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AI in Battery Storage

EES Europe, The Smarter E

Prof. Dr. Holger Hesse

University Applied Sciences Kempten

June 14, 2023



Machine-Learning and battery storage?

Battery value chain analysis

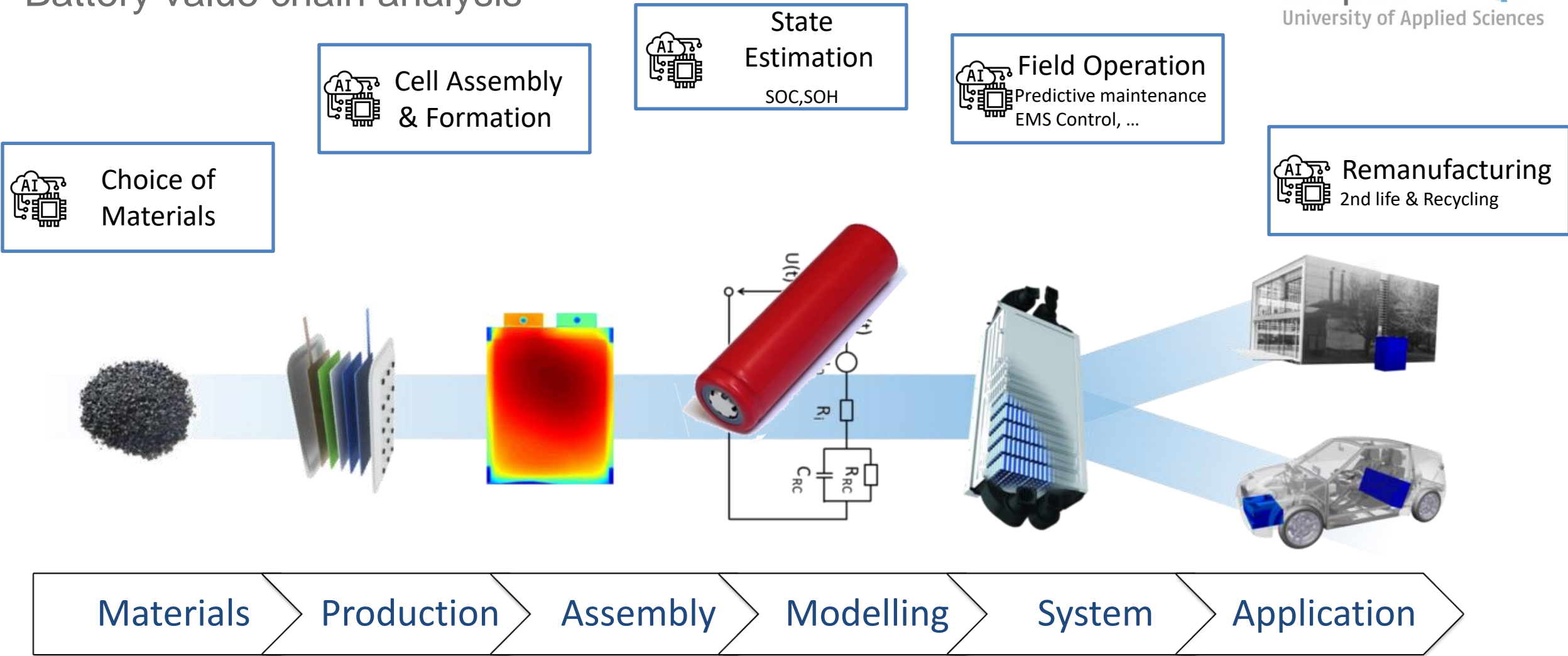


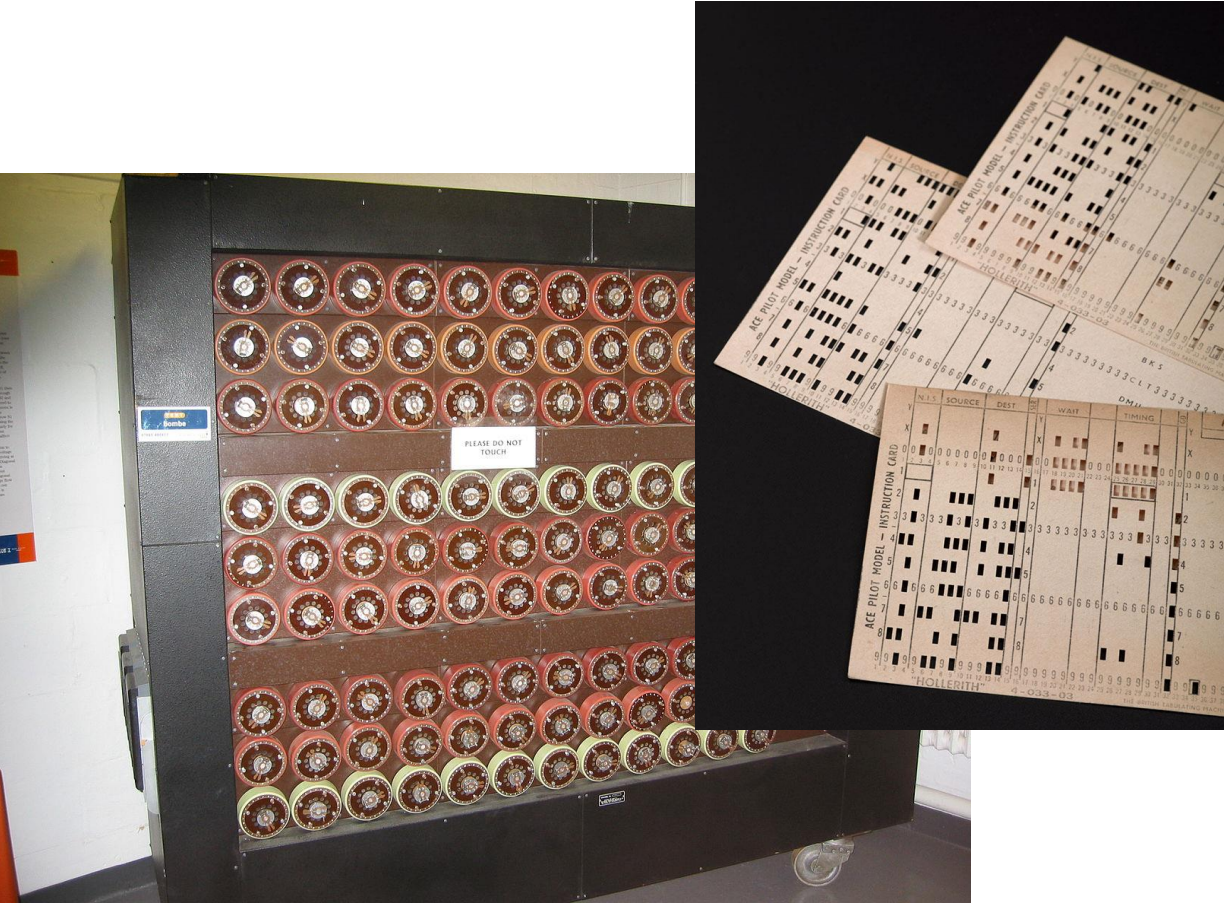
Image credits: TUM – Chair for Electric Energy Storage technology

What is AI / Machine-Learning?

A historic view



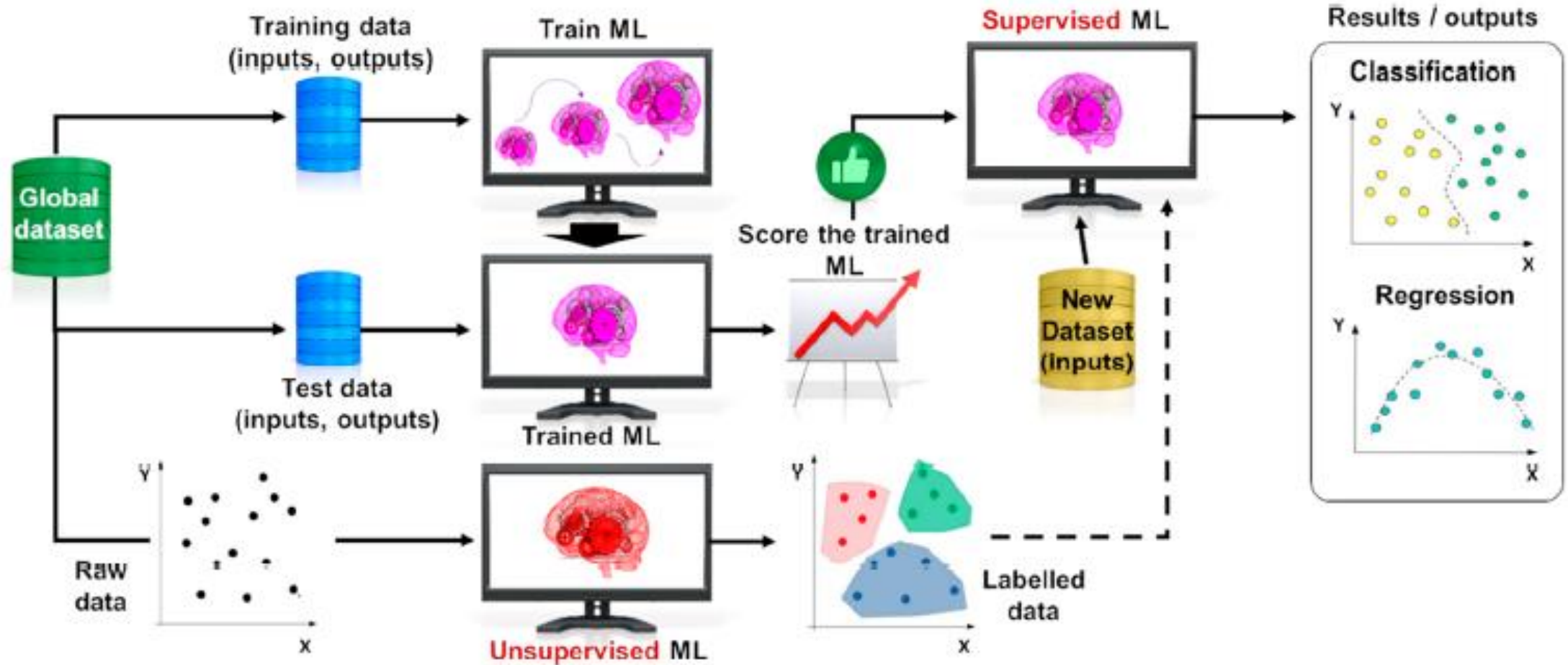
Alan Turing (1938)



Punch Card Computer © Magnus Manske CC BY-SA 3.0

How can Machine-Learning be classified?

A dip Into data driven optimization approaches



Lombardo, Teo, et al. "Artificial intelligence applied to battery research: hype or reality?." *Chemical Reviews* 122.12 (2021): 10899-10969.

AI in battery safety?

Production outlier detection & defect analysis



Cell Assembly
& Formation

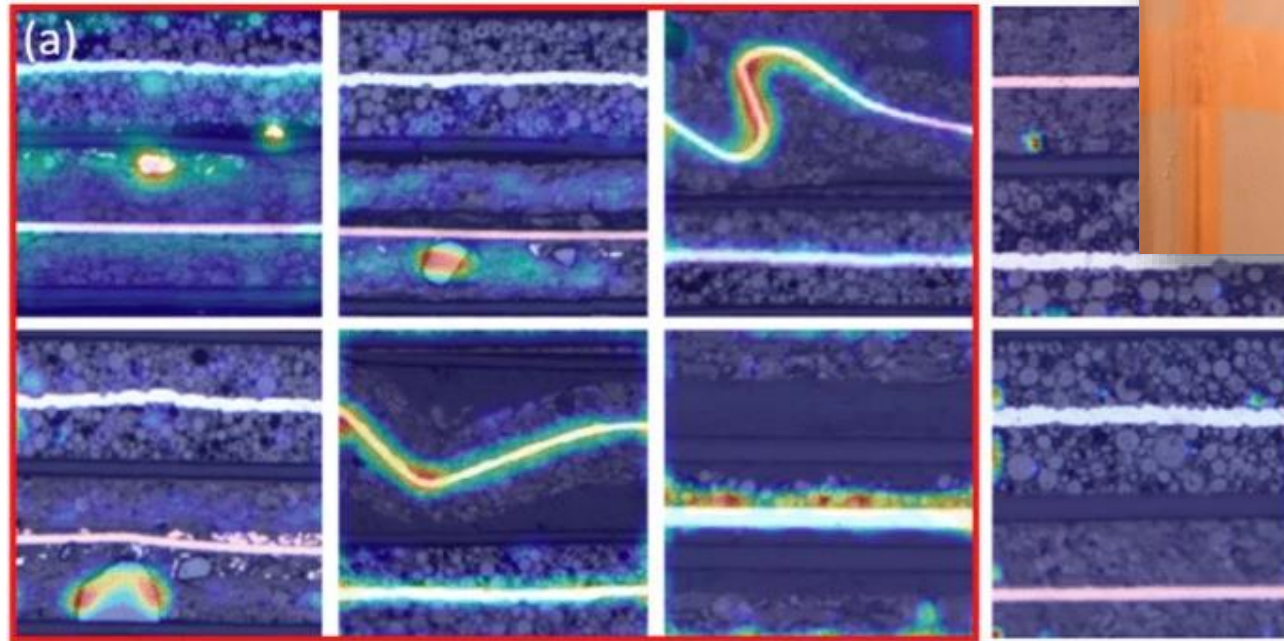


Image Source: TUM-create Asia

Video Source: TTUM – iwb institute

Badmos, O., Kopp, A., Bernthaler, T. et al. Image-based defect detection in lithium-ion battery electrode using convolutional neural networks. J Intell Manuf 31, 885–897 (2020)

AI for state estimation?

SOH: Empirical “Test-Model-Prediction-Loop”

State Estimation

SOC, SOH

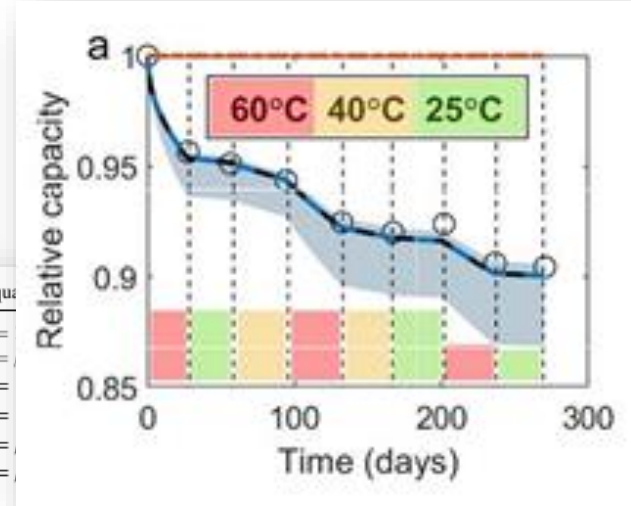
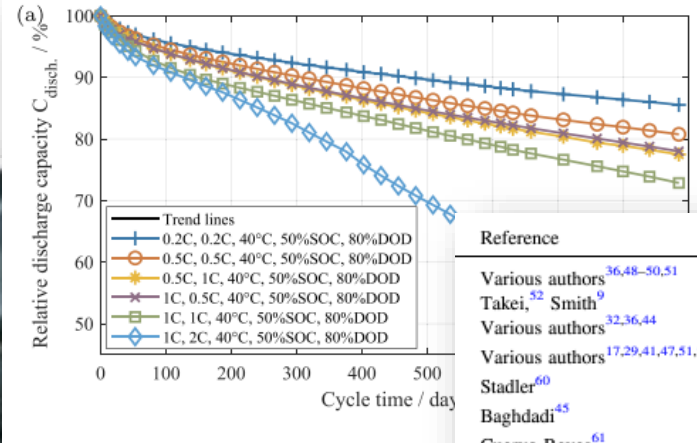


Image credits: TUM – Chair for Electric Energy Storage technology

Naumann, M., Schimpe, M., Keil, P., Hesse, H. C., & Jossen, A. (2018). Analysis and modeling of calendar aging of a commercial LiFePO4/graphite cell. *Journal of Energy Storage*, 17, 153-169.

Gasper, P., Collath, N., Hesse, H. C., Jossen, A., & Smith, K. (2022). Machine-Learning Assisted Identification of Accurate Battery Lifetime Models with Uncertainty. *J. Electrochemical Society*, 169(8), 080518.

AI for state estimation?

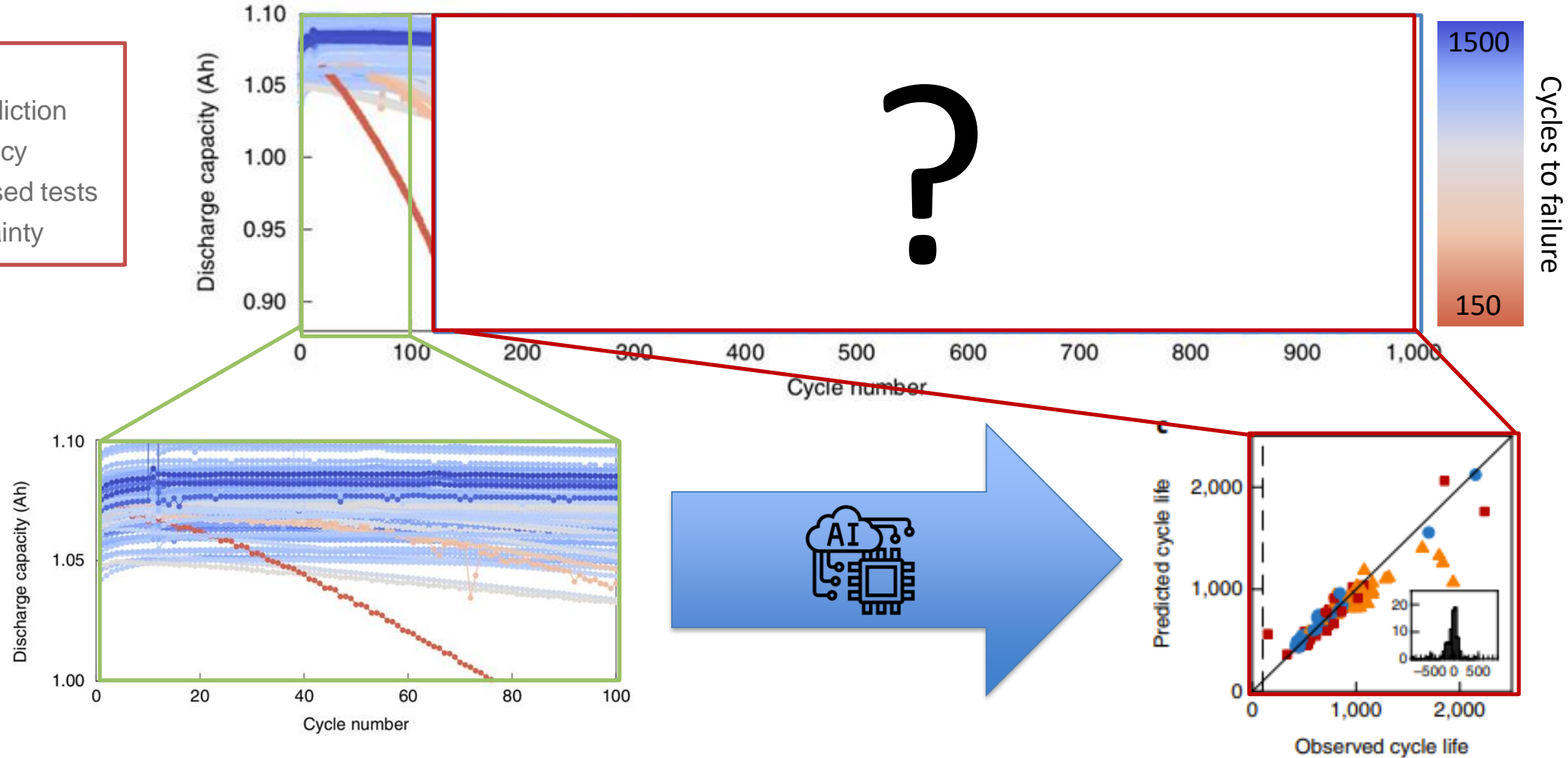
ML assisted SOH-prediction



State Estimation
SOC,SOH

Aims:

- Early SOH prediction
- Improve accuracy
- Reduce lab-based tests
- Monitor uncertainty



Severson, Kristen A., et al. "Data-driven prediction of battery cycle life before capacity degradation." *Nature Energy* 4.5 (2019): 383-391.

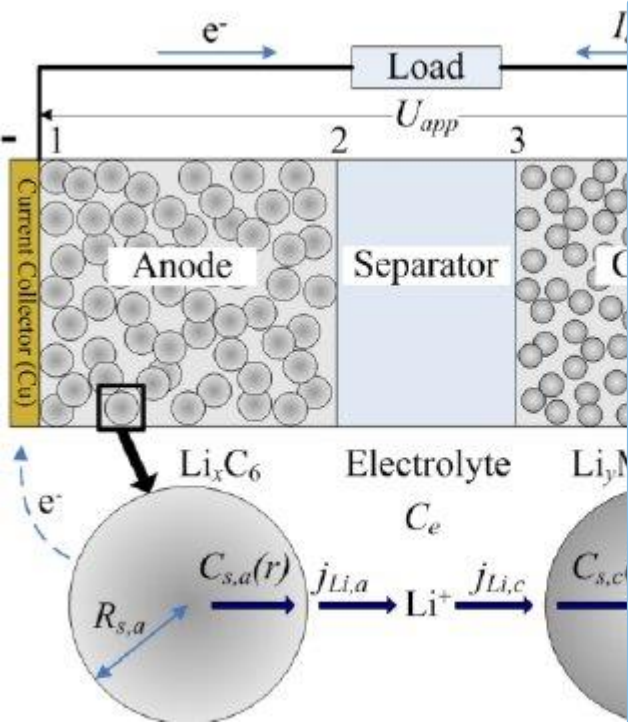
AI for state estimation?

Perspective: "Physics informed Machine-Learning"

State Estimation

SOC, SOH

Physical-chemical model (e.g. p2D):



Zhang, Liqiang, et al. J. Electrochemical Society

- + Understanding battery physics
- Parametrization elaborate
- Computational cost

Machine-Learning assisted approaches:

Physics informed Machine-Learning:

Type	Architecture
B1. Hybrid: Physics-constrained MLM	
B2. Hybrid: ML-accelerated PBM	

PBM

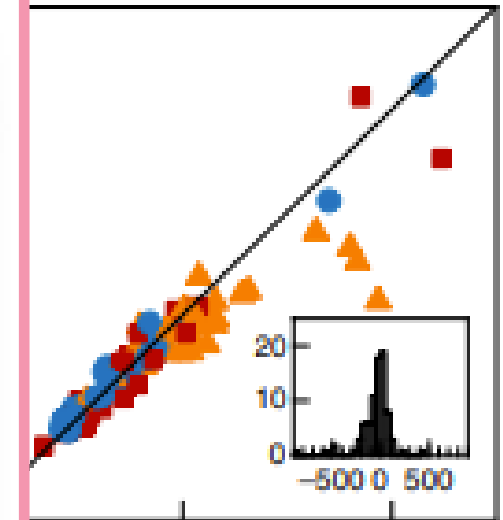
MLM

exp. data

PBM Physics-based model (Full or reduced-order)
 MLM Machine learning model (NN, Random Forest, GP, etc.)
 exp. data Experimental data

Muratahan Aykol et al. J. Electrochem. Soc. (2021) 168 030525

++ Combine benefits of both approaches



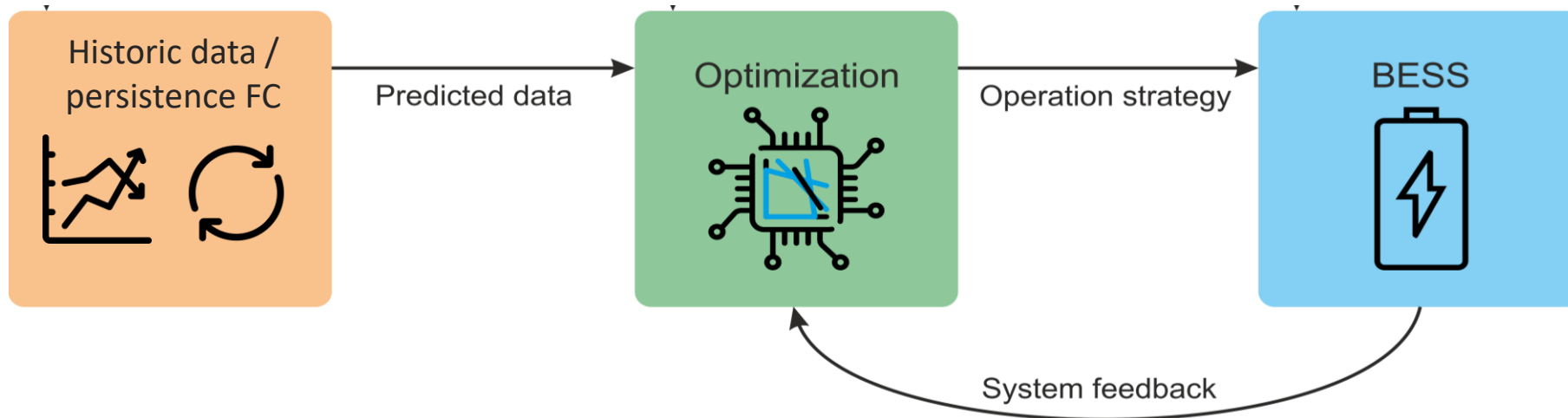
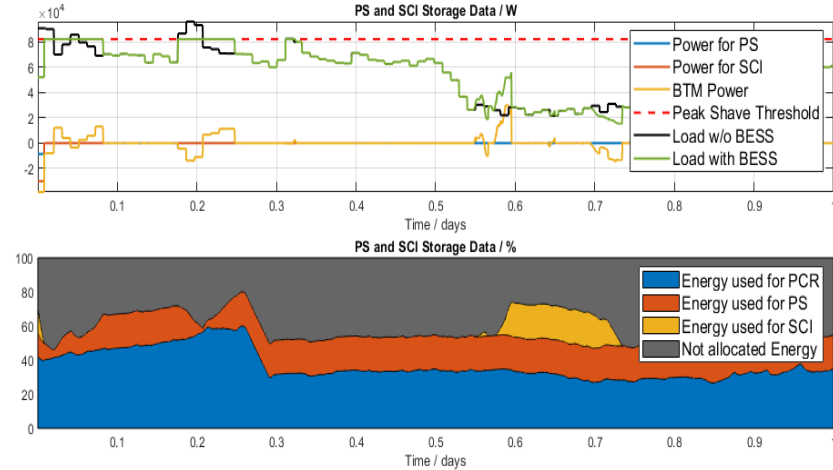
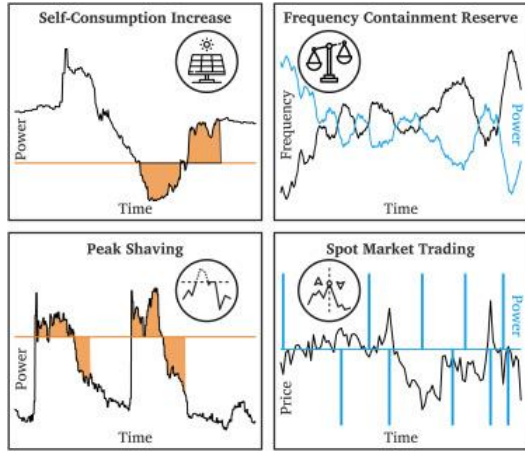
Observed cycle life

data battery agnostic
predict unseen effects

AI for energy management and control?

Multi-Use + Battery aging control challenge (1)

AI Field Operation
 Predictive maintenance
 EMS Control, ...

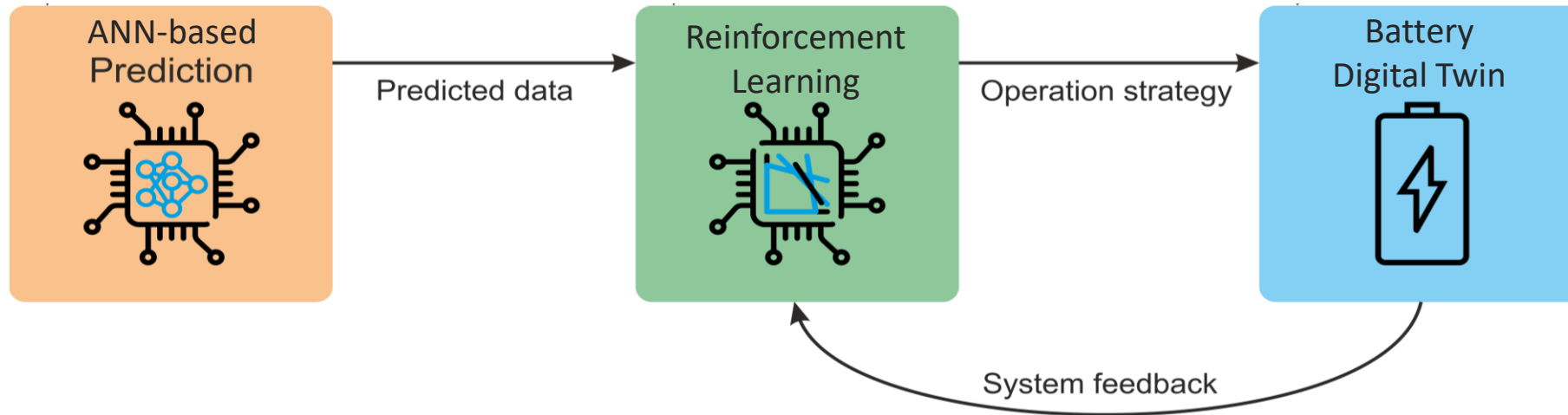
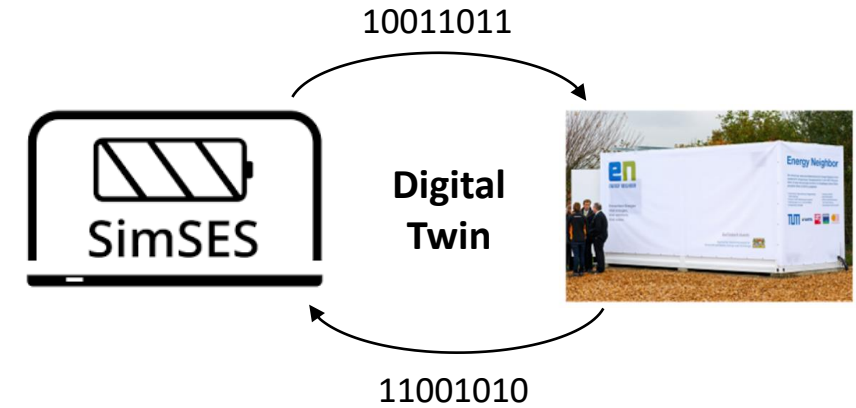
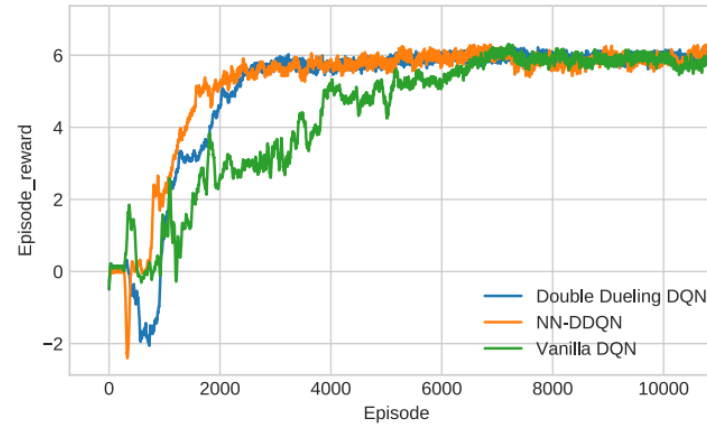
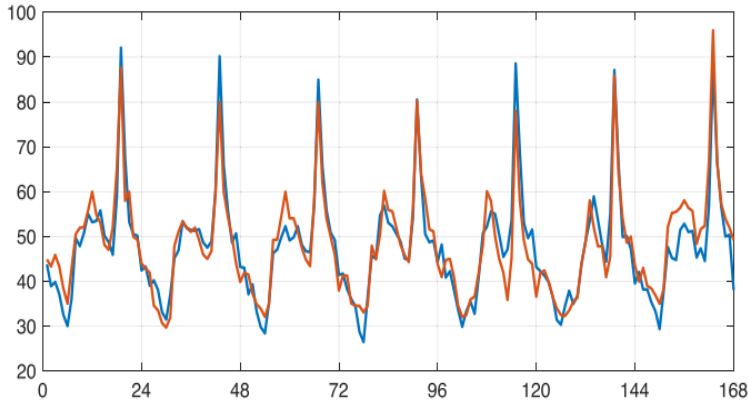


Englberger, S., Gamra, K. A., Tepe, B., Schreiber, M., Jossen, A., & Hesse, H. (2021). Electric vehicle multi-use: Optimizing multiple value streams using mobile storage systems in a vehicle-to-grid context. *Applied energy*, 304, 117862.
 Englberger, S.; Jossen, A.; Hesse, H.: *Unlocking the potential of battery storage with the dynamic stacking of multiple applications*, in: *Cell Reports Physical Science* 1 (11), 2020

AI for energy management and control?

Multi-Use + Battery aging control challenge (2)

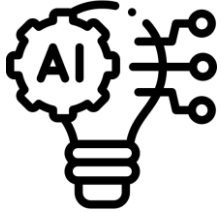
Field Operation
 Predictive maintenance
 EMS Control, ...



Deep Reinforcement Learning-Based Energy Storage Arbitrage With Accurate Lithium-Ion Battery Degradation Model, J.Cao et al. IEEE Transactions on Smart Grid

Opinion and outlook

AI in battery storage



AI in battery storage?

- AI entering development and deployment of battery storage
- Applications spanning from production over state estimation to recycling



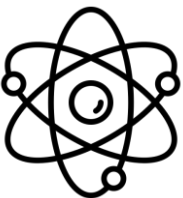
Task 1: Data quantity and quality

- Battery related data sets growing rapidly
- Ensuring data availability and quality



Task 2: Quality assurance and improvement

- Model traceability through open-source developments
- Benchmark & evaluation of crucial to assessing model quality



Prospect: Physics informed Machine-Learning

- SOH prediction → couple physical models with ML approaches
- EMS control → integration of forecasting, operation and battery digital twin

Call for Papers

Machine Learning and Data Based Optimization for Smart Energy Systems

This Special Issue aims to collect, compare, and assess novel machine learning and data science techniques that can be used to address challenges of battery storage integration to smart energy systems

Topics of interest for publication include but are not limited to:

- Presentation of machine learning- and artificial intelligence-derived control strategies for smart energy systems.
- Data-analytics-derived methods for the sizing and layout of components in smart energy systems.
- Statistical analysis of prediction errors and databased learning techniques for the stochastic optimization of electrical power dispatch with storage.
- Verification of new modelling approaches through field tests or assessments compared to traditional computational approaches (e.g., heuristics, linear and non-linear optimization).
- Assessment of the accuracy and computational speed of competing algorithms, computational frameworks, and solution techniques.



Deadline for manuscript submissions: **6 Nov 2023**

Guest Editor:

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mdpi.com/si/118873

Acknowledgements

We acknowledge funding of projects:



Grant Number: 03EI6081A-E



Grant Number: 1563-22

Supported by:




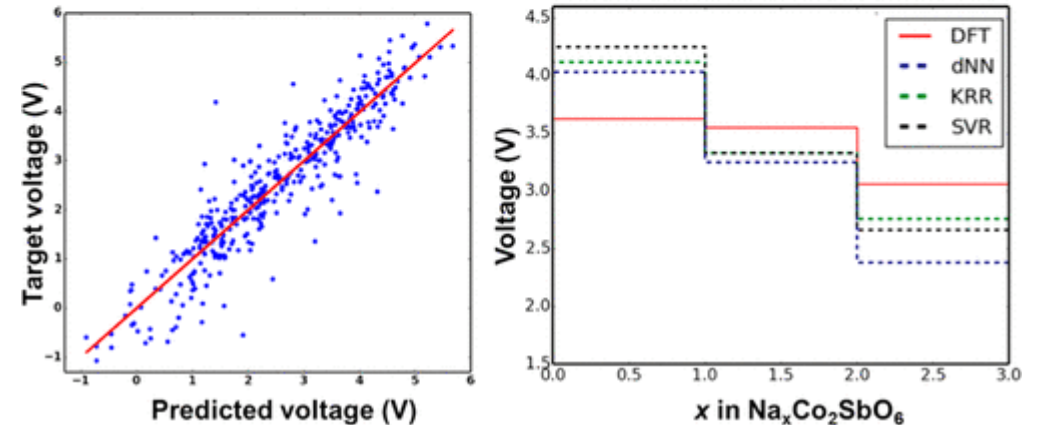
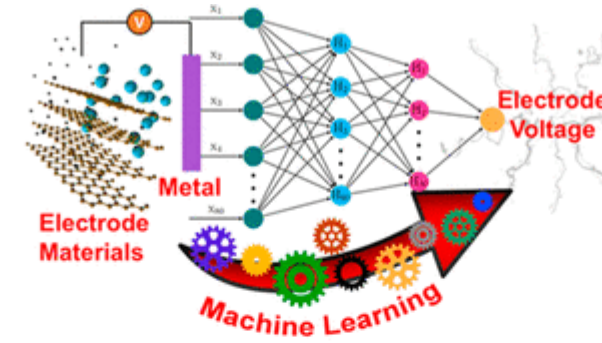
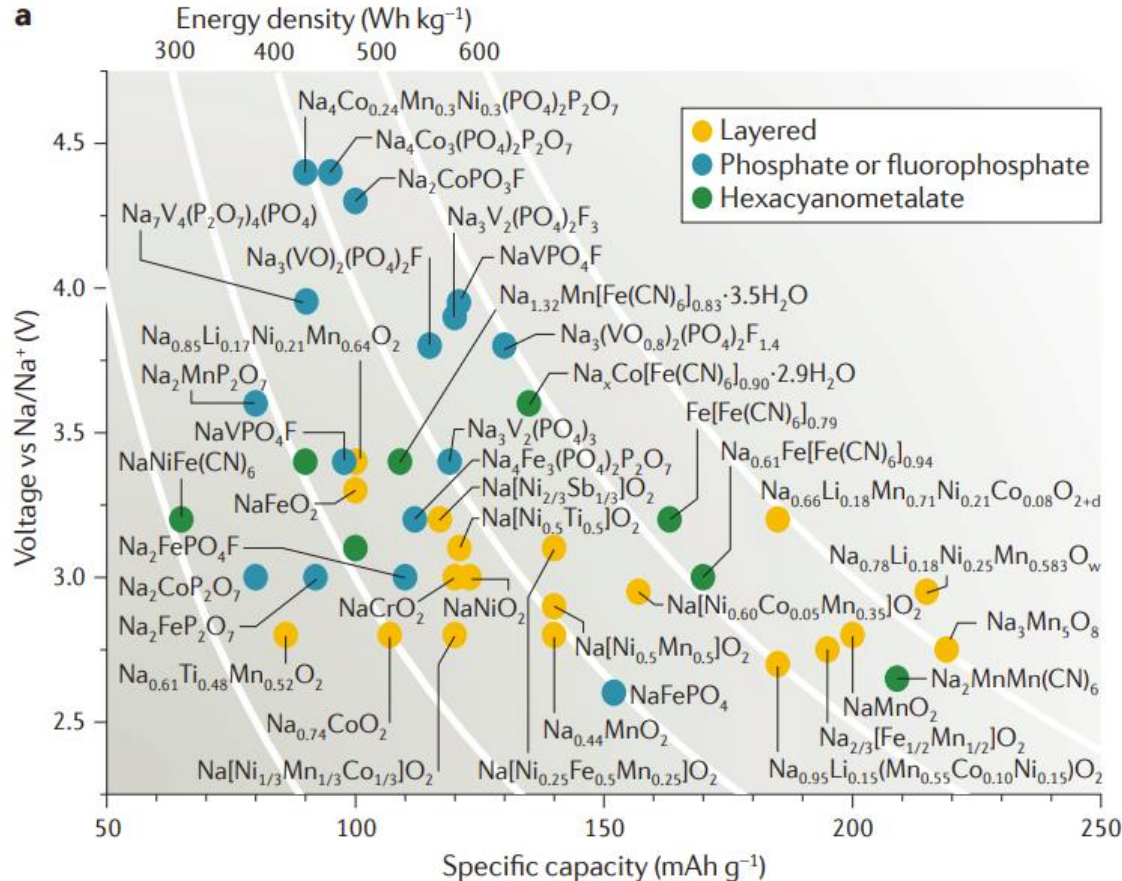
on the basis of a decision
by the German Bundestag



AI for Materials & Cell design?

Active material selection: Sodium-Ion Batteries


Choice of
Materials

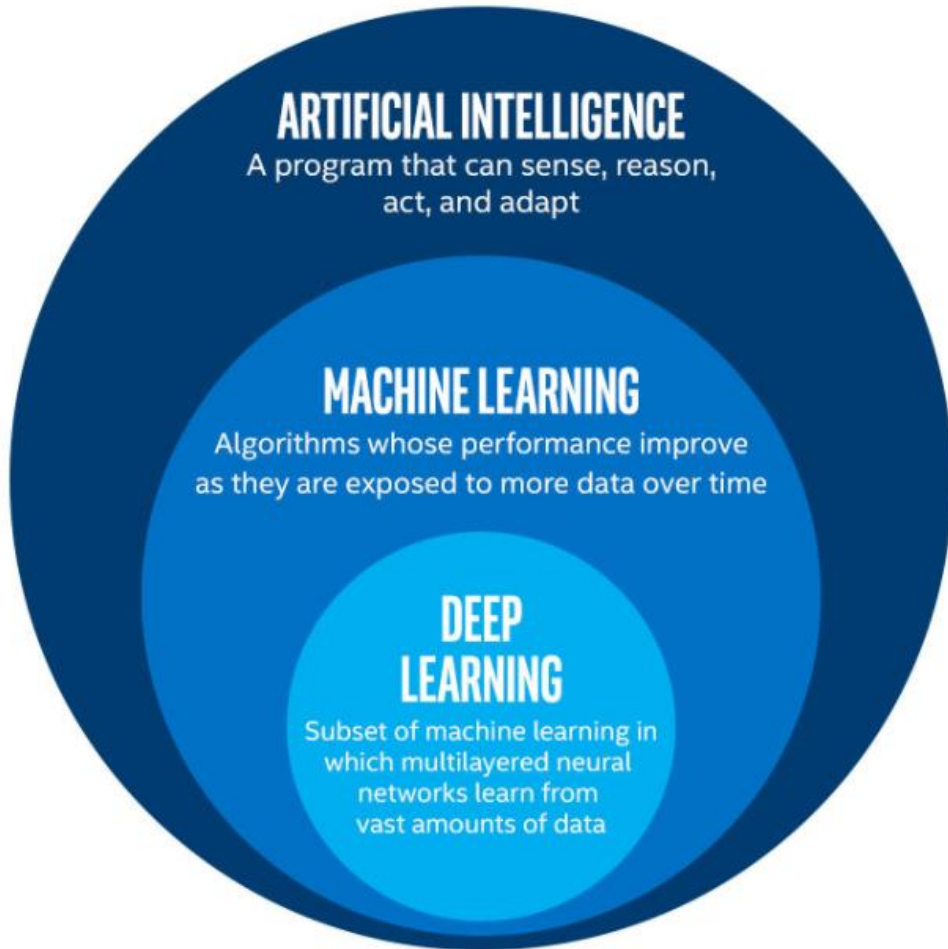


Choi, Jang Wook, and Doron Aurbach. "Promise and reality of post-lithium-ion batteries with high energy densities." *Nature Reviews Materials* 1.4 (2016): 1-16.

Joshi, R. P., Eickholt, J., Li, L., Fornari, M., Barone, V., & Peralta, J. E. (2019). Machine learning the voltage of electrode materials in metal-ion batteries. *ACS applied materials & interfaces*, 11(20), 18494-18503.

What is AI / Machine Learning?

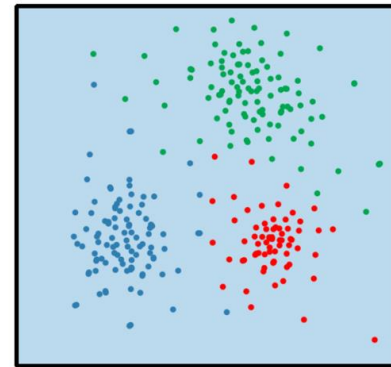
Data driven optimization approaches



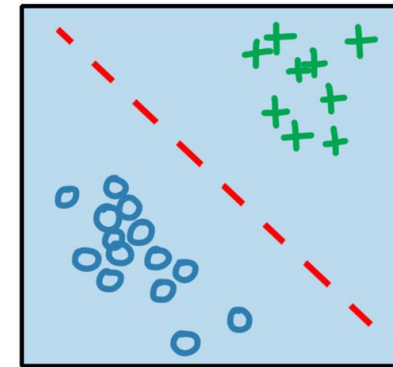
stackexchange.com

machine learning

unsupervised learning



supervised learning



reinforcement learning

