probability models, differentiable programming, stochastic optimisation, and the visualisation and explainability of deep models.

- **Establish and expand AI infrastructure**, particularly that of clusters that support Machine Learning and Deep Learning for example with special AI accelerators such as GPUs, TPUs, etc. Experts in Artificial Intelligence and Machine Learning and politicians should in the short term enter into in-depth dialogue about how such an infrastructure can be designed and implemented. The most important consideration is that the infrastructure should be available to all stakeholders with proven expertise and be able to meet the performance requirements of a wide range of applications. Furthermore, it must be possible to test out various concepts, for instance, with regard to security and confidentiality requirements.

- **Reinforce research into innovative computational platforms**. At present, AI infrastructures are based on CPU and GPU clusters. Future AI infrastructures are likely to differ considerably. Researching new computational platforms and accumulating expertise in this area could become a competitive advantage, particularly during fundamental upheavals in the hardware sector. That is why Germany should not rely solely on technologies that are already mature, but also carefully research future underlying technologies for Artificial Intelligence.

- **Reinforce system and integration expertise**. This covers the combination and trade-off analysis of AI processes and conventional processes, as well as Artificial Intelligence with an energy consumption in the milliwatt range, secure and guaranteed AI applications and Artificial Intelligence on low-cost platforms. A focus should be placed on the architecture of these systems with AI components. After all, right now the main challenge lies more in efficiently delivering data to the computing nodes, rather than the efficient design of the nodes themselves.

- **Reinforce expertise in additional relevant AI methods** such as drawing conclusions, efficient searches (e.g. Monte Carlo Tree Search), constraint programming, knowledge representation, planning algorithms and static relational approaches.

- **Reinforce expertise in additional areas of data science** that are not already covered by Machine Learning and Artificial Intelligence, such as data acquisition, data management, distributed computing or particularly hardware-based AI acceleration.

- **Reinforce expertise in the application of AI methods and investigating the social, socioeconomic and political effects** brought about by the increased use of self-learning systems and automatic decisions: Interpretability of AI models, AI quality assurance, discrimination through and bias of AI systems and observance of human rights when utilising AI systems, etc.

- **Commence the nurturing of statistical expertise and other skills for Artificial Intelligence and Machine Learning in schools**, so people learn from an early age how to handle uncertainties and operate in imprecisely defined environments. Understanding, interpreting and handling statistical statements are important examples of learning content.

Interdisciplinary cooperation along the value chains in a European context will ensure that research into Artificial Intelligence, Machine Learning and Deep Learning can continue to grow to the benefit of everyone in Germany and will make "AI made in Germany" a quality seal with a global profile.

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