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The Norwegian centre for knowledge-driven machine learning

Nordic Perspectives 2023

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Challenges of contemporary machine learning:

- Algorithms are fragile and lack robustness
- Most methods lack transparency and explainability
- Data and loss functions/rewards might be biased and discriminating
- Uncertainty around results are not, or poorly, quantified
- Algorithms depend on huge amounts of curated data
- Algorithms require excessive energy to train and run (and store)
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Integreat will transform machine learning to address these challenges

Today

Machine learning is mostly data centric and has difficulties in incorporating excisting knowledge

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Knowledge-driven and data informed machine learning

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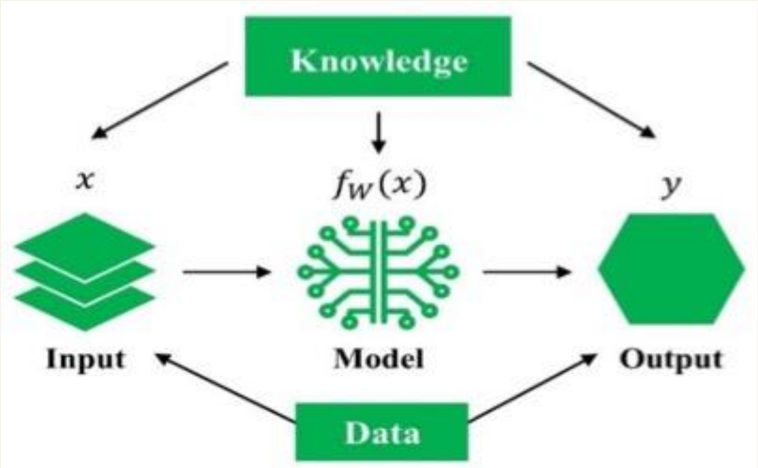
Knowledge-driven and data informed machine learning

- Accurate
- Sustainable
- Explainable and trustworthy
- With quantified uncertainty

Knowledge-driven?



Knowledge about

- structures, processes and dynamics of the system
- data generating mechanisms

Knowledge might be

- exact (in the form of must-links and cannot relationships, logical formalisations and formal ontologies, mathematical models)
- more imprecise, soft or subjective (in the form of most-likely-links, prior beliefs and stochastic relations)

Accurate

Knowledge can compensate for bad data:

- Makes it possible to solve problems that otherwise would not be solved, due to bad data, small data, or lack of (enough) labelled data

Sustainable

Knowledge-driven ML saves energy:

- Reuseing and integrating data, exploiting transfer learning and causal inference, using more parsimonious models
- Storage also consumes energy: Knowledge-driven methods to compress, project and reduce data, while controlling the loss of information

Quantifying uncertainty

Data are incomplete, noisy and inconsistent; knowledge and models are imperfect; algorithms are approximate. Therefore, estimates, predictions and decisions are uncertain:

- Represent and model multiple sources of uncertainty probabilistically
- Uncertainty quantification can reveal disagreement between data and knowledge, as well as between different data sources
- Develop methods that automatically alert of such discrepancies
- By combining knowledge and data, we reduce the uncertainty of solutions

Explainable and trustworthy

- Declaring knowledge allows its critique
- Using knowledge to de-bias datasets and models
- Understand the inner-workings of black- and grey-boxes, by augmenting them with knowledge-based explainable white-box components

Others already do
- physics-informed deep learning
- hybrid modelling

We integrate ML, statistics and logic

- **ML** is inductive, learns about the world by examples
- **Logic** is deductive, with rules, principles and reasoning describing and representing knowledge
- **Statistics** is inferential, learns models, quantifies uncertainty

Example: Learning from inconsistent preference data

Preference learning

- Users compare items in pairs: which is preferred?
- Used in psychology, social sciences, marketing …

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Some comparisons of 300 items

1 million users

```
{( A3 < A5 ), ( A7 < A5 )}
{( A2 < A9 ), ( A6 < A5 ), ( A6 < A10 ), ( A8 < A1 ), ( A8 < A7 )}
{( A1 < A9 ), ( A4 < A5 ), ( A4 < A10 ), ( A8 < A7 ), ( A9 < A2 )}
{( A1 < A4 ), ( A2 < A9 ), ( A3 < A4 ), ( A7 < A4 ), ( A9 < A1 )}
{( A4 < A3 ), ( A4 < A7 ), ( A7 < A3 ), ( A7 < A10 )}
{( A2 < A8 ), ( A1 < A2 ), ( A8 < A1 )}
{( A4 < A1 ), ( A9 < A3 ), ( A10 < A5 )}
{( A2 < A4 ), ( A8 < A4 ), ( A9 < A5 )}
{( A1 < A7 ), ( A5 < A9 ), ( A10 < A4 ), ( A10 < A8 ), ( A10 < A9 )}
{( A1 < A10 ), ( A2 < A4 ), ( A3 < A4 ), ( A3 < A5 )}
{( A1 < A8 ), ( A9 < A6 )}
{( A1 < A5 ), ( A7 < A5 ), ( A8 < A7 ), ( A9 < A7 ), ( A10 < A3 )}
{( A2 < A10 ), ( A4 < A7 ), ( A4 < A9 ), ( A6 < A3 ), ( A6 < A5 )}
{( A1 < A4 ), ( A1 < A9 )}
{( A2 < A8 ), ( A3 < A10 ), ( A5 < A6 ), ( A7 < A8 ), ( A9 < A1 )}
```

Estimate individual preference

```
{( A3 < A5 ), ( A7 < A5 )}
{( A2 < A9 ), ( A6 < A5 ), ( A6 < A10 ), ( A8 < A1 ), ( A8 < A7 )}
{( A1 < A9 ), ( A4 < A5 ), ( A4 < A10 ), ( A8 < A7 ), ( A9 < A2 )}
{( A1 < A4 ), ( A2 < A9 ), ( A3 < A4 ), ( A7 < A4 ), ( A9 < A1 )}
{( A4 < A3 ), ( A4 < A7 ), ( A7 < A3 ), ( A7 < A10 )}
{( A2 < A8 ), ( A1 < A2 ), ( A8 < A1 )}
{( A4 < A1 ), ( A9 < A3 ), ( A10 < A5 )}
{( A2 < A4 ), ( A8 < A4 ), ( A9 < A5 )}
{( A1 < A7 ), ( A5 < A9 ), ( A10 < A4 ), ( A10 < A8 ), ( A10 < A9 )}
{( A1 < A10 ), ( A2 < A4 ), ( A3 < A4 ), ( A3 < A5 )}
{( A1 < A8 ), ( A9 < A6 )}
{( A1 < A5 ), ( A7 < A5 ), ( A8 < A7 ), ( A9 < A7 ), ( A10 < A3 )}
{( A2 < A10 ), ( A4 < A7 ), ( A4 < A9 ), ( A6 < A3 ), ( A6 < A5 )}
{( A1 < A4 ), ( A1 < A9 )}
{( A2 < A8 ), ( A3 < A10 ), ( A5 < A6 ), ( A7 < A8 ), ( A9 < A1 )}
```

A7	A2	A5	A1	A10	A8	A2	A9	A6	A3
A1	A3	A5	A7	A10	A8	A2	A6	A9	A4
A1	A7	A3	A5	A10	A8	A9	A6	A2	A4

A2	A3	A1	A7	A5	A9	A8	A4	A6	A10

Consistent comparisons?

- Consistent user, transitive preferences

  $A1 > A2$ and $A2 > A3$ and $A1 > A3$

- Non-consistent user

  $A1 > A2$ and $A2 > A3$ but $A1 < A3$

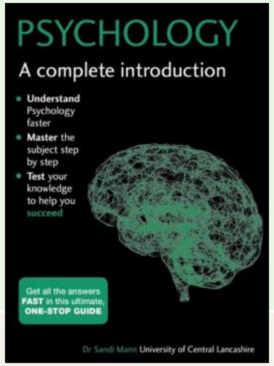
- Non-consistent user

  $A1 > A2$ and $A1 < A2$

What to do with inconsistent users?

A1 > A2 and A1 < A2

Knowledge	Model
• User confused, no information in this data	• Drop both preferences ~~A1 > A2 and A1 < A2~~
• Similar users share preferences to some degree	• A measure of similarity of users • Use only one of A1 > A2 or A1 < A2, the one expressed by similar users
• Similar users share preferences to some degree • It is easier to be uncertain when comparing similar items	• A measure of similarity of users • Use only one of A1 > A2 or A1 < A2, the one expressed by similar users • A1 and A2 are close in preference for this user



The new centre…

- builds on a team of **statisticians, logicians, machine learning researchers and ethicists**

- will develop theories, methods, models and algorithms which exploit **knowledge together with data**

- will solve important **real-world problems** in science, industry and society together with domain experts integreat.no

Thank you!

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