Shaping the Digital Future of ErUM Research: Sustainability & Ethics

1. Sustainability & Ethics in ErUM-Data
2. Fundamental Research on Universe and Matter
3. Humans and Machines in Information Processing
4. AI-Tools when Studying Physics

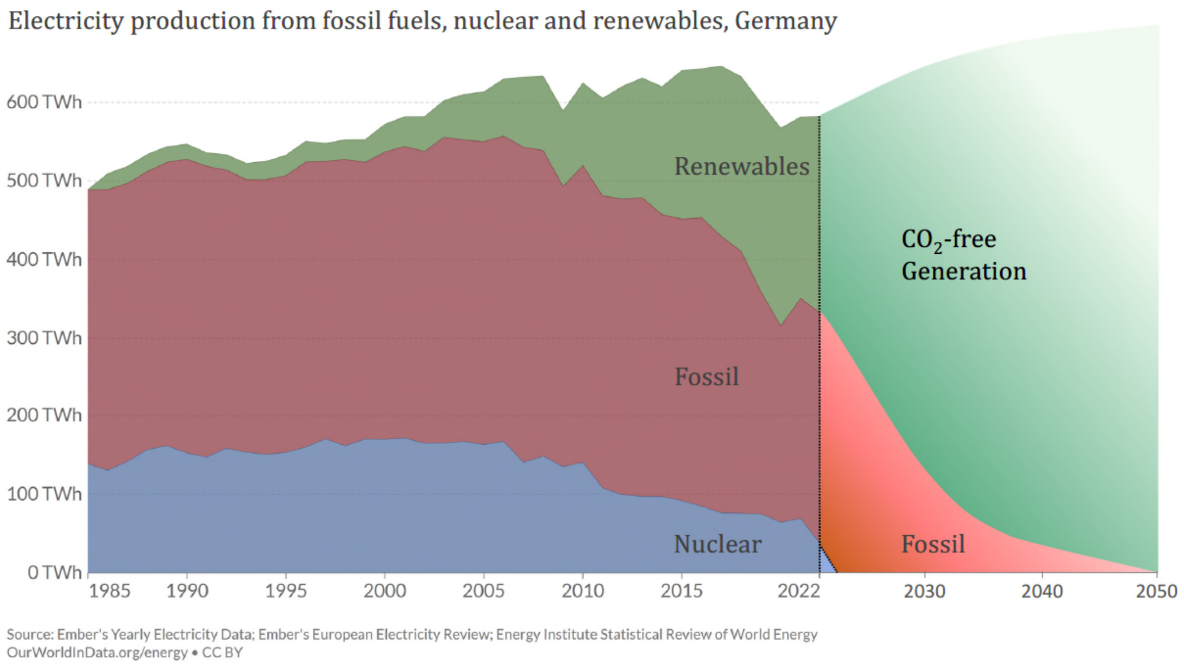
DIG-UM

Prof. Dr. Martin Erdmann, RWTH Aachen University, 28-Jul-25

Sustainability

4-day Workshop May 23

→ Awareness in daily research: balance *knowledge gain* with *resource usage*



[Portfolio of measures](https://doi.org/10.1140/epjs/s11734-024-01436-4)

Short term

Medium term

Longer term

Item	Call-to-action
	Immediately or on **short time scale** with little effort these measures that can be implemented:
S1	Raise awareness of the climate challenge at all levels.
S2	Disseminate knowledge of measures to address the challenge.
S3	Monitor and report energy consumption at job level.
S4	Consider carbon footprint for all investments and project plans.
	On a **medium time scale** of a few years the following measures can be realized:
M1	Make data FAIR to promote reuse.
M2	Reduce and compress data having the anticipated scientific value of the retained information and the resource requirements in mind.
M3	Optimize the choice of storing against re-calculating intermediate results.
M4	Use workflow management to make processing FAIR.
M5	Make software FAIR and reliable by following good software development practices and ensuring sustainable support.
M6	Design software for optimized energy consumption and provide tools to measure it.
M7	Continue research on potential of AI or other new technologies for efficient use of resources, but balance gain of research action against resource consumption of these developments.
M8	Monitor and report energy consumption at site and project level, provide information of the individual use per scientist/project/publication.
M9	Extend monitoring of resources beyond CO_2e (water, material etc.).
M10	Train scientists in good practices.
M11	Regularly review and update the CO_2e reduction plan.
M12	Strive to become a role model at all levels and help to establish sustainability in everyday life.
	A **longer term** coordinated planning is required for the following measures:
L1	Adjust computing in space and time to the availability of renewable energy, e.g. computing centers close to off-shore wind parks with a job scheduling using only or mainly the surplus available at a given time.
L2	Develop software and middleware that can respond dynamically to the availability of energy.
L3	Optimize power usage effectiveness.
L4	Re-use of produced heat.
L5	Adjust hardware lifetime considering emissions due to procurement and operation.
L6	Include the resources needed for continuous IT support into project planning.

https://doi.org/10.1140/epjs/s11734-024-01436-4

This Workshop 2025: Progress since 2023

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German Ethics Council Opinion (Mar-2023)
Humans and Machines – Challenges of Artificial Intelligence

Illustration: Hannah Robold
Berliner Ideenlabor

Distinction humans ↔ machines

Human
- possess reason
- embedded in social context
- → rational action

Software systems
- possess no reason
- do not act independently
- are not personal counterpart

Machines cannot relieve humans of their responsibility

Illustration:
pinkeyes/Shutterstock.com

Key question for ethical evaluation

Does AI expand (+) or diminish (-) human authorship
and conditions necessary for responsible action?

This Workshop 2025: New topic for ErUM-Data

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Fundamental Research on Universe and Matter

Research Mission

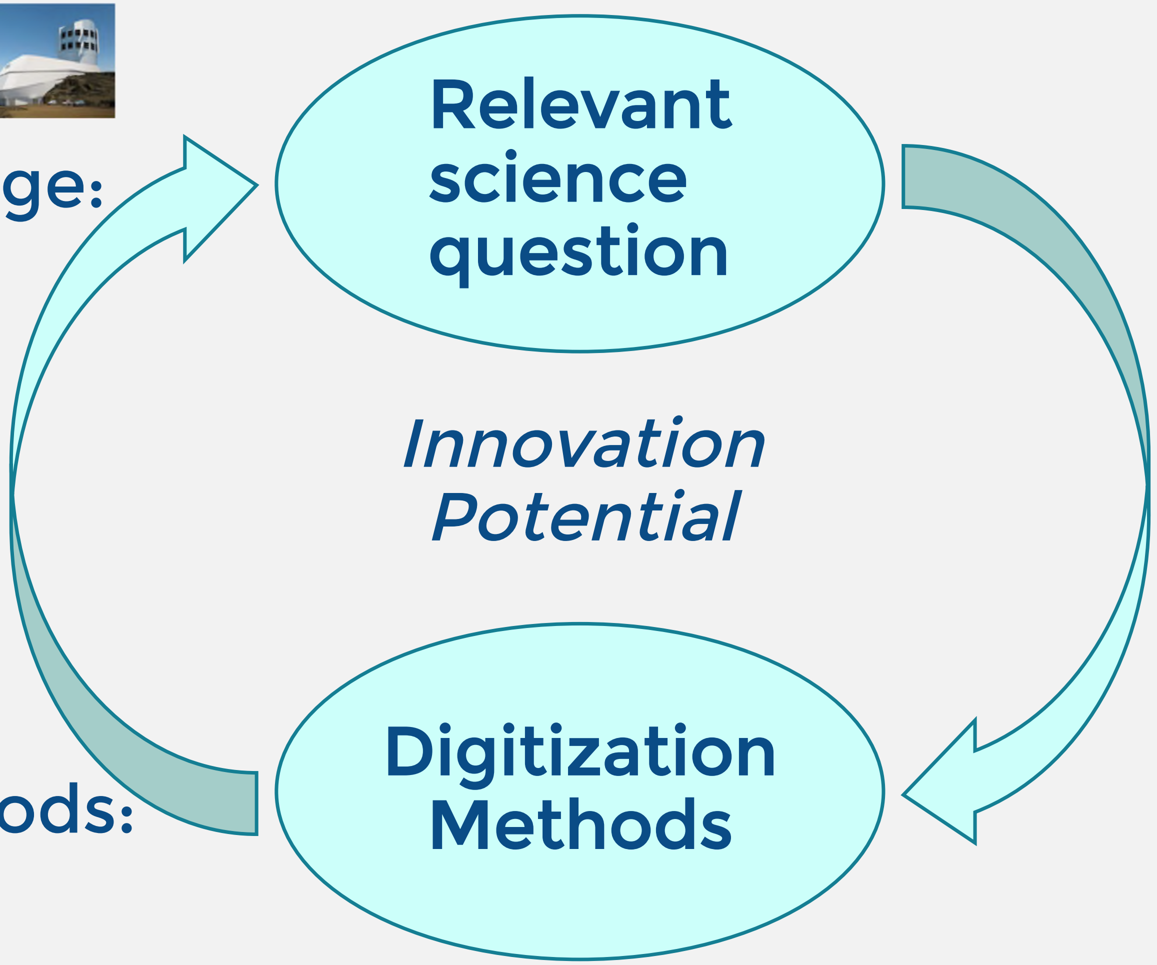





- We discover new particles yielding deep insights into the fundamental laws of physics
- Observe and explore distant galaxies, stars and new planets
- Investigate the structure and function of proteins drugs and viruses
- Discover new materials
- Observe chemical reactions in real-time

Innovation: Domain Knowledge *and* AI

Science domain knowledge:



Know-how modern methods:

Adapt Computer Science Methoden, e.g. Deep Learning

- Fully connected
- Convolutional
- Graph
- Recurrent
- Autoencoder
- Generative Adversarial
- Normalizing Flows
- Diffusion
- Reinforcement
- Transformer
- Kolmogorov-Arnold
- Lorentz Boost

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Structure for Digital Transformation

Community Self-Organization

Komitee	
KAT	Astroteilchenphysik
KET	Elementarteilchenphysik
KfB	Beschleunigerphysik
KFN	Forschung mit Neutronen
KFS	Forschung mit Synchrotronstrahlung
KFSI	Forschung nuklearen Sonden & Ionenstrahlen
KHuK	Hadronen- und Kernphysik
RDS	Rat Deutscher Sternwarten

BMFTR Funding

ErUM-Pro

Project funding for Experiments

ErUM-Data

120 M€ / 10 years

Digital Transformation

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Overview Board (OB) 8 ErUM Committee Chairs, 1 Resource Provider Board Chair, 1 Spokesperson, 1 BMBF Representative, 1 PT-DESY Representative

Coordination

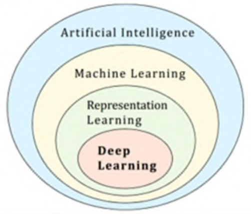
Spokesperson / 5 Co-spokespersons	Digitization Board (DB)	Resource Provider Board (RB)
	1 Spokesperson, 5 Co-spokespersons, 8 Experts from ErUM committees, 1 Resource Provider Representative	10 Resource Provider Representatives

Annual Conference of the ErUM-Data Working Groups

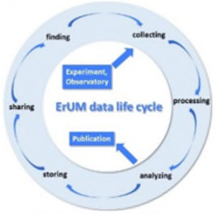
Topic Groups

Federated Infrastructures

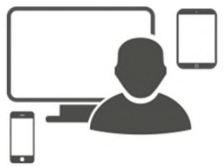
Big Data Analytics



Research Data



User Interface



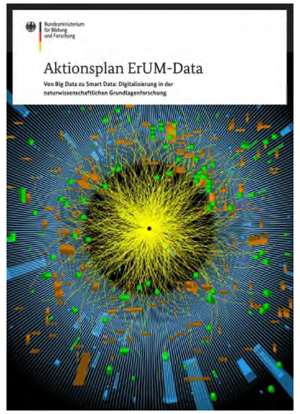
Knowledge Distribution

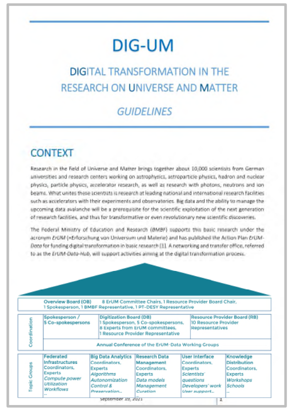
Time Line Digital Transformation

2018 → 2019 → 2020 → 2021 → 2022 → 2023 → 2024 → **2025** → 2026 → ...

BMBF Workshop in Bonn

Challenges and Opportunities of Digital Transformation in Fundamental Research on Universe and Matter



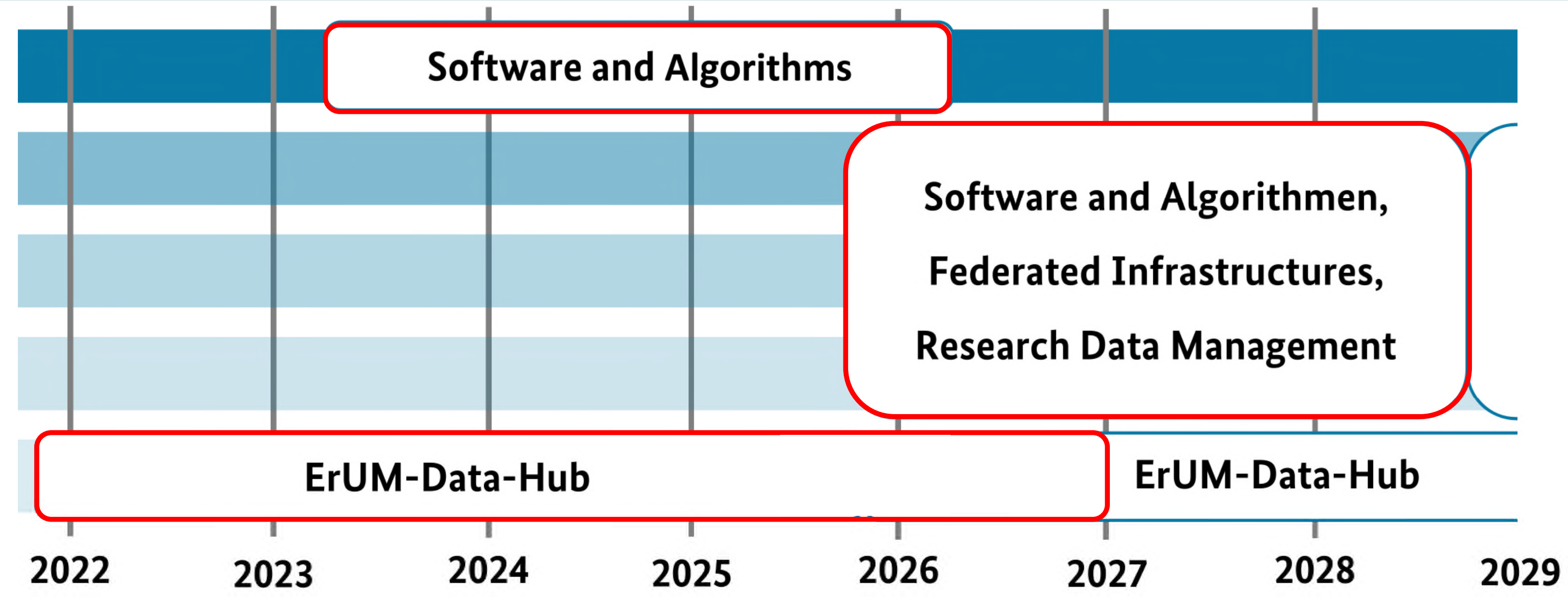


ErUM-Data: BMFTR Funded Projects

ErUM-Data
120 M€
for 10 years

7/2025 waiting for funding announcements

This Workshop: Organization →



Excerpt from BMBF presentation 12-Dez-2022

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Humans and machines in information processing

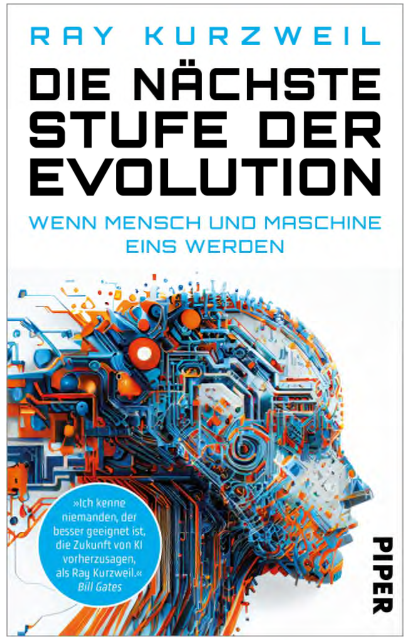
Evolution of information processing

Past to present

table translated by o3

	Epoch	Medium	Time span
	First	Non-living matter	Billions of years (non-biological atomic and chemical synthesis)
	Second	RNA and DNA	Millions of years (until natural selection introduces a new behavior)
	Third	Cerebellum	Thousands to millions of years (to evolve new complex abilities), hours to years (for very simple learning)
	Fourth	Neocortex	Hours to weeks (to learn new complex abilities)
4th	**Fourth**	**Digital neural networks**	**Hours to days (to learn new complex abilities at superhuman level)**
5th	**Fifth**	**Brain-computer interfaces**	**Seconds to minutes (to explore thoughts unimaginable to today's humans)**
	Sixth	Computronium	< seconds (to push cognition step by step to the very limits of physical possibility)

Future (next 30 years?)



Ray Kurzweil: author, inventor, futurist,
Director of Engineering at Google

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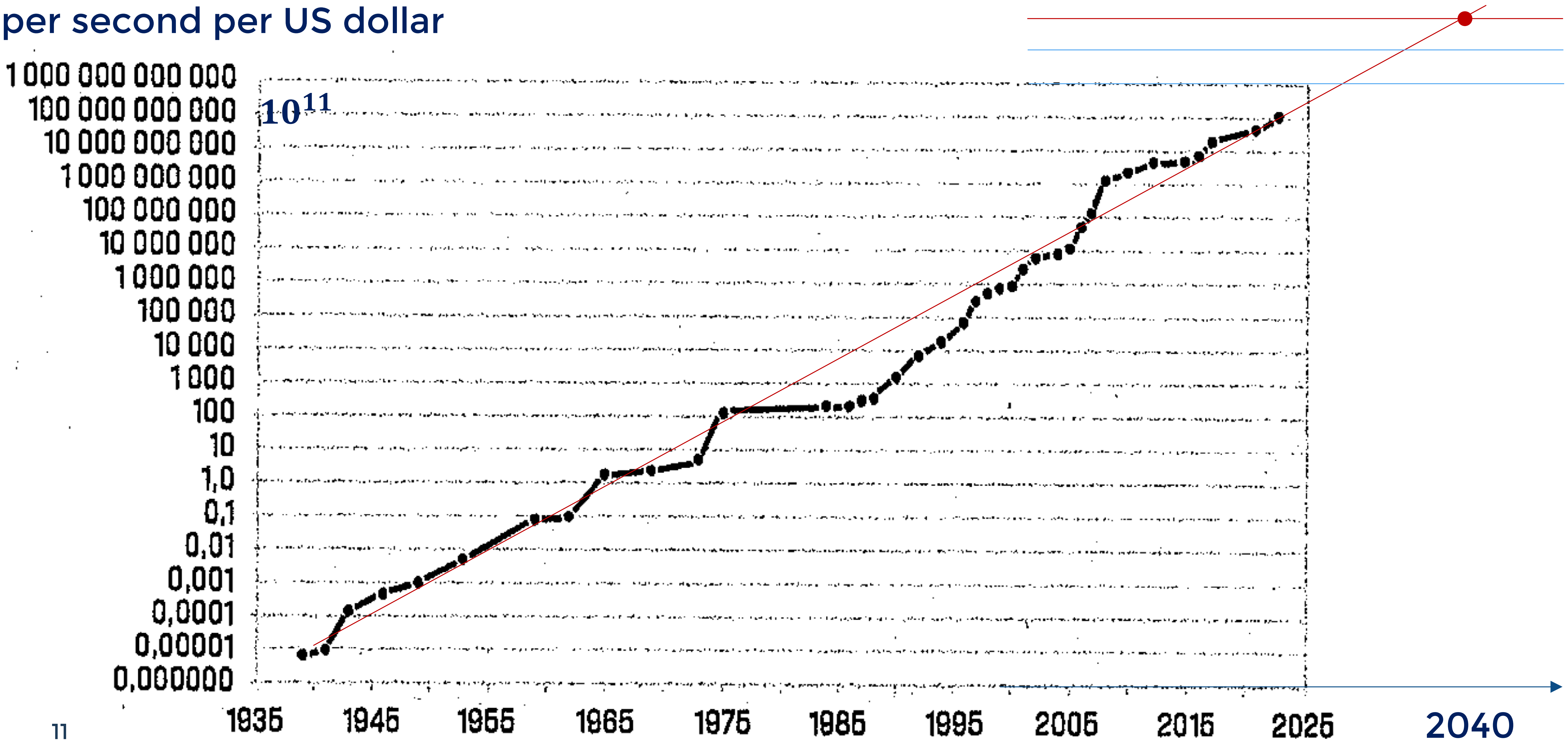
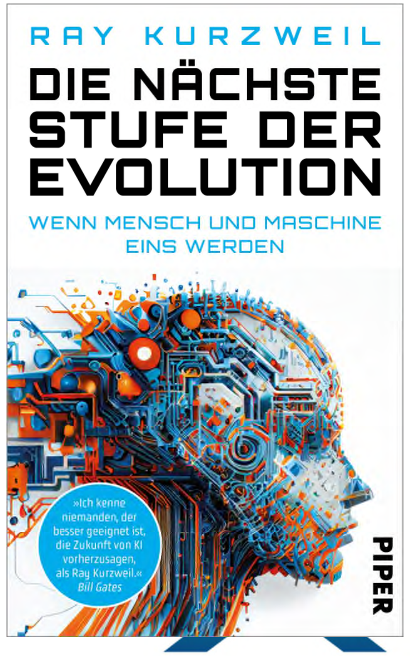
Price-performance ratio of Computing power

Supercomputer: $10^{18}\,\frac{1}{s}$

Estimated human maximum calculations per second: $10^{14}\,\frac{1}{s}$

Price per number of calculations per second per US dollar





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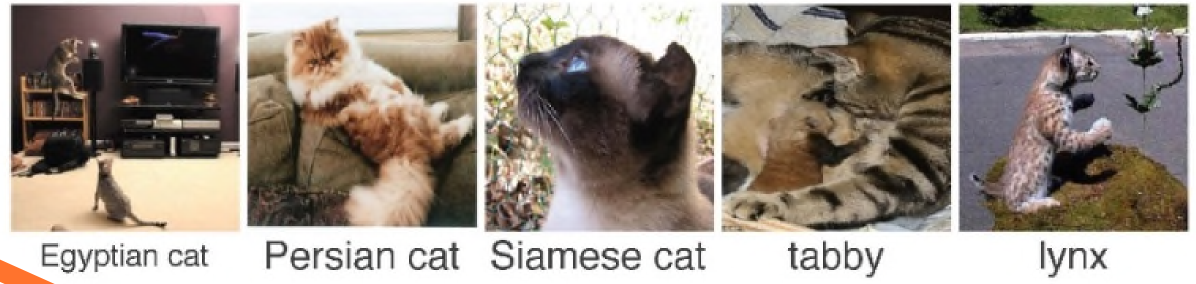
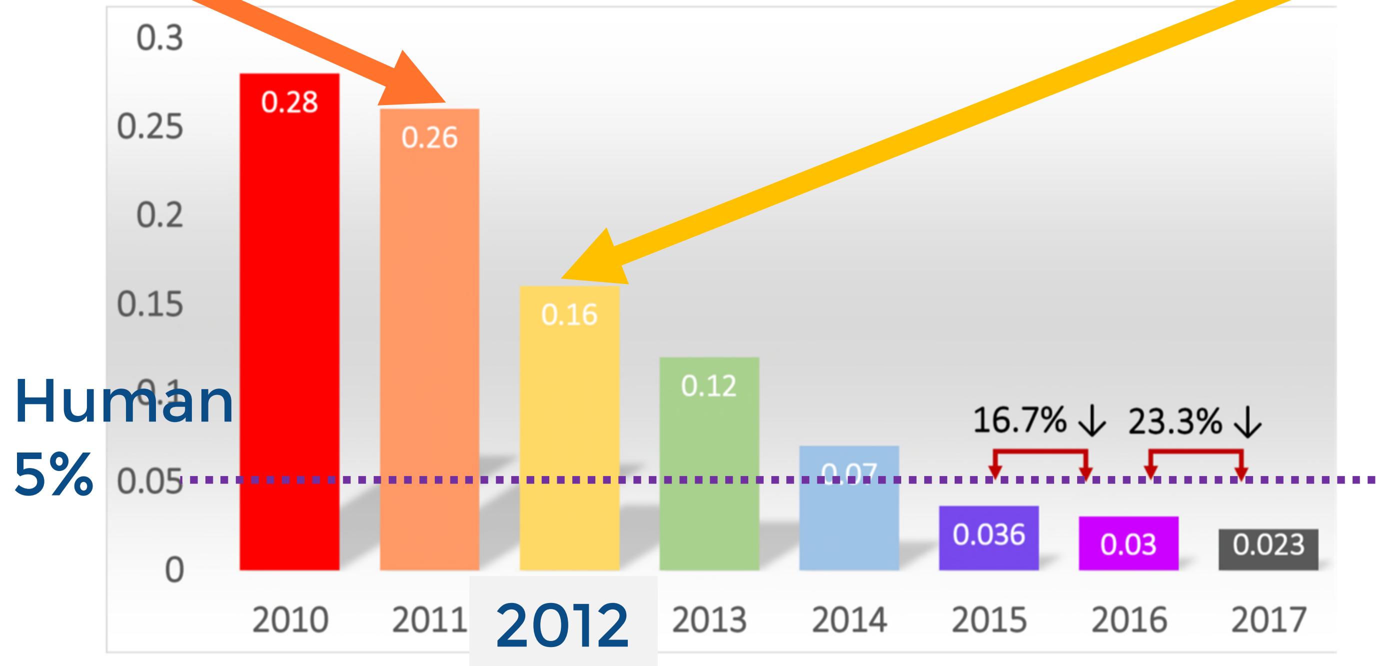
Competition of Algorithms

Rule-based Systems if… then…

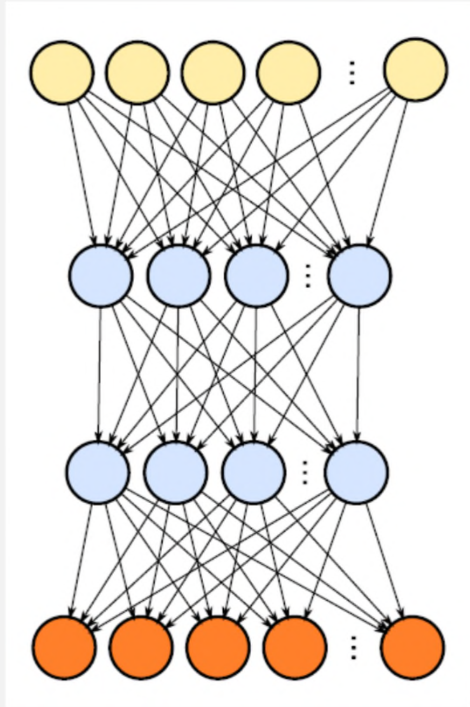
Classification error rate

1.2 million natural images with numerous aspects as criteria





Connectionist methods



"Intelligence" by structure not through content

O. Russakovsky et al, arXiv:1409.0575; K. He, X. Zhang, S. Ren, J. Sunar, arXiv:1512.03385
WMW Jie Hu, Li Shen (Oxford), Gang Sun, 2017 R. Kurzweil, Die nächste Stufe der Evolution, 2024

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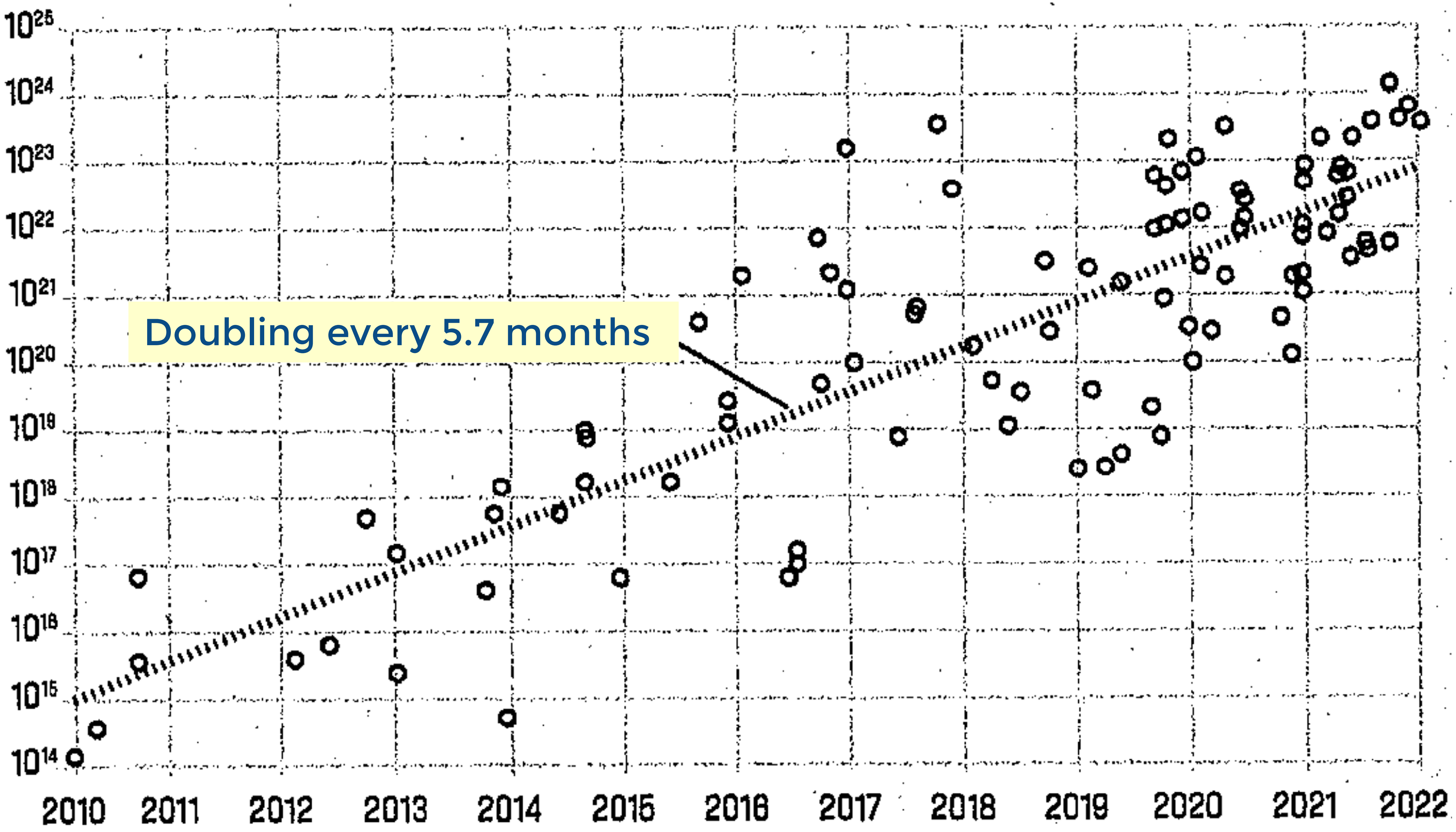
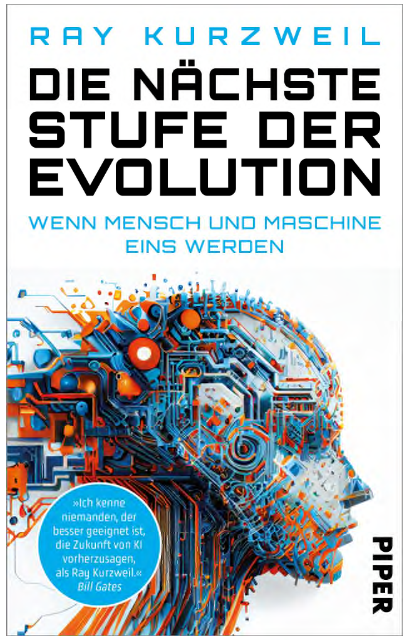
Computing power in machine learning

Computing power for training of machines in Flops





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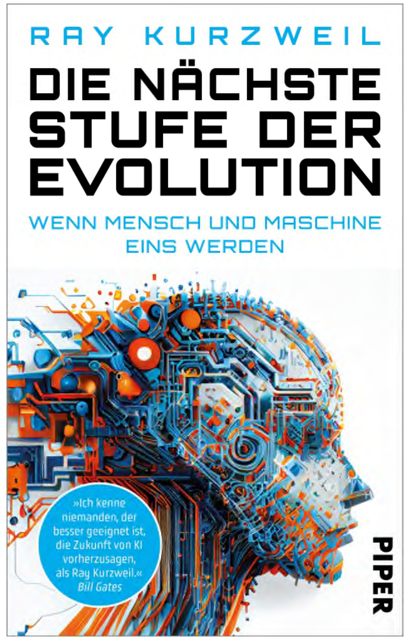
Turing Test

In 1950, the British mathematician Alan Turing (1912-1954) published an article in the journal Mind entitled “Computing Machinery and Intelligence”. In it, Turing posed the most important question in the history of science: “Can machines think?” … Turing reduced the idea to something that could be tested empirically.

He proposed using the “imitation game” - now known as the Turing test - to determine whether a machine was capable of performing the same cognitive tasks as our brains. In this test, human examiners communicate with an AI and human test subjects via text messages without seeing who they are talking to. The examiners ask questions on any topic or situation. If, after a certain period of time, they cannot tell which interlocutor was the AI and which was human, the AI has passed the test.



We are not there yet.

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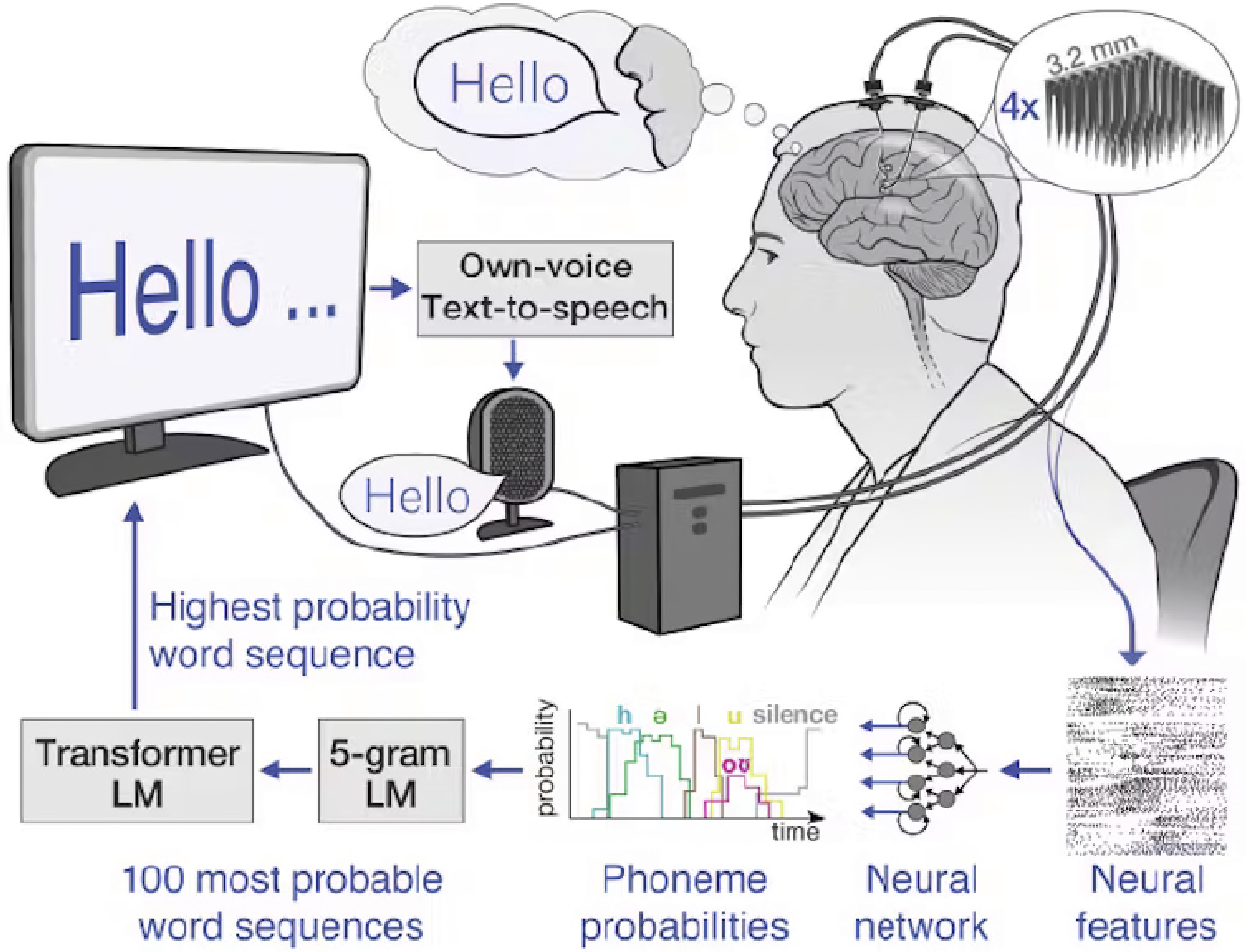
From thoughts to words:
How AI deciphers neural signals to help a man with ALS speak

similar Stephen Hawking

We've enabled Casey Harrell, a man with ALS, to "speak" with over 97% accuracy using just his thoughts.



August 22, 2024
https://theconversation.com/from-thoughts-to-words-how-ai-deciphers-neural-signals-to-help-a-man-with-als-speak-236998
Progress in 2025 but similar results

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Meta AI Thought-to-Text

magnetoencephalography (MEG)

Fifth Epoch	Brain-computer interfaces

Future Implications of Thought-to-Text Technology

brain-to-text communication—no surgery required

1. **Communication:** Enables people with paralysis or speech disabilities to type just by thinking
2. **Hands-Free Control:** Allows phones, computers, and AI assistants to be operated by thought
3. **Faster AI Interaction:** Instant commands to AI speed up work, research, and creativity
4. **Military & Security:** Silent, thought-based communication for high-risk situations

Still early-stage—miniaturization & accuracy needed for real-world adoption

Next Steps in Thought-to-Text Technology

1. **Wearable MEG Devices:** Miniaturized, portable brain sensors—no bulky machines
2. **Advanced AI Models:** Improved accuracy through continuous learning from brain signals
3. **Brain Stimulation:** Potential for “writing” information back to the brain—enabling direct brain-to-brain or AI-to-brain communication
4. **Real-World Testing:** Moving experiments from lab settings to everyday environments

Goal: Small, fast, accurate systems for practical mind-controlled communication

adapted from https://www.godofprompt.ai/blog/thought-to-text

Meta AI Thought-to-Text: Ethical Concerns

1. **Mind Privacy:** Who controls brain data? Risk of unauthorized access by companies or governments
2. **Security Risks:** Potential for hackers to intercept and misuse brain signals
3. **Consent & Control:** Ensuring users have full control—preventing unintended thought capture
4. **AI Bias & Errors:** Responsibility for misinterpretations; risk of unfair use in legal/medical contexts

Need for Regulation: Strong safeguards essential to balance benefits and risks

adapted from https://www.godofprompt.ai/blog/thought-to-text

AI-Tools when studying physics

What physicists will need to be able to do in the future

- Knowing and being able to use physical concepts on a mathematical/numerical basis
- Ability to abstract, recognize the most important concept from a variety of information
- Know and use mathematical tools
- Develop and implement experimental methods
- Project management
- Working in a team

} remaining

- **Understanding machines** (e.g. deep learning) conceptually, developing them and using them sensibly
- Being able to use the **human-machine interface** as a **knowledge base** and for **solving tasks**
- Professional **assessment** of whether a calculation, a result, a technical formulation is **trustworthy**

Implications: Changes in prioritization of **training and examination formats.**

} new

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Recommendation for the use of AI tools when studying physics

RWTH Aachen physics department 14-Apr-2025

A) Physics department **welcomes** use of **AI tools** when studying physics

B) Students need to develop **AI literacy**

C) **Disclosure** in scientific work

D) **Assessment** of AI-generated contributions

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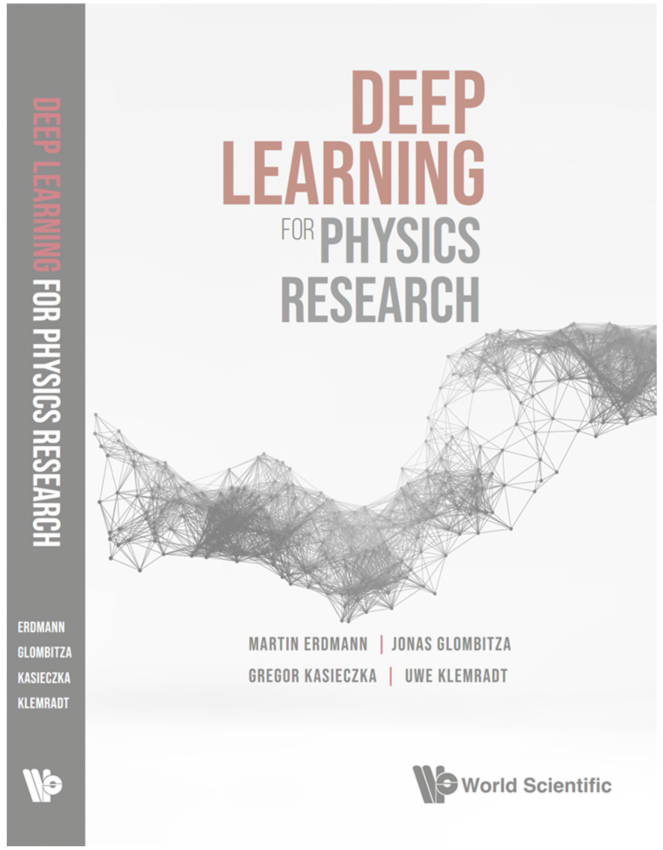
AI Literacy

Early Bachelor Course

Summary – Key Prompting Principles K.Zoch

- **Be specific:** say *what* you want, *how* to format it, and *who* it's for.
- **Structure matters:** lists, examples, or step-by-step formatting to anchor the output.
- **Use prompting strategies when appropriate:**
  - **CoT** for problems needing logical steps
  - **DSP** for patterns or repetitive tasks
  - **ReACT** for lookup/tool reasoning (real or simulated)
- **Control output through text, not hope.**
  - Don't rely on "please" — rely on **clarity, constraints, and cues**.
- **Prompting is debugging:** if the model gets it wrong, fix the prompt — and iterate.

Master Deep Learning Course



Not yet teaching ethical evaluation

Does AI expand (+) or diminish (-) human authorship and conditions necessary for responsible action?

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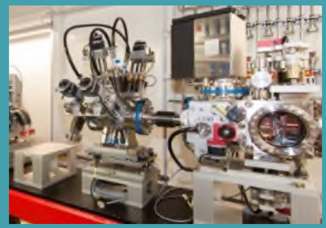
Messages



- Research on Universe & Matter → Digital Transformation
- Innovation: Combine science domain knowledge with AI
- Structured approach: Community strategies and BMFTR funding
- This Workshop: Sustainability & Ethics, are we on the right track?

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Backup

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German Ethics Council : Humans and Machines – Challenges of Artificial Intelligence

Normative Considerations of the German Ethics Council Regarding Artificial Intelligence

The German Ethics Council starts from a fundamentally normative distinction between humans and machines. Software systems possess neither theoretical nor practical reason. They do not act or decide independently and cannot assume responsibility. Even when they simulate empathy, willingness to cooperate, or insight, they are not personal counterparts.

Human reason is always embedded within a concrete social context and environment. This embeddedness is what enables human reason to become effective in action. Individuals act rationally only as members of a social community and within a cultural setting.

“Even if machines in the form of artificial intelligence are highly advanced, they cannot relieve humans of their responsibility.” – Julian Nida-Rümelin

Humans develop digital technologies and use them as tools for human purposes. However, these technologies also have significant feedback effects on human agency. While machines themselves do not act autonomously, they profoundly alter human capacity to act—and can either greatly expand or restrict our range of possible actions.

“When human activities are delegated to machines, this can have very different consequences for various groups, actors, and those affected.” – Judith Simon

For the Ethics Council, the central key question for ethical evaluation is: Does the use of AI expand or diminish human authorship and the conditions necessary for responsible action? The delegation of formerly human tasks to machines should principally aim at expanding human agency. Any reduction thereof—as well as diffusion or evasion of responsibility—should be prevented.

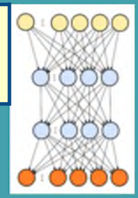
“AI must not replace humans.” – Alena Buyx

To ethically assess the value and utility of delegating previously human actions to machines, it is always necessary to take a context-specific perspective—one that considers both the viewpoints of all stakeholders involved and the long-term consequences of such transfers. As so often, the challenges lie in the details: specifically, in the technical specifics, application contexts, and institutional as well as socio-technical environments.

The differences between humans and machines

	Distinctive Human Skills	How GenAI can supplement learning processes
Create	Engage in both creative and cognitive processes that leverage human lived experiences, social-emotional interactions, intuition, reflection, and judgment to formulate original solutions.	Support brainstorming processes; suggest a range of alternatives; enumerate potential drawbacks and advantages; describe successful real-world cases; create a tangible deliverable based on human inputs
Evaluate	Engage in metacognitive reflection; holistically appraise ethical consequences of alternative courses of action; identify significance or situate within a full historical or disciplinary context	Identify pros and cons of various courses of action; develop and check against evaluation rubrics
Analyze	Critically think and reason within the cognitive and affective domains; justify analysis in depth and with clarity	Compare and contrast data, infer trends and themes in a narrowly-defined context; compute; predict; interpret and relate to real-world problems, decisions, and choices
Apply	Operate, implement, conduct, execute, experiment, and test in the real world; apply human creativity and imagination to idea and solution development	Make use of a process, model, or method to solve a quantitative or qualitative inquiry; assist students in determining where they went wrong while solving a problem
Understand	Contextualize answers within emotional, moral, or ethical considerations; select relevant information; explain significance	Accurately describe a concept in different words; recognize a related example; translate to another language
Remember	Recall information in situations where technology is not readily accessible	Retrieve factual information; list possible answers; define a term; construct a basic chronology or timeline

Bloom‘s taxonomy revisited: https://ecampus.oregonstate.edu/faculty/artificial-intelligence-tools/blooms-taxonomy-revisited



Transformers for theory calculations

Transformers can learn mathematics

- A new field for research
- With applications in physics

Learning Greatest Common Divider

Predicting gluon scattering amplitudes (Cai, Merz, Nolte, Wilhelm, Cranmer, Dixon, Charton, 2023)

The three gluon form factor

L	number of terms
1	6
2	12
3	636
4	11,208
5	263,880
6	4,916,466
7	92,954,568
8	1,671,656,292

TABLE II. Number of terms in the symbol of $F_3^{(L)}$ as a function of the loop order L.

François CHARTON, Meta AI, EuCAIF conference Amsterdam 2024

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Recommendation for the use of AI tools when studying physics

RWTH Aachen physics department 14-Apr-2025

A) The physics department welcomes the use of AI tools when studying physics.

B) Students need to develop **AI literacy**

1. Students understand the functionality of AI-based tools conceptually, can use them sensibly and possibly develop them themselves. They can explain and assess the possibilities and limitations of the support provided by such tools.
2. Students can use AI-based tools in the sense of assistance systems for their academic activities, so that these tools can support them in sharpening ideas and argumentation, in calculations and in the formulation of texts and their stylistic revision if desired. This includes the ability to reflect on the output of AI tools, edit it and integrate it into their own work.
3. Students can explain the legal framework conditions for the use of AI-based tools (e.g. disclosure requirements) and apply them in their own academic work.

C) **Disclosure** in scientific work

The declaration of authorship in examinations and the rules of good scientific practice for scientists result in an obligation to declare the use of aids. As authors of scientific work, there must be a human-creative activity in which the influence of AI is of a subordinate nature.

It must be recognizable to third parties which parts of a scientific work were generated by an AI and to what extent:

1. If a detailed prompt or a concatenation of strongly controlling prompts was used (so that these specify all essential design decisions and the AI tool only appears as an executive instrument, which also includes the English translation of own German texts) or the users further processed the generated output in the sense of a thought-opening stimulus, a corresponding notice at the beginning or at the end is sufficient.
2. If, in contrast to 1. above, a simple or prefabricated prompt was used and the AI results were adopted unchanged, a “classic” citation is recommended.

Documentation of the prompt history is not required.

D) **Assessment** of AI-generated contributions

Students are responsible for the content of their academic work, including the AI-generated text parts, unless these are based on citations from recognized sources such as primary literature and textbooks. Even when AI tools are utilized, it remains essential to properly cite all relevant literature. Parts of academic work created with AI support can only be included in the assessment if either the contribution of the author (e.g. a task given to the AI) or the contribution of the AI (e.g. restriction to linguistic formulation aids) is clearly recognizable to the examiner. The use of AI tools within the meaning of C.2. is not assessed as part of the grading process.

www.zfw.rub.de/kiedu-nrw

https://hss-opus.ub.ruhr-uni-bochum.de/opus4/frontdoor/index/index/docId/9734

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