Nordic Energy Informatics Academy Conference 2025

Towards a Taxonomy for Application of Machine Learning and Artificial Intelligence in Building and District Energy Management Systems

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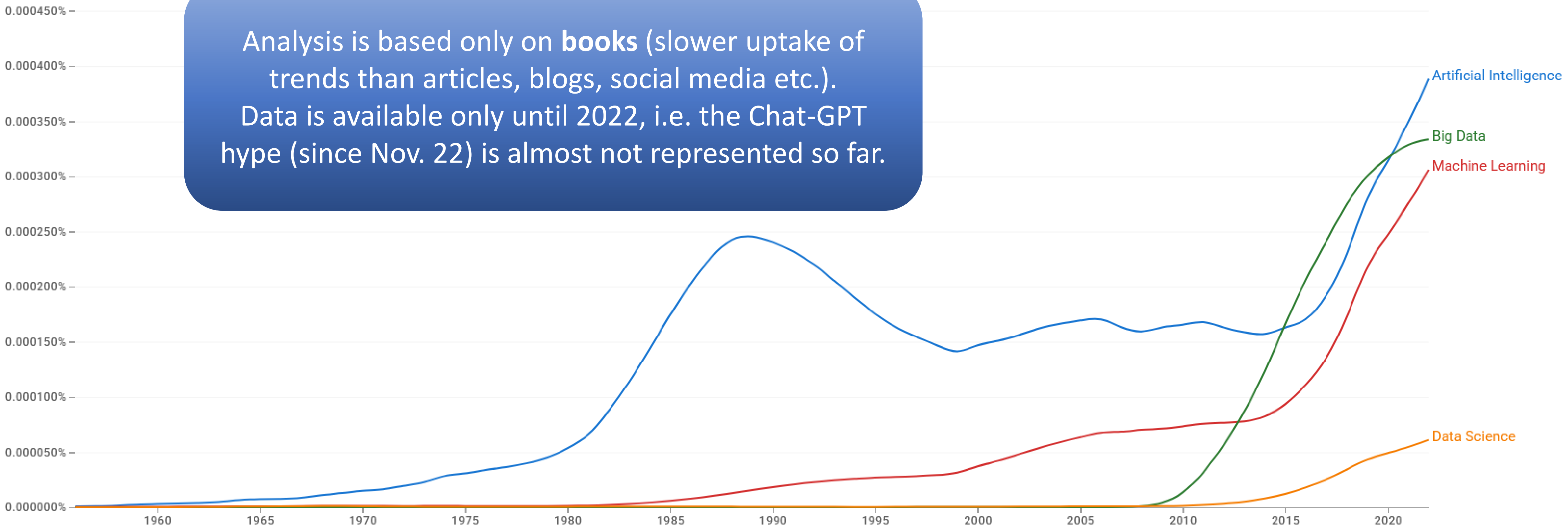
The Rise of Machine Learning and Artificial Intelligence

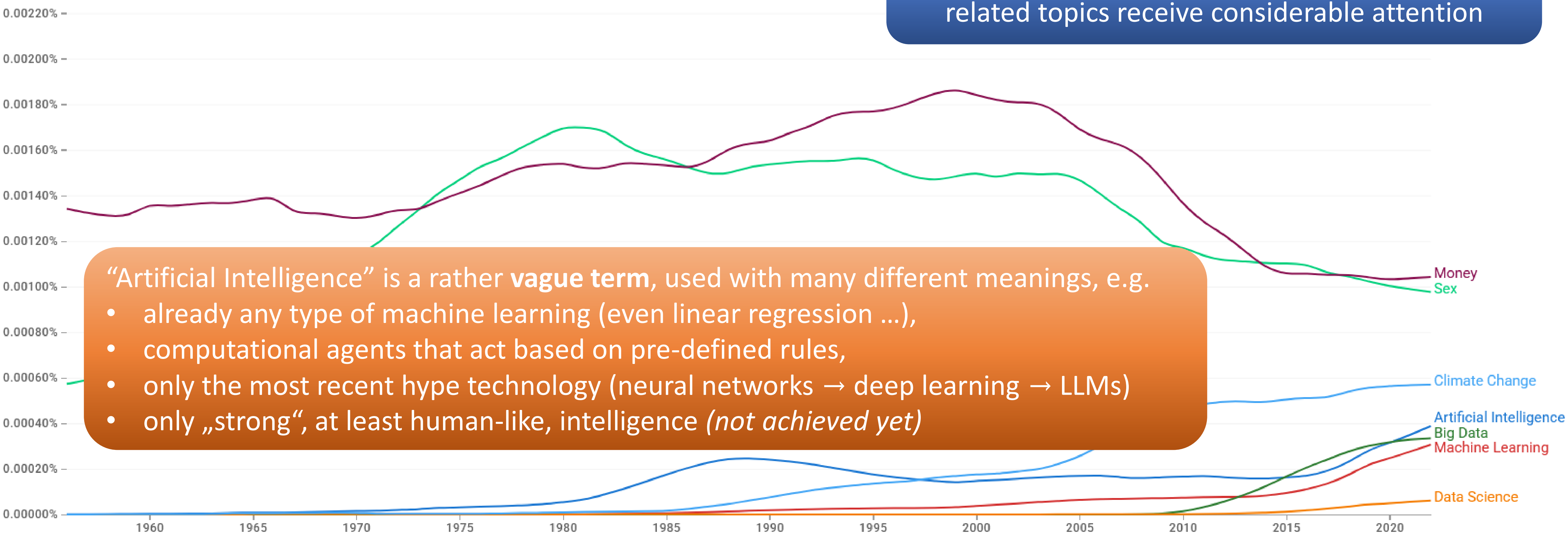
Analysis is based only on **books** (slower uptake of trends than articles, blogs, social media etc.).
Data is available only until 2022, i.e. the Chat-GPT hype (since Nov. 22) is almost not represented so far.



From https://books.google.com/ngrams/

To put it into perspective …

There are still more prominent topics, but Artificial Intelligence (AI), Machine Learning (ML) and related topics receive considerable attention



"Artificial Intelligence" is a rather **vague term**, used with many different meanings, e.g.

- already any type of machine learning (even linear regression …),
- computational agents that act based on pre-defined rules,
- only the most recent hype technology (neural networks → deep learning → LLMs)
- only „strong“, at least human-like, intelligence *(not achieved yet)*

From https://books.google.com/ngrams/

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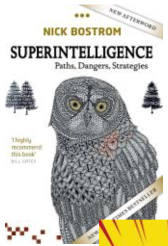
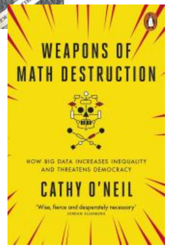
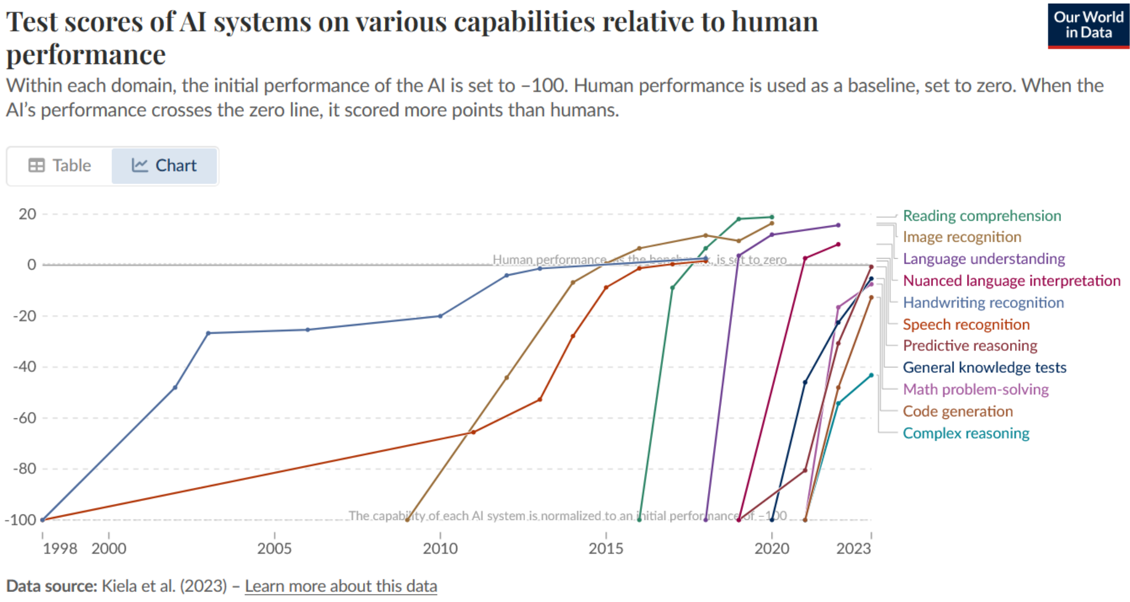
Benefits and Risks/Dangers

- Many useful applications for ML and AI for pattern recognition (in business analytics, for medical purposes), automatization of routine task, by now also in algorithm development and scientific research …
- … but there are considerable risks and dangers as well, e.g.:
  - Superintelligence (beyond human level + self-improving): might still be far away, but can we be sure of that?
  - Biased big data analysis, social media bubbles (possibly stoking conflicts)
  - Elimination of certain job profiles, in particular trainee & junior-level positions
  - Misuse of technologies due to lack of orientation and understanding

not the greatest danger, but the topic of this talk







https://ourworldindata.org/grapher/test-scores-ai-capabilities-relative-human-performance

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Troubles with the AI Hype in Science

- Like fashion (albeit a bit slower), science follows trends. When writing research grants, one should be aware of them and include the right "buzz words" in proposals.
- Since Artificial Intelligence is (once again) fashionable, there are attempts to increase the chance of funding by (almost arbitrarily) claiming to solve problems with some "AI magic".
- Often, such investigations have rather little value, due to:
  - lack of systematic planning of AI integration,
  - lack of proper comparison of approaches (AI methods between each other, comparison with conventional or direct optimization-based methods),
  - lack of complete evaluation (including data requirements, computational effort and scaling properties)

What Can We Do About It?

- Increase of method competence:
  - Know about the structure of data science processes / pipelines
  - Learn which types of ML models exist (types of learning), which applications they have and which limitations they face
  - Understand pitfalls, possible biases from unbalanced data etc.

Reasonable content for a complete master study programme, e.g. https://www.fh-joanneum.at/en/studies/masters-degree-programme-in-data-science-and-artificial-intelligence/ or https://www.tugraz.at/en/studying-and-teaching/degree-and-certificate-programmes/masters-degree-programmes/data-science; effort ~ 2 years / 120 ECTS credits

- Structured approach to use of ML/AI:
  - Provide **Checklist** for raising awareness for essential issues – motivation for answering some important questions **before** just writing some code,
  - List important **Evaluation Criteria**
- Specific use case for energy informatics:
  Control of building / district energy systems

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Checklist for ML/AI Use

- Choice of **methodic approach(es)**
- Detailed **characteristics** of the method (type of learning, key characteristics)
- **Foundation** of training – usually has some connections to the concept of a Data Management Plan (DMP)*
- **Objective**: What do we want to achieve (beyond improved chances for funding)
- Affected **system element(s)** – domain-specific, adjusted to our **use case**

ML/AI Approach Chosen

- ○ Linear / Logistic Regression
- ○ Linear Discriminant Analysis
- ○ k-Nearest Neighbour
- ○ Naive Bayes Classification
- ○ Decision Tree Learning
- ○ Random Forest / Boosted Tree
- ○ Isolation Forest
- ○ Support Vector Machine
- ○ Bayesian Networks (PGMs)
- ▷ Clustering: ○ k-Means, ○ hierarchical, ○ density-based, ○ spectral, ○ soft, ○ fuzzy, ○ ____________
- ▷ Dimensional Reduction: ○ PCA, ○ (t-)SNE, ○ UMAP, ○ Autoencoder, ○ prob. PCA, ○ ____________
- ▷ Neural Network: ○ MLP, ○ CNN, ○ RBM, ○ RNN, ○ (x)LSTM, ○ Transformer, ○ ____________
- ○ Bayesian probab. modelling
- ○ Deep-Q learning / PPO
- ○ ____________

Type of Learning

○ unsupervised ○ reinforcement ○ self-supervised ○ imitation ○ classification ○ regression *supervised* ○ flexible imputation

☐ discriminative
☐ generative

Model Key Characteristics

(Architecture, Hyperparameters, ...)

Complexity
Transparency
Effort { Training, Evaluation

0 10

Foundation of Training

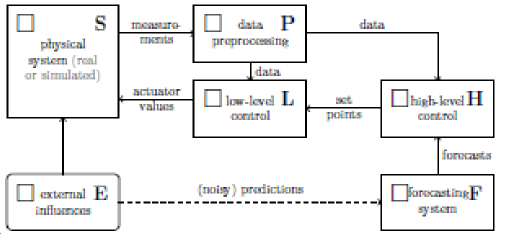
- ☐ historic data – *Source:* ____________ ☐ open data
  format: ____________, *amount:* ____________ ☐ augmentation
- ☐ simulation data – *Model:* ____________
  format: ____________, *amount:* ____________ ☐ augmentation
- ☐ simulation environment: ____________ ☐ co-simulation
- ☐ ____________

Objective of ML/AI Application

- ☐ improvement of existing element
- ☐ replacement / surrogate
- ☐ analysis / explainability
- ☐ ____________

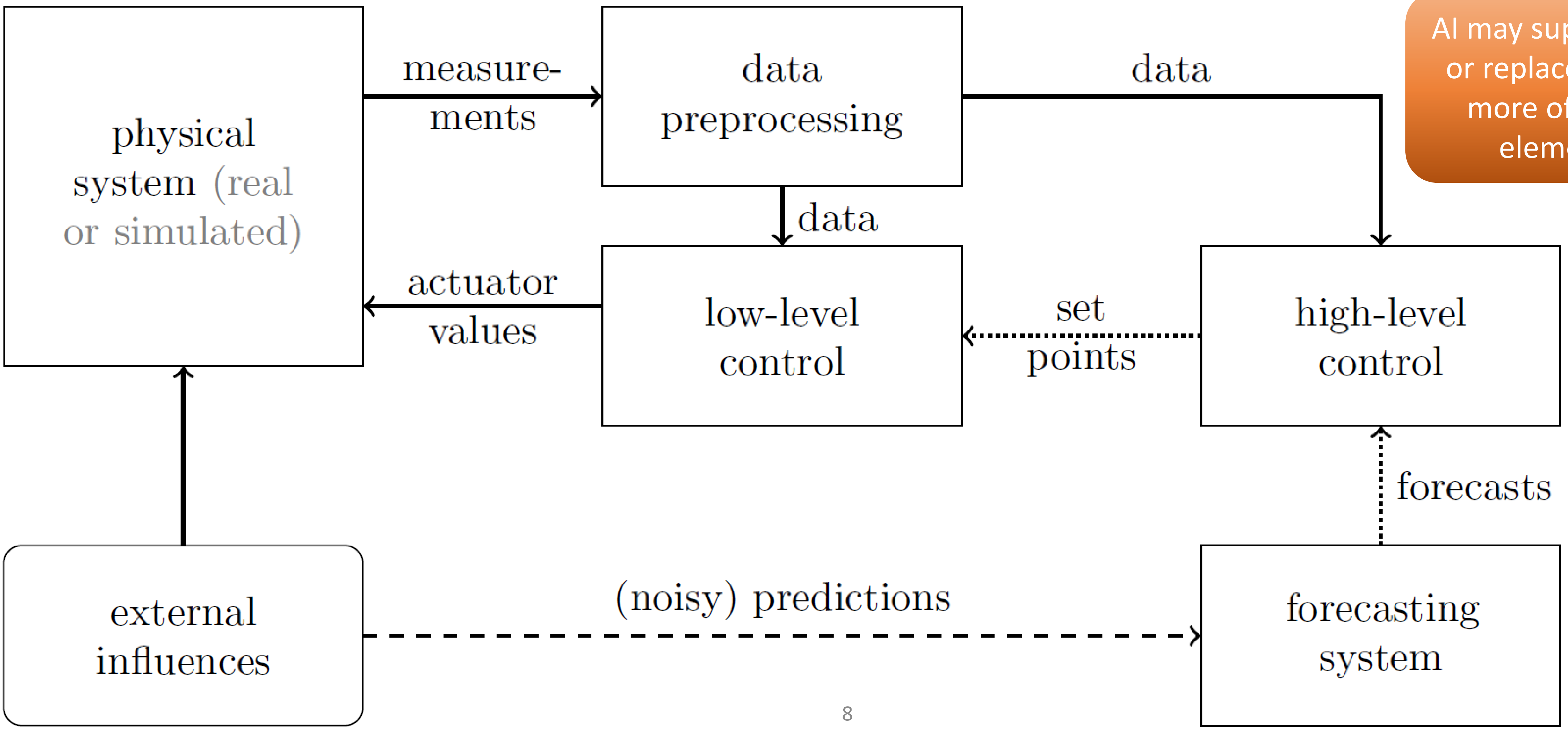
specific objective:

System Element(s) Affected



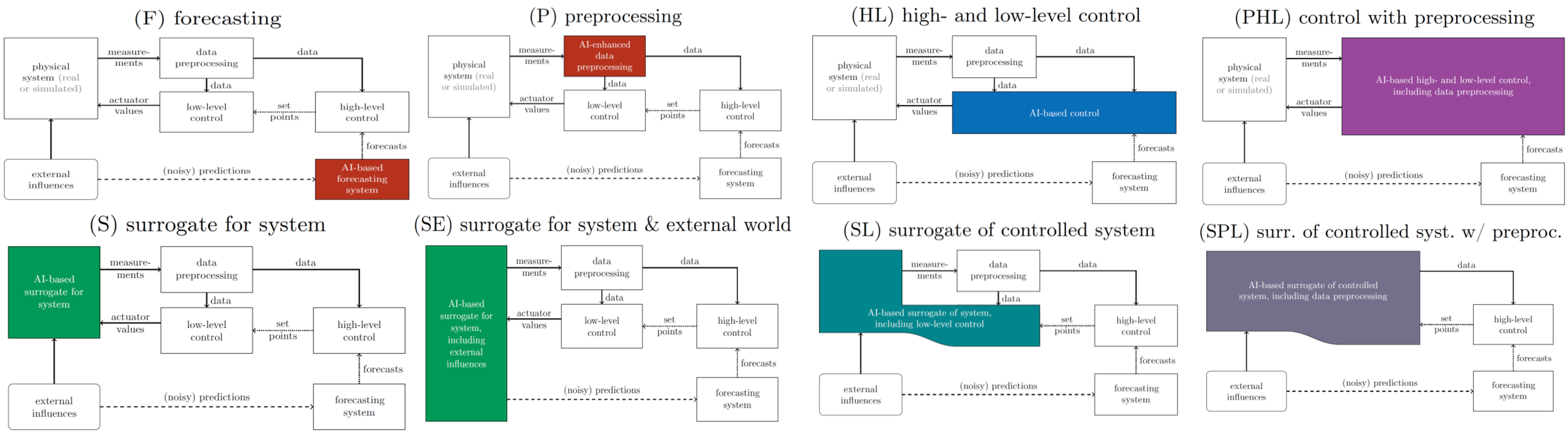
* see e.g. https://www.tugraz.at/sites/rdm/dmps/data-management-plans

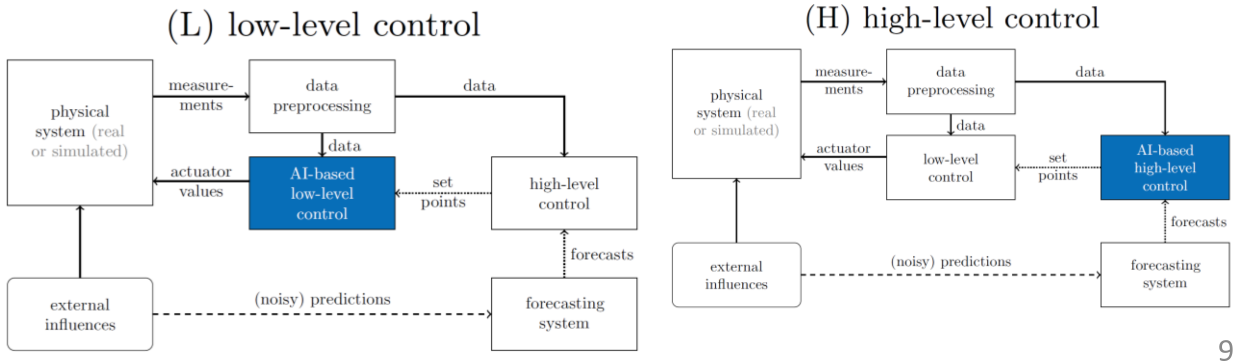
Use Case: Control Structure for Energy Systems (& beyond)



AI may supplement or replace one or more of these elements

Control Structure (Energy Systems & beyond)



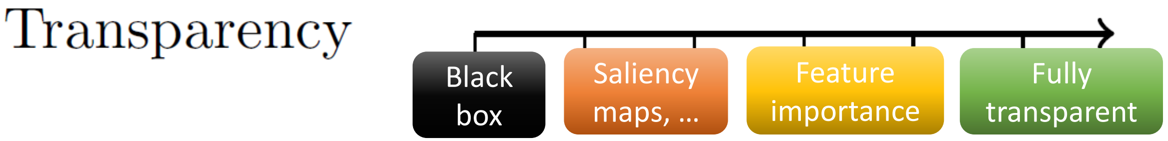


- Forecasting / preprocessing (classical applications for AI and ML)
- Surrogates (AI models) of the system
- Low-level or high-level control (e.g. with Reinforcement Learning)
- Combined system elements

Important Evaluation Criteria

- **Data Requirements**:
  - The amount of data available often limits the types of model that should be used.
  - Evaluate performance of models as function of amount and diversity of training data.
- **Computational Effort** and **Hardware Requirements**:
  - While simple models can already run on a Programmable Logic Controller (PLC), other models require large computational resources, e.g. Graphical Processing Units (GPUs).
  - Is real-time operation required / possible?
  - One has to distinguish between the effort for **training** and for **inference** (calling the model)
- **Explainability**:
  - Simple models typically do not achieve quite the performance of more complex ones, but they are more transparent & trustworthy, cf. EU Artificial Intelligence Act

from https://arxiv.org/pdf/2306.13701



https://artificialintelligenceact.eu/

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Example: Use of Checklist (1)

- Use case from research project DISTEL:
  - **System:** simplified building (thermal zone) with external heater (solar) and ambient temperature
  - **Objective**: create a surrogate model for the controlled system that predicts temperature of the zone as time series, using the ambient temperature and solar radiation as inputs

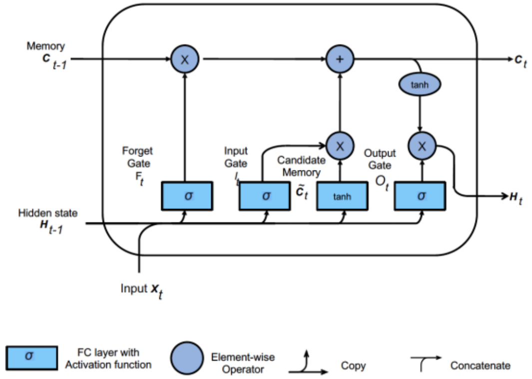
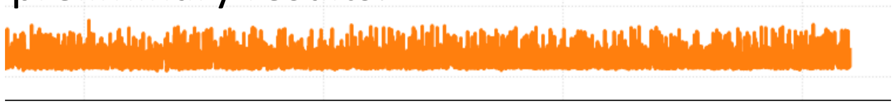


Figure 15.11 of Murphy (2022): *Probabilistic Machine Learning – An Introduction,* https://probml.github.io/pml-book/

preliminary results:



ML/AI Approach Chosen

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- ▷ Neural Network: ○ MLP, ○ CNN, ○ RBM, ○ RNN, X (x)LSTM, ○ Transformer, ○ ______
- ○ Bayesian probab. modelling
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- ○ ______

Type of Learning

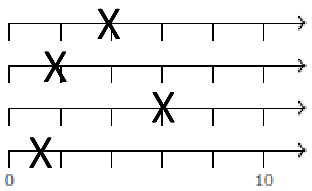
- ○ unsupervised
- ○ reinforcement
- ○ self-supervised
- ○ imitation
- ○ classification
- X regression
- *supervised*
- ○ flexible imputation
- ☐ discriminative
- ☐ generative

Model Key Characteristics

(Architecture, Hyperparameters, ...)

RNN (LSTM)
Modell Params: Learning Rate: 0.001
Lag Steps: 3
Validation Split: 0.1
Layers: 2
Patience: 5
Dropout: 0.2
Epochs: 30
Batch Size: 128
Prediction:
1 Hour Seed
1 Hour Prediction

Complexity
Transparency
Effort {Training, Evaluation}



Foundation of Training

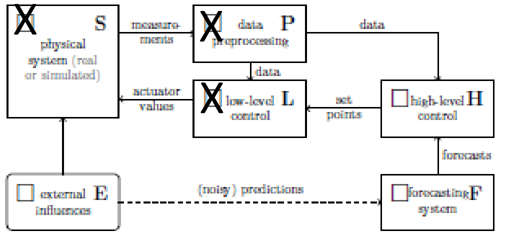
- ☐ historic data – *Source:* ______ ☐ open data
  format: ______, *amount:* ______ ☐ augmentation
- X simulation data – *Model:* internal Python library for energy systems
  format: Apache Parquet, *amount:* 50MiB – 3GiB (days – months) ☐ augmentation
- ☐ simulation environment: ______ ☐ co-simulation
- ☐ ______

Objective of ML/AI Application

- ☐ improvement of existing element
- X replacement / surrogate
- ☐ analysis / explainability
- ☐ ______

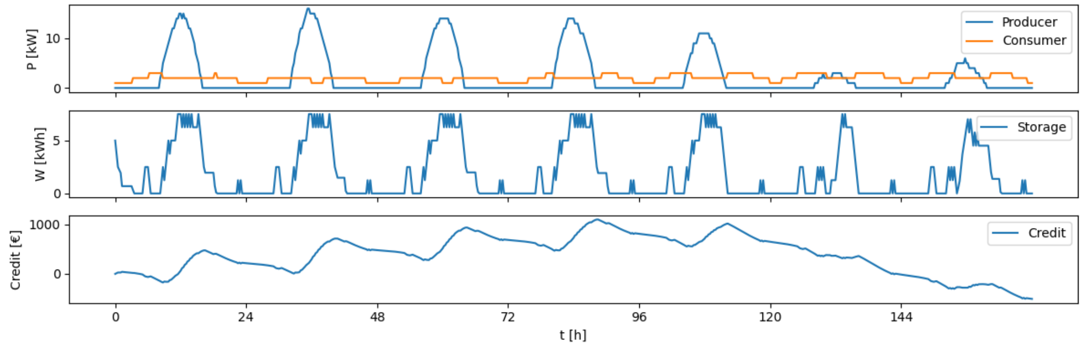
specific objective: surrogate for the controlled systems

System Element(s) Affected



Example: Use of Checklist (2)

- Use case from research project DISTEL:
  - **System:** simplified building (thermal zone) with PV, battery storage, electric heater and grid connection, subject to time-dependent electricity tariffs
  - **Objective**: operate the battery in a way that minimizes electricity costs, while keeping the room temperature within a pre-defined temperature band



ML/AI Approach Chosen

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- ○ Bayesian probab. modelling
- X (Deep-)Q learning / PPO
- ○ ______

Type of Learning

- ○ unsupervised
- X reinforcement
- ○ self-supervised
- ○ imitation
- ○ classification
- ○ regression
- *supervised*
- ○ flexible imputation
- ☐ discriminative
- ☐ generative

Model Key Characteristics

(Architecture, Hyperparameters, . . .)

Preliminary Configuration:
Env: PV module (+forecasts), Consumer, Storage, Tariffs
Q-learning: discretized state-action space
Reward signal: credit/cost
Hyperparameters: 100 episodes, α=0.1, γ=0.99
Exploration: ε=1 and decay=0.99, clipped at 0.05
Training on ½ year time frame simulated data

	0 … 10
Complexity	X (near 8)
Transparency	X (near 0)
Effort: Training	X (near 8)
Effort: Evaluation	X (near 1)

Foundation of Training

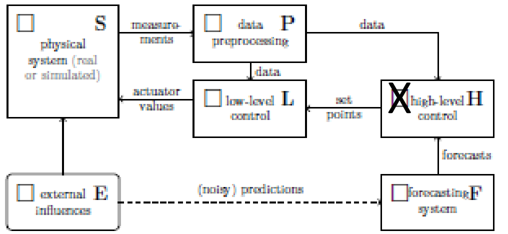
- ☐ historic data – *Source:* ______ *format:* ______, *amount:* ______ ☐ open data ☐ augmentation
- ☐ simulation data – *Model:* ______ *format:* ______, *amount:* ______ ☐ augmentation
- X simulation environment: internal Python library for energy systems ☐ co-simulation
- ☐ ______

Objective of ML/AI Application

- ☐ improvement of existing element
- X replacement / surrogate
- ☐ analysis / explainability
- ☐ ______

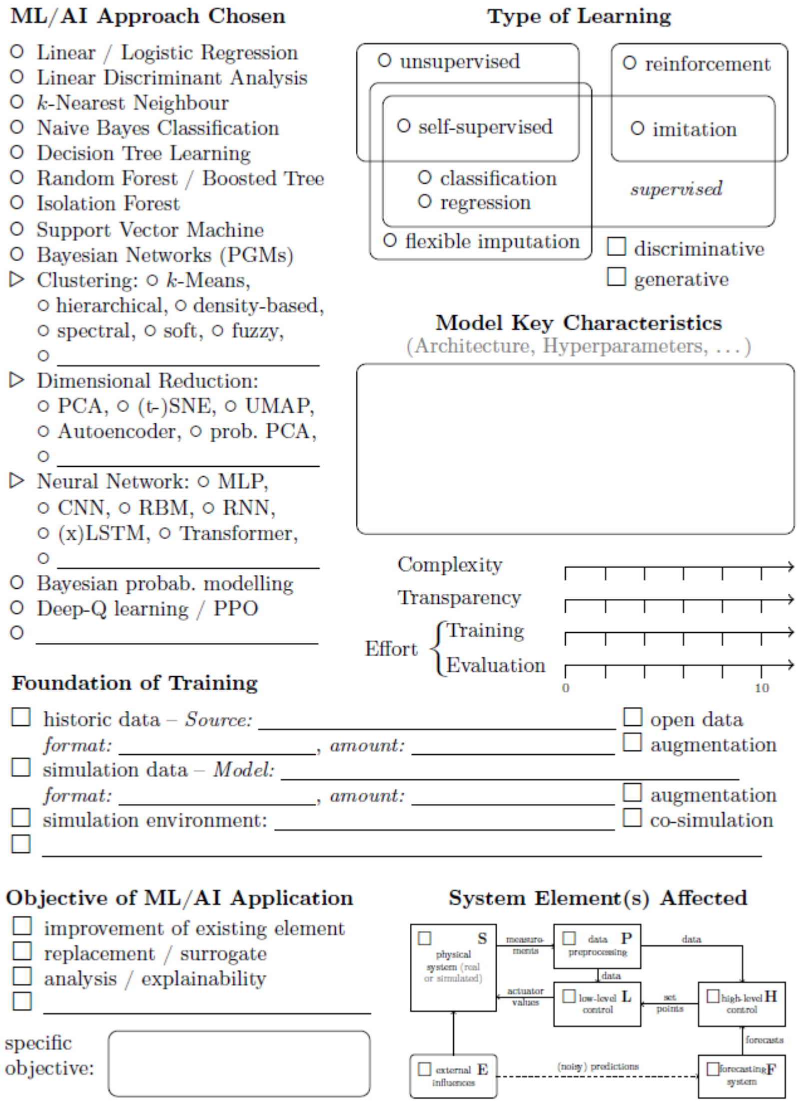
specific objective: RL-Agent for supervisory control

System Element(s) Affected



Summary, Conclusions and Outlook

- Machine Learning and Artificial Intelligence are powerful tools but also pose certain risks.
  - Often, AI methods are applied in an unstructured, unsystematic way
- Suggested methods and tools:
  - **Checklist**: To fill it, one must at least properly think about the objective, the characteristics of the method and the system element(s) affected
  - **Systematic evaluation** concerning essential characteristics: data requirements, computational effort, explainability / transparency
- Planned next steps:
  - Further application in current research projects and iterative refinement of the process / checklist



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ZUKUNFTSFONDS STEIERMARK

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