From machine learning towards autonomous, explainable artificial intelligence in industrial automation for steel processing

Marcus J. Neuer and Moritz Loos

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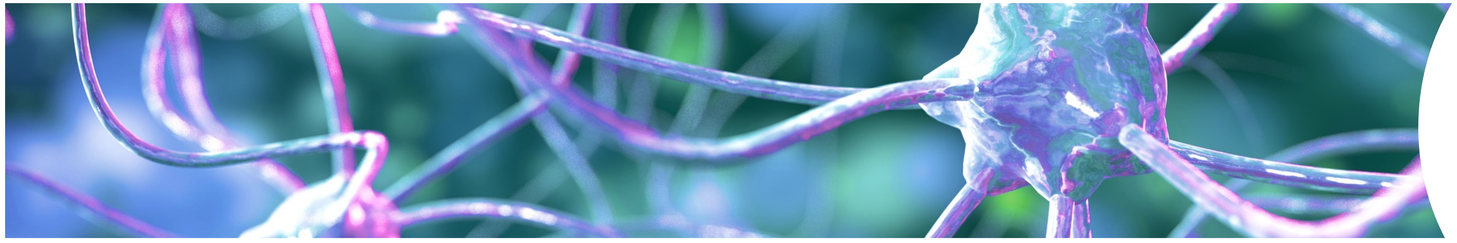
Artificial intelligence vs. explainable artificial intelligence

„Artificial intelligence is the science and engineering of making computers behave in ways that, until recently, we thought required human intelligence“,

- Andrew Moore, Carnegie Melon University

„Machine learning is the study of computer algorithms that allow computer programs to automatically improve through experience“,

- Tom Mitchell, Carnegie Melon University



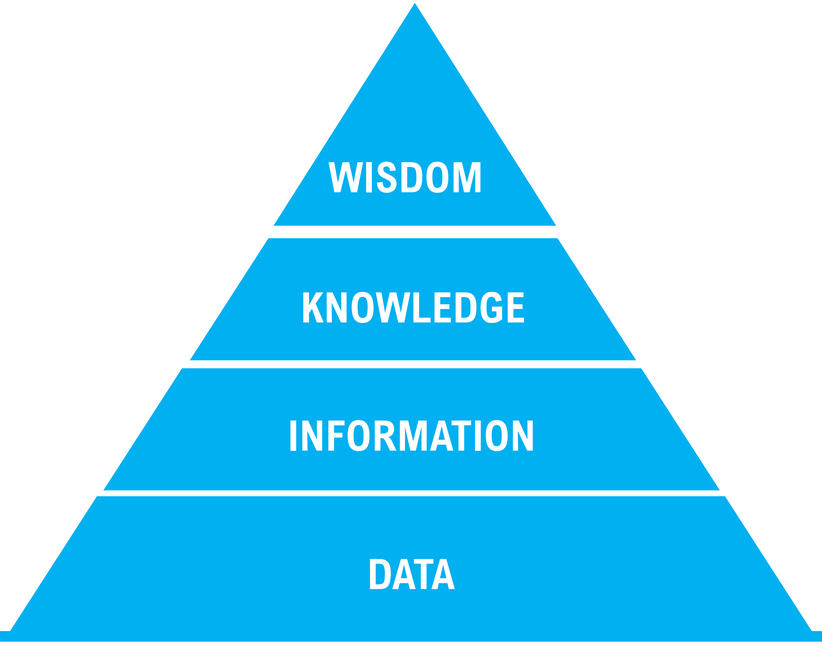
Natural intelligence

Combine models, realize relevances

Model returns v = ds / dt

Get function s(t) and its derivative ds / dt

Measurement of t, s



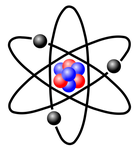
Colleague with enough experience to setup process based on stomach feeling

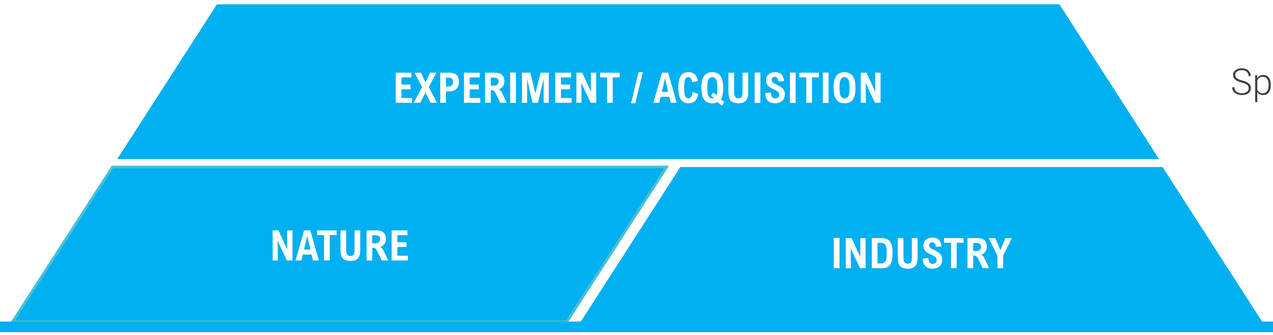
Apply model, e.g. to control roll forces

Organize, put into context

Measurement of flatness

Design of experiment





Specific sensorial infrastructure

Flat steel production

Natural intelligence applied to process

PROCESS

Changes & Optimizes

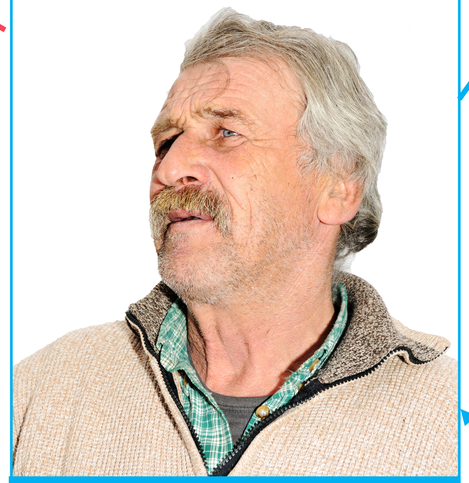
Observe

ACQUISITION

Record

DATA

Interprete & Draw Conclusion



EXPERT

Process

KNOWLEDGE

UNDERSTANDING / MODEL

Analyse

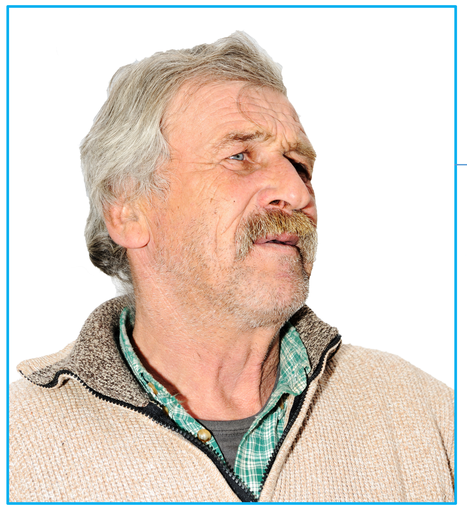
METHODS

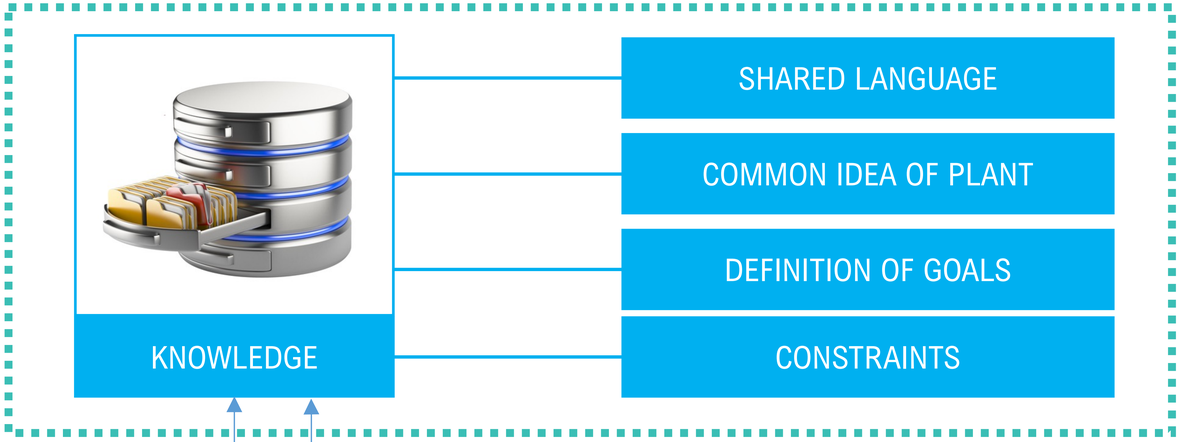
Visualization
Data Mining
Machine Learning

*experts in your plant may differ from picture

Explainable natural intelligence

Shared Knowledge Repository

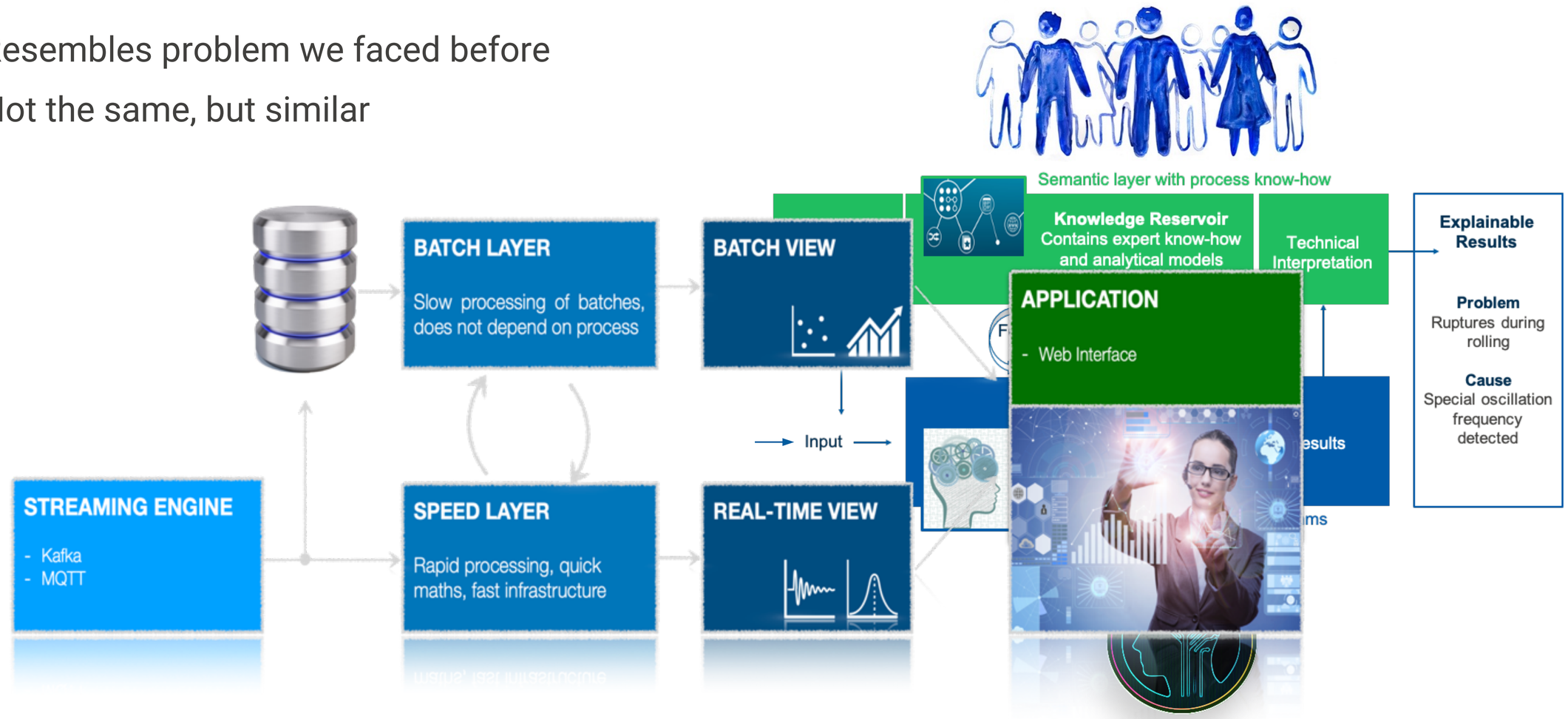




Discuss,
Argue,
Explain

„Lambda-Architecture“ expansion for Explainable AI

- Resembles problem we faced before
- Not the same, but similar



Need for Human-AI-Collaboration

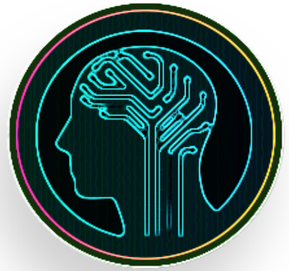
- AI **onboarding strategy** as part of implementation projects

Instead, AI must become part of the team

- Fear of job loss
- Fear of being outperformed
- Fear of becoming obsolete

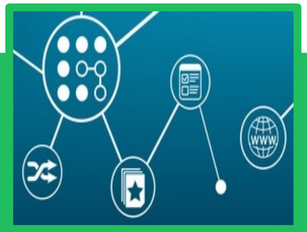
Collaboration-oriented design of user interfaces

- Allow staff to embrace AI as **helpful tool**
- Design of user interfaces that do not disclose the full AI solution
  - Provide a **mode of choice**, always **integrate personnel in decision process**
- **Gamification** can be used as motivational factor
- Diskussion of last week



Explainable AI - Fusing know-how with AI methods

Semantic layer with process know-how



Relevance

Knowledge Reservoir
Contains expert know-how and analytical models e.g. for physics-infusion

Technical Interpretation

Explainable Results

Problem
Ruptures during rolling

Cause
Special oscillation frequency detected

Forensics of decision finding process

Input

Learning algorithm
Neural Network, Decision Tree, Forest

Results

Machine learning layer with algorithms

A short look into history...

Numbers
Congo
20,000 BC

Counting
Sumeria
4,000 BC

Abacus
Babylon
2,400 BC

Term „Data“
England
1640

Hebb, Hebbian Learning
Canada
1940

Shannon
Theory of communication
1948

Deep Learning
1971

Digitalisation
Rise of PC
1985

LSTM
1997

Big Data
2011

Proto-Language
200,000 BC

Agriculture
< 9,500 BC

Train
Germany
1804

Car
Germany
1886

CD
1982

Internet, WWW
1990

Netflix, Streaming
2007

Autonomous Digital Twins
2014

Industrial evolution over time

Accompanying theoretical concepts / maths / algorithm introduction

Production planning
Scheduling

Control theory

Decentral systems
Advanced algorithms

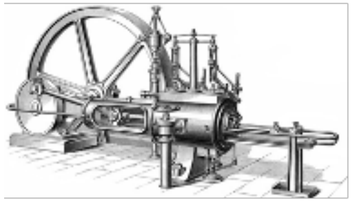
Industry 1.0
Machines

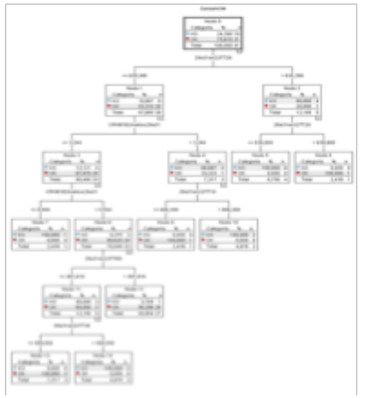
Industry 2.0
Assembly line
Mass production

Industry 3.0
Computer
Automation

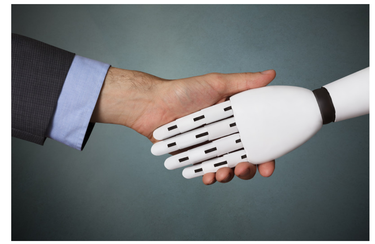
Industry 4.0
Networks
Communication
Integration

Industry 5.0



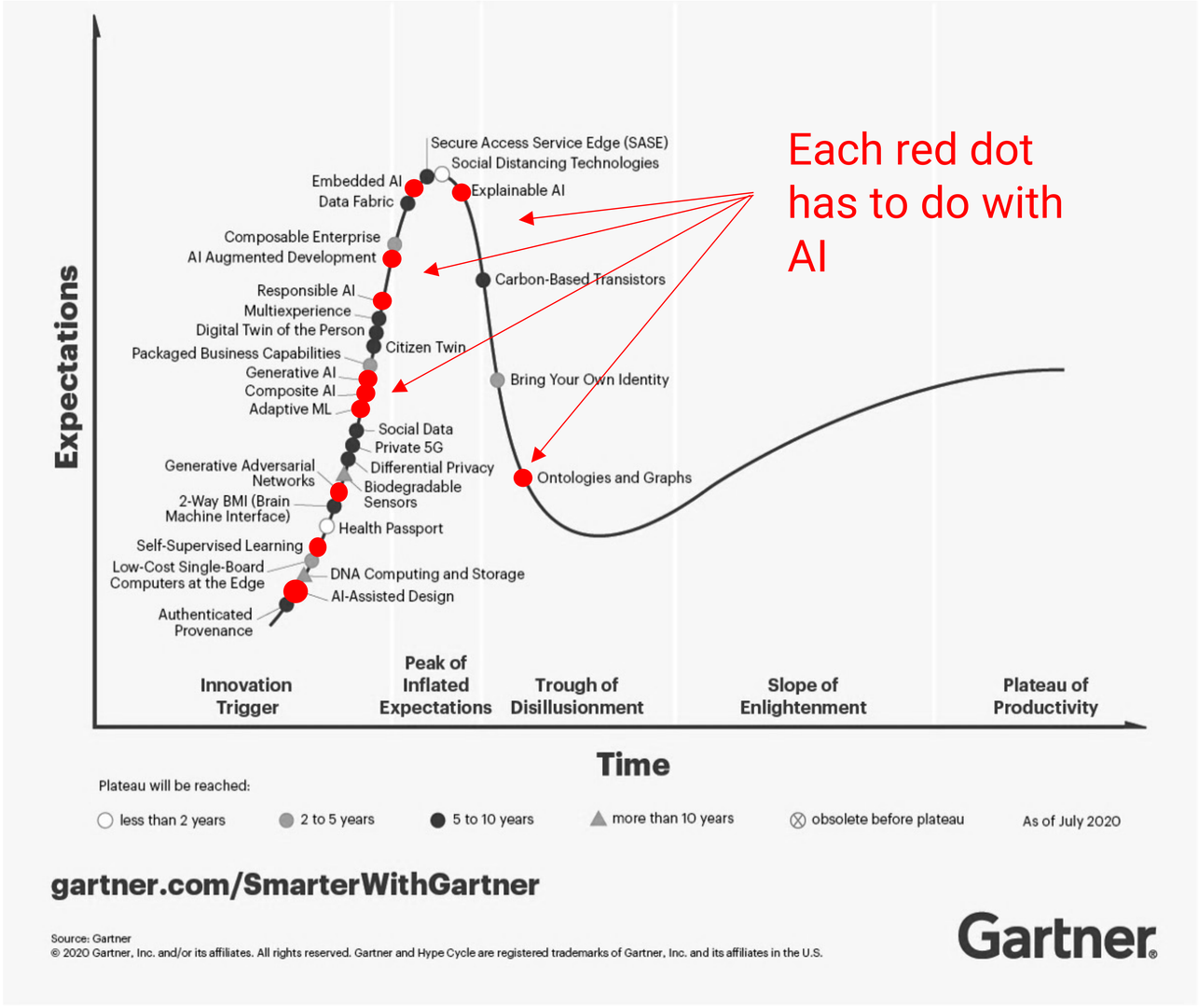


Horizontal & Vertical Integration



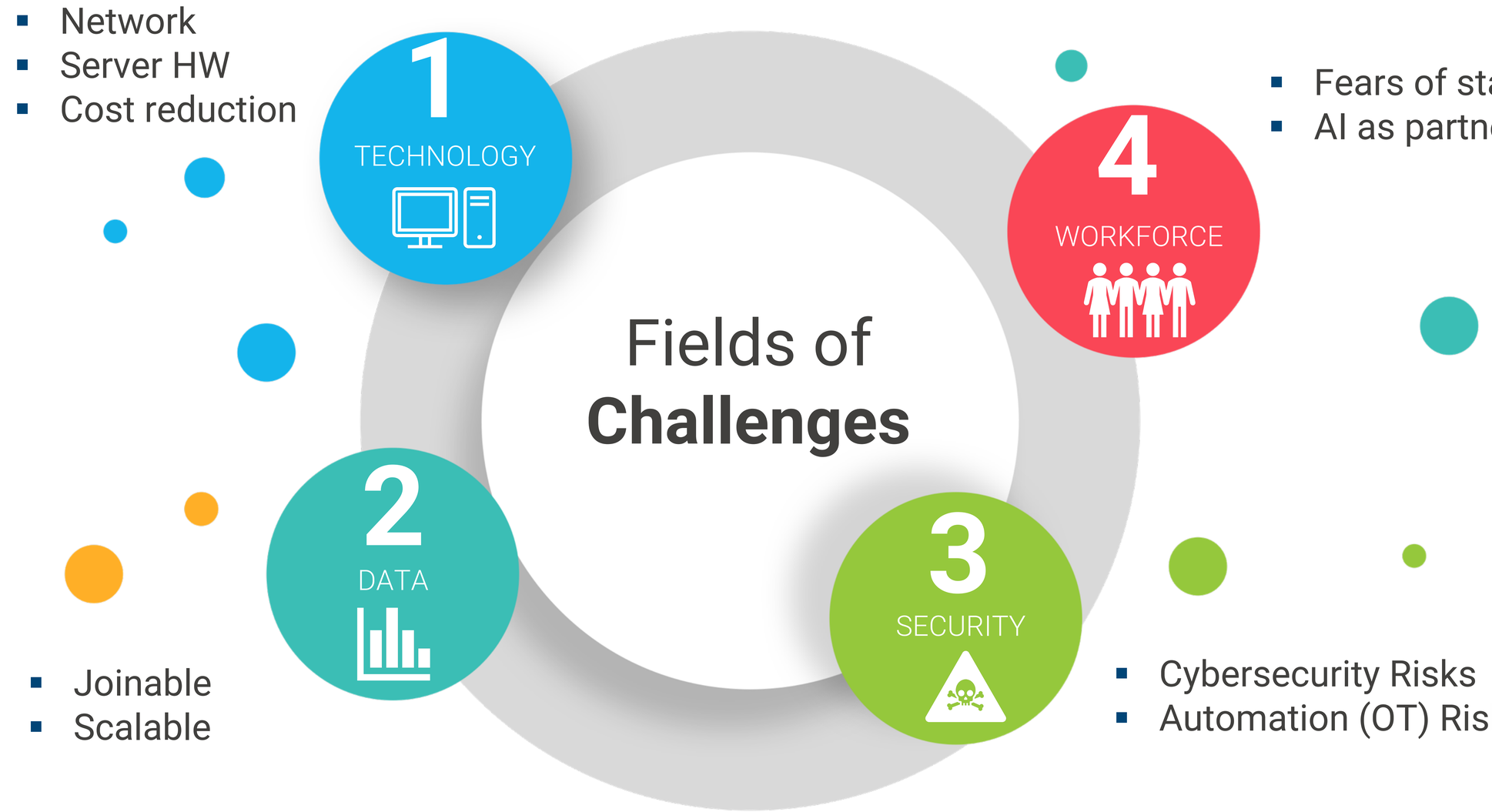
Integration of people, AI and robotic automation

Emerging technologies in 2020



- Hype wave features 11 elements touching AI
- 5-6 related to overcoming current barriers
  - Ontologies
  - Explainable AI
  - AI Augmentation
  - Generative AI
  - Adaptive AI
  - Responsible AI

Important areas of challenges for AI in process industry



- Network
- Server HW
- Cost reduction

- Joinable
- Scalable

- Cybersecurity Risks
- Automation (OT) Risks

- Fears of staff
- AI as partner

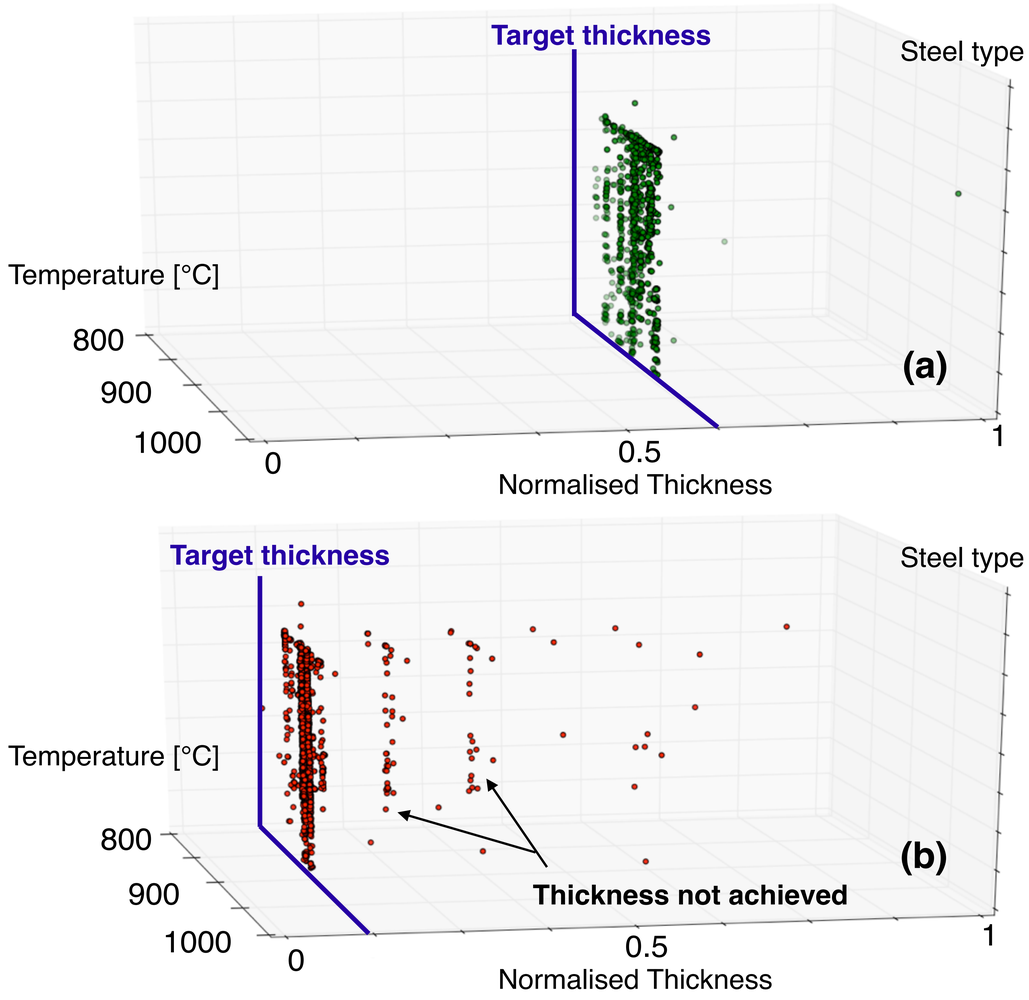
Application example: Risk of process failure

Prediction of the **process failure risk** during roughing, using a regression approach

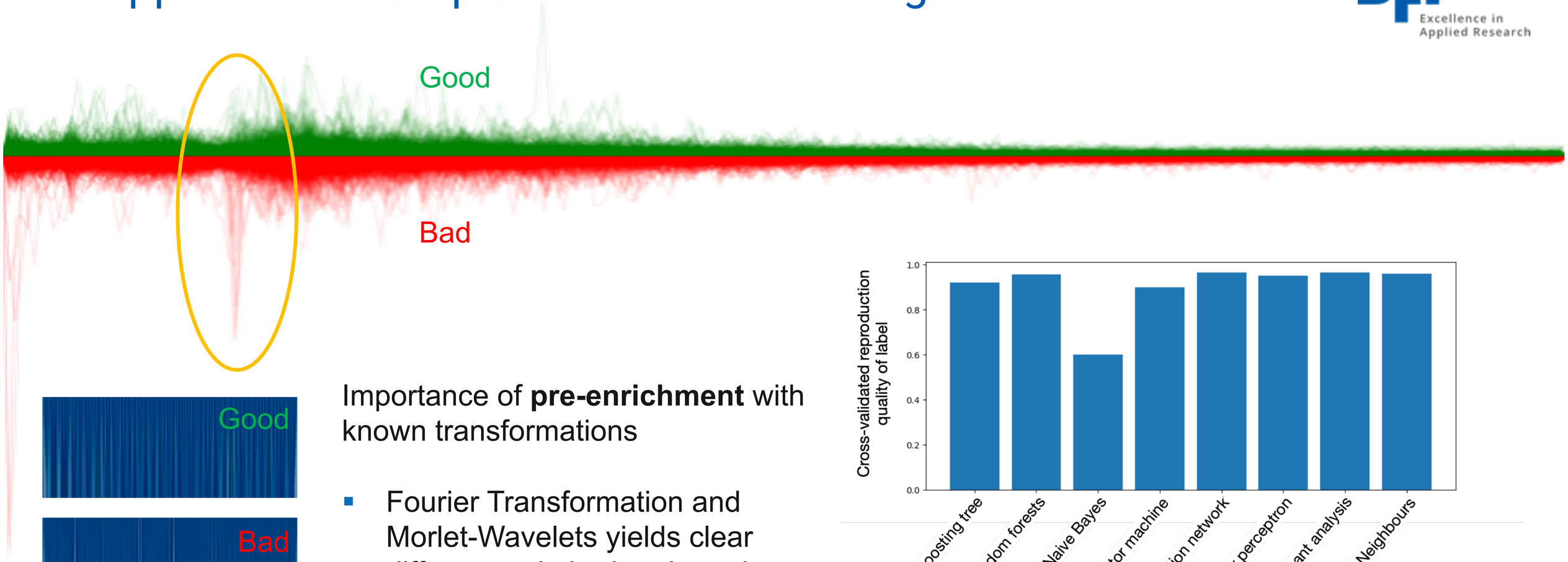
- Normal target thickness: easy to reach (green dots in the picture)
- Small target thickness: harder to reach, not all red dots achieve it

Solution: Deep Belief Regression

- **Floating-point prediction** of the process risk allocating this risk to each product



Application example: Continuous casting

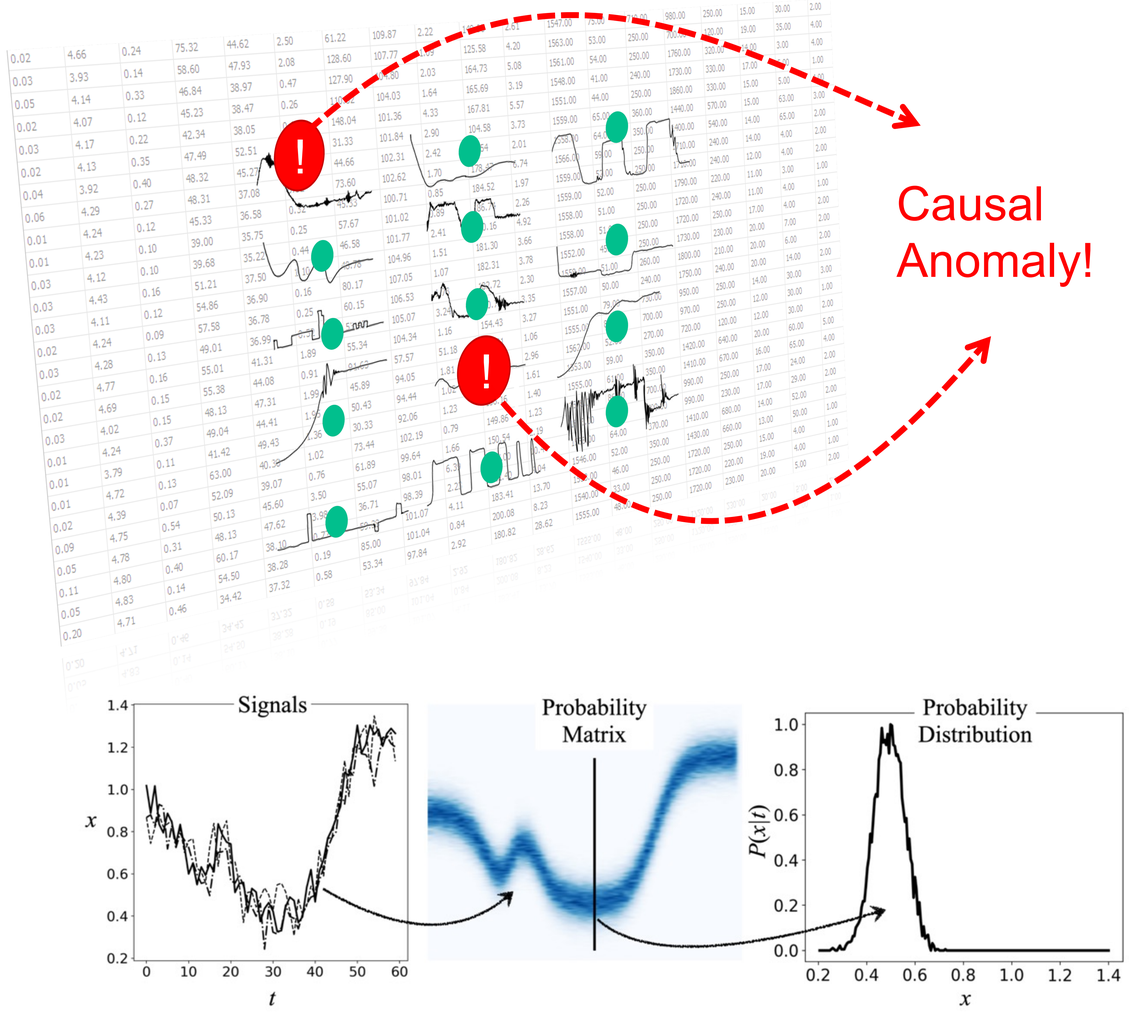


Importance of **pre-enrichment** with known transformations

- Fourier Transformation and Morlet-Wavelets yields clear differences in bad and good cases

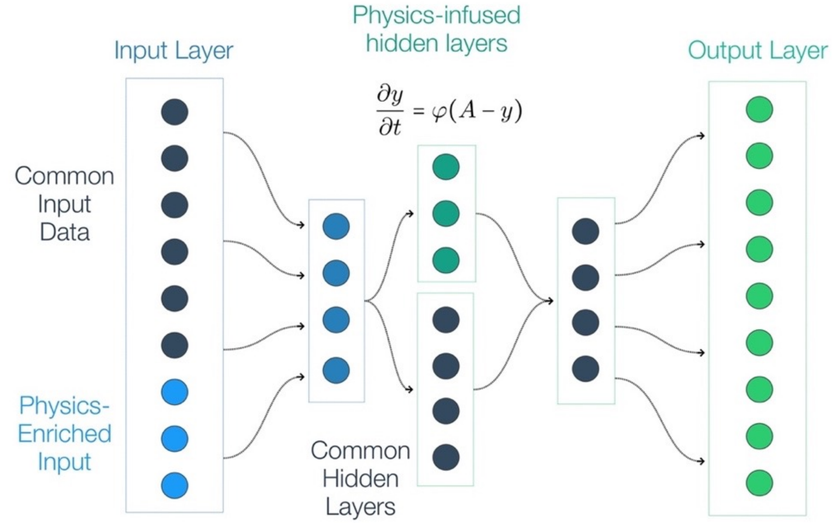
Results from the RFCS project PRESED, SupportCast, CastDesMon

Application example: Analysis of multiple signal streams



Extending the idea to the big picture

- How do anomalies **relate in multiple signals**?
- How early can an anomaly be detected?
- Details: Talk from 2020-10-15



Results from the ZIM projects ADC, SitErk and MeDeLe funded by German SME programme

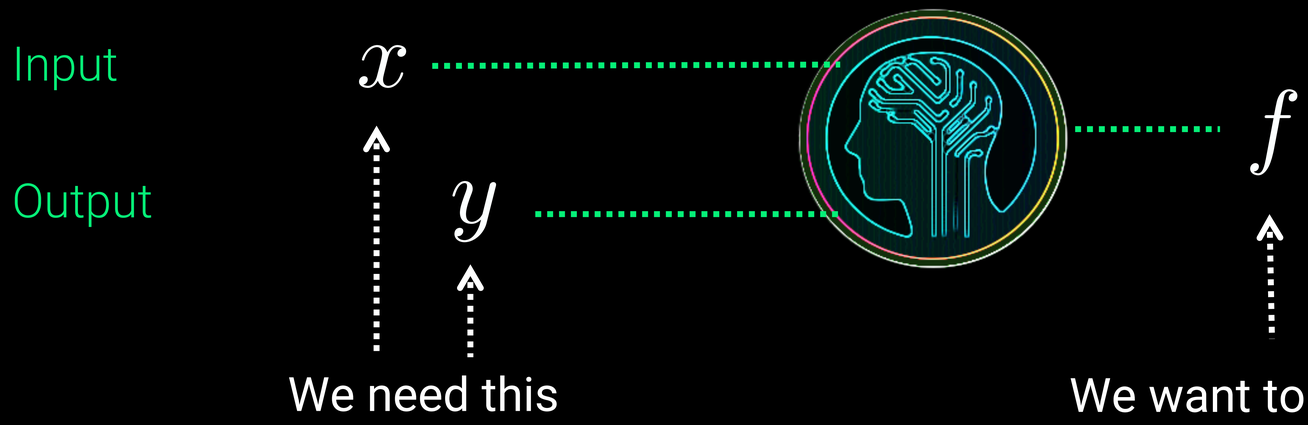
Idea of many machine learning approaches

Function, mapping

$$y = f(x)$$

Output — Input data

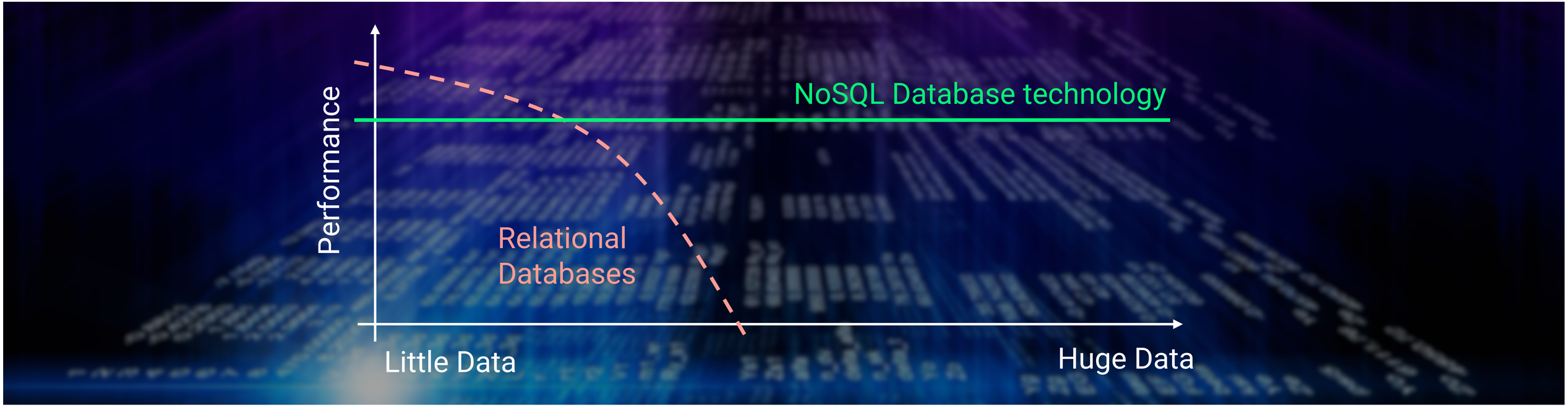
Credit: Similar explanation as seen on the Future Steel Forum 2019



Important preconditions prior to apply AI

Data generated during the processes must be associated with core elements of the production

- Products, machines and parts **tracking**
- **Digital graph** of the production
  - What routes are possible and where are intersections?



Infrastructural challenge: Implementing Lambda-Architecture to foster AI application

Model training (takes some time)

NoSQL Database technology

BATCH LAYER

Slow processing of batches, does not depend on process

BATCH VIEW

APPLICATION

- Web Interface

STREAMING ENGINE

- Kafka
- MQTT

SPEED LAYER

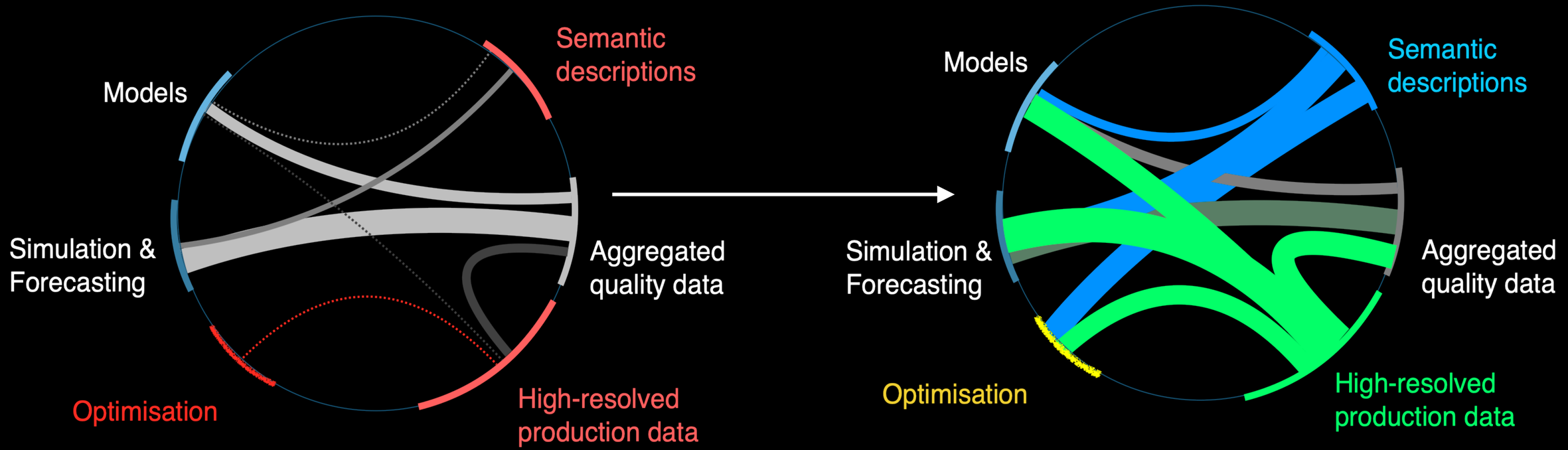
Rapid processing, quick maths, fast infrastructure

REAL-TIME VIEW

Model application (quick)

λ Architecture

Frontiers, now and then



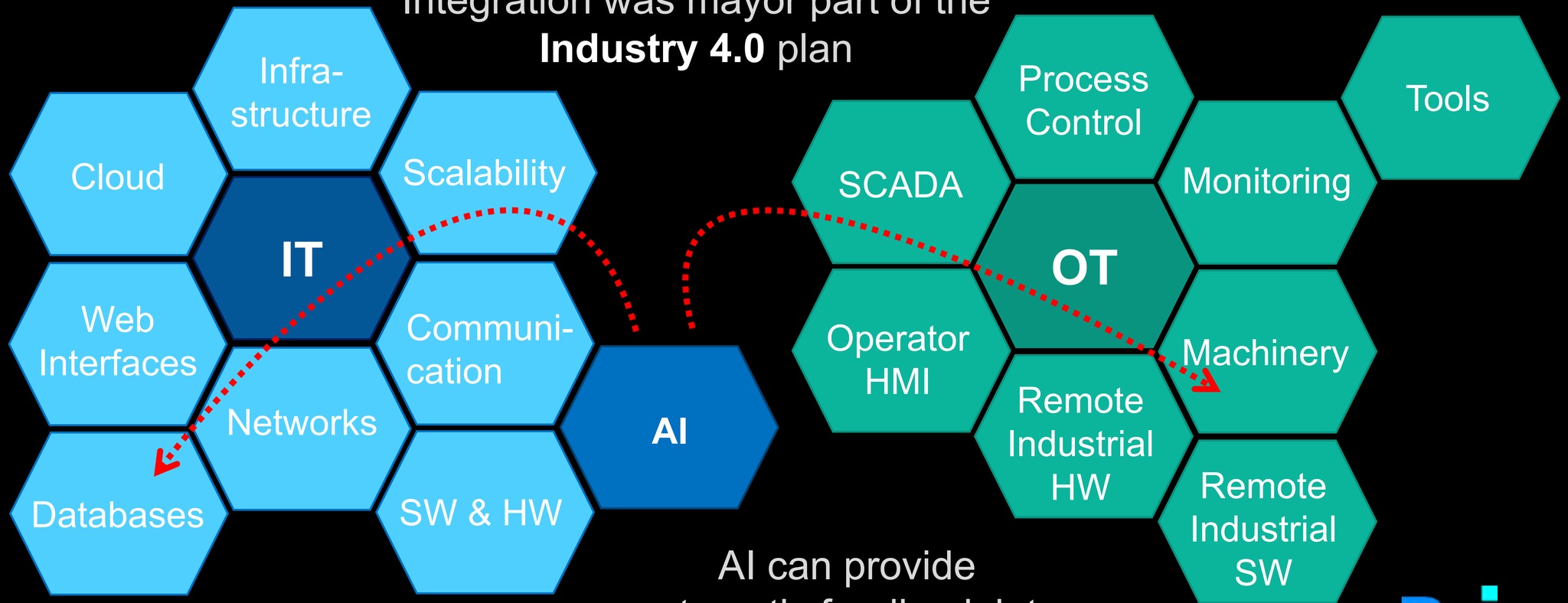
Where we are...

...where we have to go.

Results from the RFCS dissemination project ControlInSteel

Integration also brings „problems“

Integration was mayor part of the
Industry 4.0 plan



AI can provide
automatic feedback into
production = access to OT layer

Summary

- For successful application of AI techniques…
  - An appropriate technical infrastructure must be established for **plant wide data collection**
  - The data management must be optimised and availability should be complete
  - All network structures, IT systems and automation systems must be secured
  - A Human-AI-collaborative approach must take the interests of workforce into account to overcome acceptance barriers

- Betriebsforschungsinstitut (BFI)
  - We are supporting the process industries, especially steel industry, in the digital transition
  - We develop proposals for funding research projects and coordinate subsequent projects
  - We offer direct, contracted research for those with urgent problems

Thank you for your interest!

Dr. Marcus J. Neuer

Head of Department Automation Downstream

VDEh-Betriebsforschungsinstitut GmbH

Stahl-Zentrum · Sohnstraße 65 · 40237 Düsseldorf

Telefon +49 211 6707-254 · Mobil **+49 175 2064672**

E-Mail marcus.neuer@bfi.de · www.bfi.de

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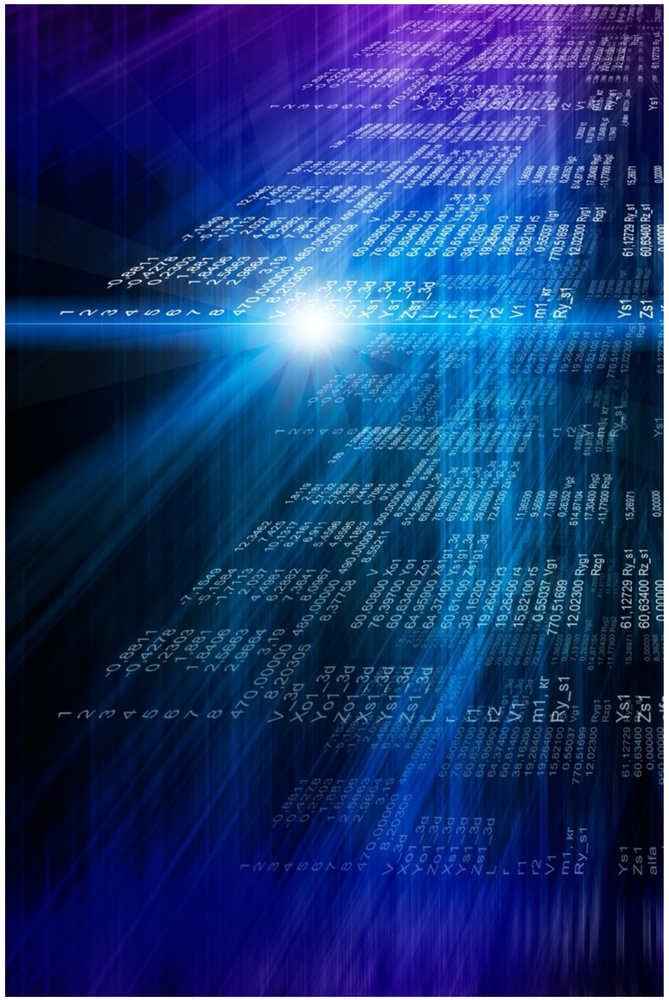
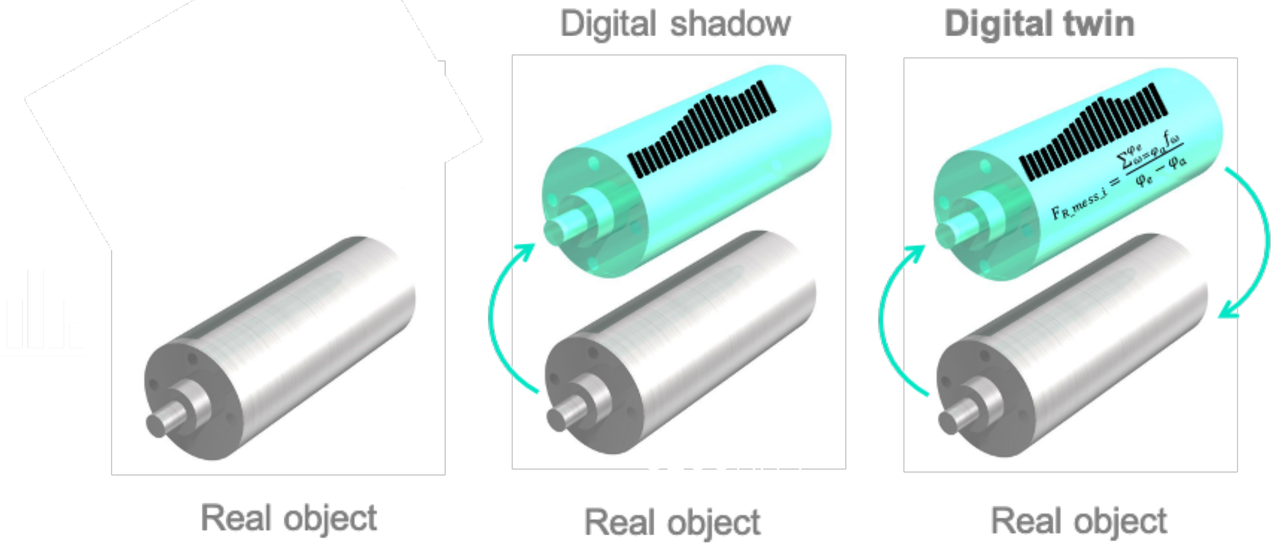
Important preconditions prior to apply AI

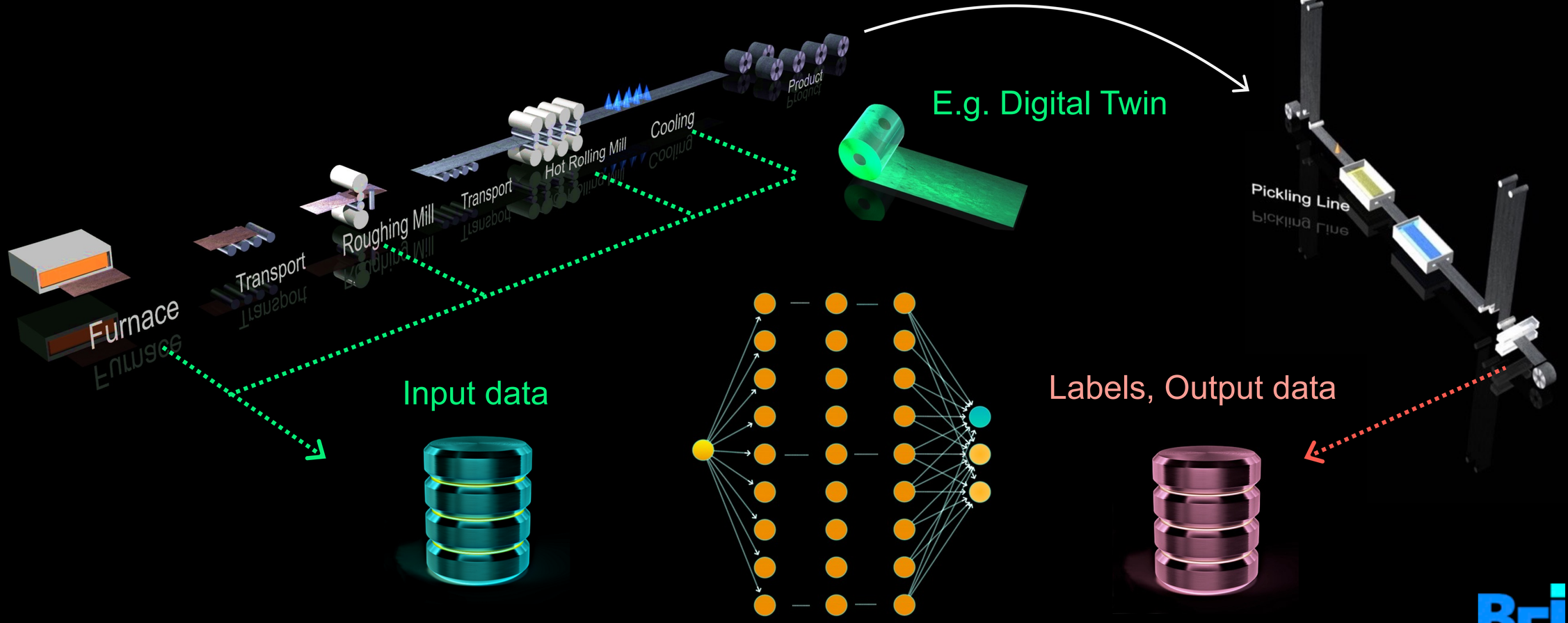


AI requires data for training and testing

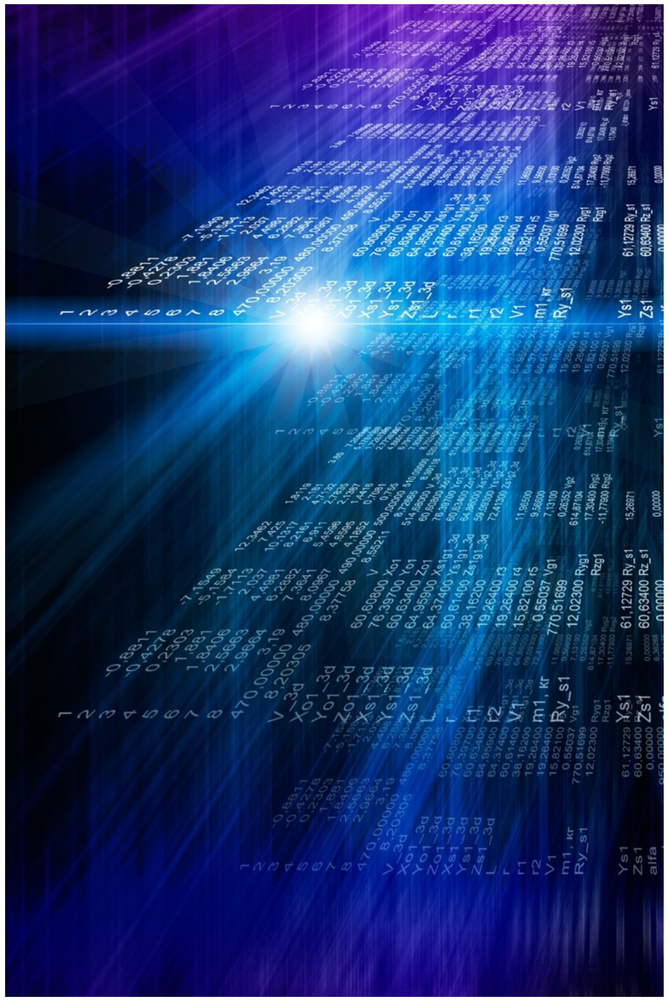
- Data must be **available** over the whole production chain
- Data must be associated with a product, machine or part
- **Design of experiment** concept



Challenge: Provide product-(object)-oriented data



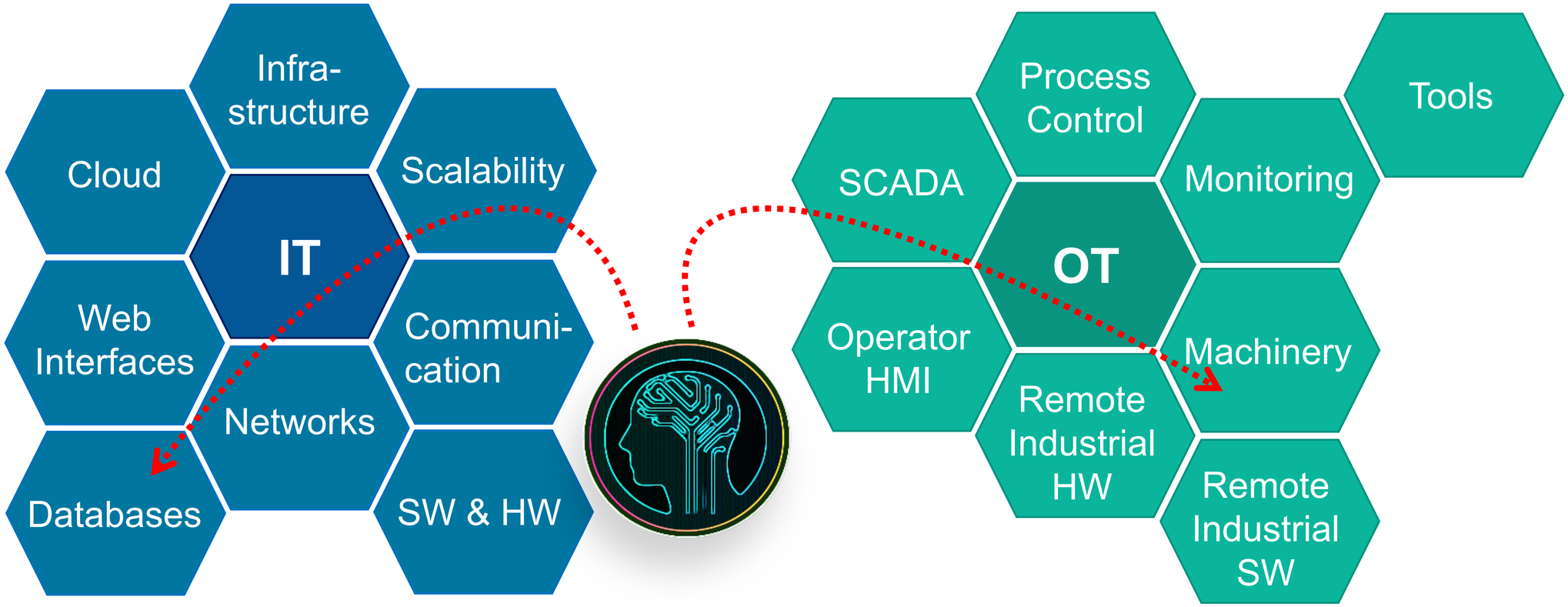
Challenge: Sequence effects with AI



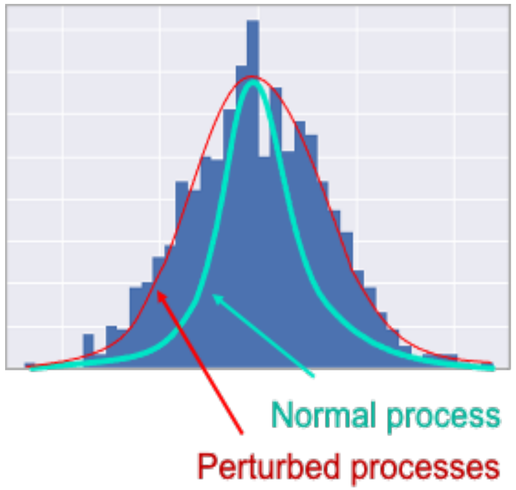
Example where a common „AI“ approach may fail

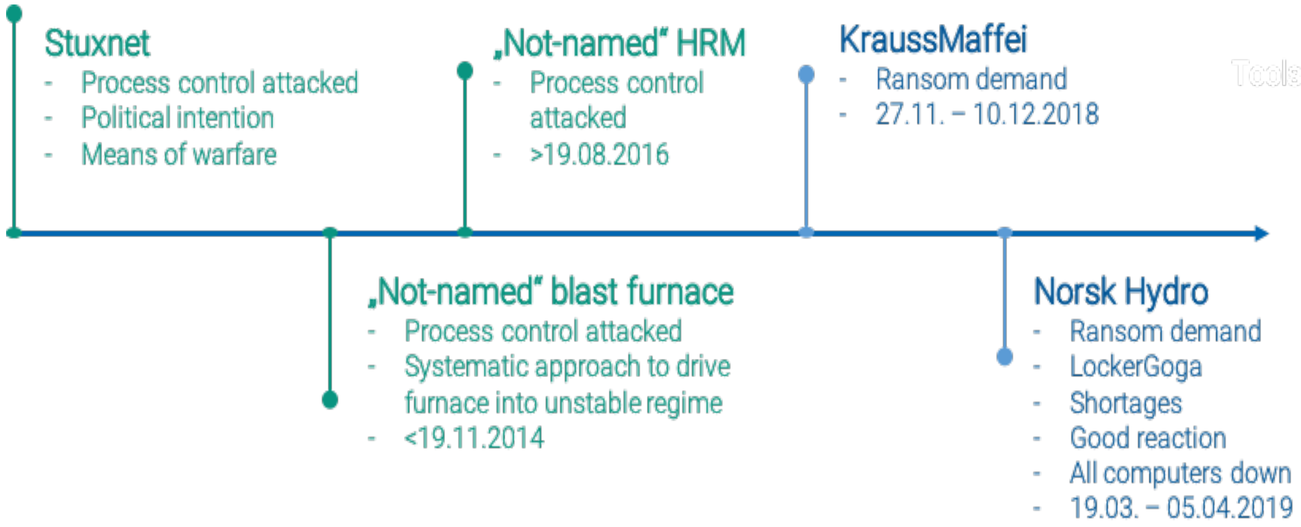
- Associate each time series of a coil with the coil object, e.g. with a digital twin
- Collect labels for these coils
- Look for the cause-effect relation with learning approach to see what leads to the defect
  - **Sometimes this is wrong...**

Integration also brings „problems“



Challenge: Cybersecurity





- IT attacks, commonly associated with ransomware
- Longterm, latent perturbation of European steel production processes by invisible attacks on **automation layer (OT)**
- AI also provides a solution here !