POLITÉCNICA
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CAMPUS DE EXCELENCIA INTERNACIONAL
Universidad Politécnica de Madrid
ETS de Ingenieros Industriales
INDUSTRIALES ETSII | UPM

FROM DATA AND ALGORITHMS TO VALUE CREATION IN THE INDUSTRY 4.0

Doctoral Thesis Defense

Economía y Gestión de la Innovación

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13.05.2022

CONTENT

CONTEXT

Digitalisation is transforming our lives

- Smartphones have become ubiquitous
- Instant worldwide communication has become reality
- Digital media consumption has risen tremendously

Digitalisation is transforming business

- Digital economics have many advantages towards physical economics
- This enables new business models
- New forms of automation have become possible

Digitalisation is transforming the industry

- Rise of Industry 4.0
- Gaining the advantages of digital economics in the industry: e.g. one software update applied to all sites of the company with no further costs

PROBLEM

A digital transformation will be necessary for the Industry

- Companies raking the benefits of digitalization will be cheaper and faster
- “Analog” companies will not be able to compete

“Every Company is Now a Software Company” [1]

- Large parts of value generation will come from its software
- Knowledge is digitized

[1] Satya Nadella, CEO at Microsoft

But transformation processes are often not successful

- ~70% of companies still in the early and developing stages of digital transformation [2]

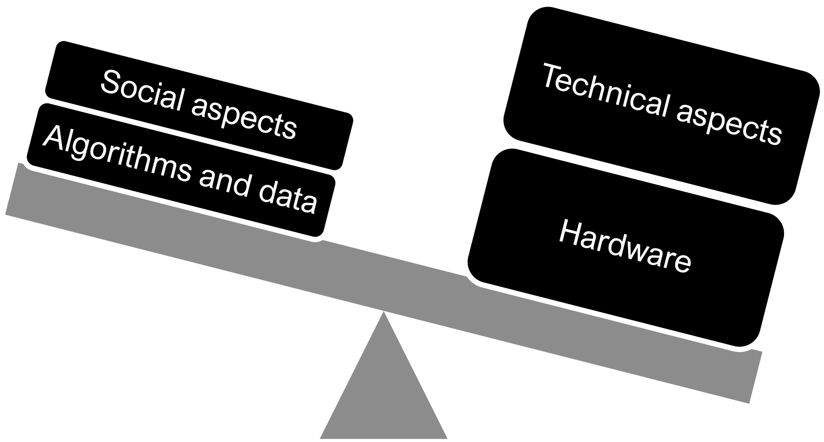
[2] Strategy, not Technology, Drives Digital Transformation

IDENTIFIED GAP

The focus is often misaligned

Hardware > Algorithms and data

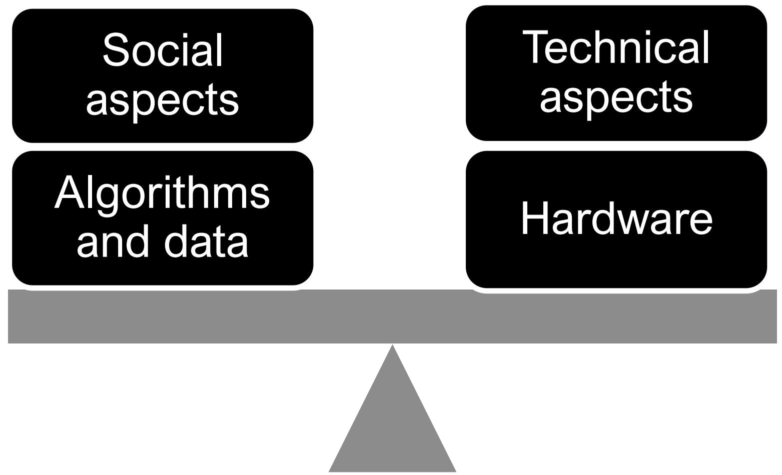
Technical aspects > Social aspects



How can a balanced view be integrated?

Higher focus on algorithms and data

Higher focus on social aspects



GOAL

The main goal of this thesis is to demonstrate that data and algorithms create value in the Industry 4.0 by considering strategic alignment, internal processes and an external facing process within a socio-technical context.

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Data: Facts in "digital form that can be transmitted or processed" and can be used to create value.

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Algorithm: A “step-by-step procedure for solving a problem or accomplishing some end”.

GOAL

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Value: Lean management view of *something that the customer is willing to pay for*. The removal of waste eliminates all non-value adding steps in the process.

GOAL

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Industry 4.0: "The general definition of Industry 4.0 is the rise of digital industrial technology. Industry 4.0 transformations allow us to work alongside machines in new, highly productive ways."

GOAL

The main goal of this thesis is to demonstrate that data and algorithms create value in the Industry 4.0 by considering strategic alignment, internal processes and an external facing process within a socio-technical context.

Strategic alignment: The process of ensuring that all aspects of an organization are working towards the same goals. Making sure that all employees understand and are aligned with the company's strategy.

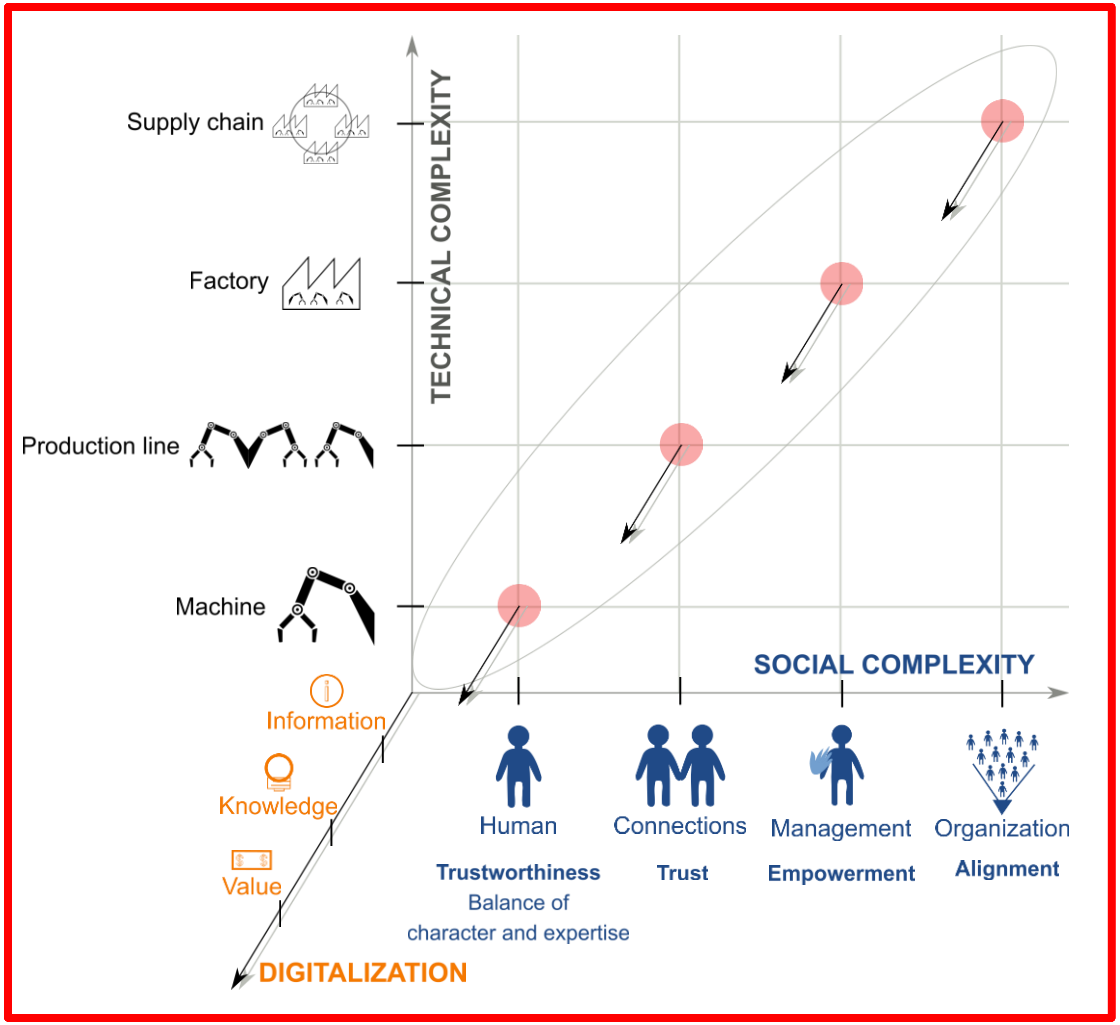
GOAL

The main goal of this thesis is to demonstrate that data and algorithms create value in the Industry 4.0 by considering strategic alignment, internal processes and an external facing process within a socio-technical context.

Socio-technical system: A system that integrates social and technical elements. The social elements include the people who design, operate, and maintain the system. The technical elements include the tools and technology used.

OBJECTIVES

- All implementations need to take technical **and** social complexity into account
- Digitalization gives tools to handle the complexity
- Linear growth line used in thesis



RESEARCH QUESTIONS

Research Question 1:

How can algorithms and data be used to improve the strategic alignment in a business?

Research Question 2:

How can data and algorithms be used to reduce costs and add value to a manufacturing line?

Research Question 3:

How can data and algorithms be used to reduce the complexity of the customer-manufacturer interaction?

IMPROVING STRATEGIC ALIGNMENT

Research Question 1:

How can algorithms and data be used to improve the strategic alignment in a business?

- Strategic alignment is formed through people and the used management tools
- A better understanding of these management tools can help understand the effects they have on strategic alignment
- Algorithms and data can be used to get further insights

IMPROVING STRATEGIC ALIGNMENT

Balanced Score Cards (BSC):

- Different objectives are tracked (SQDV, …)
- Targets are set for these objectives
- The aim is to achieve a holistic view of the organization

IMPROVING STRATEGIC ALIGNMENT

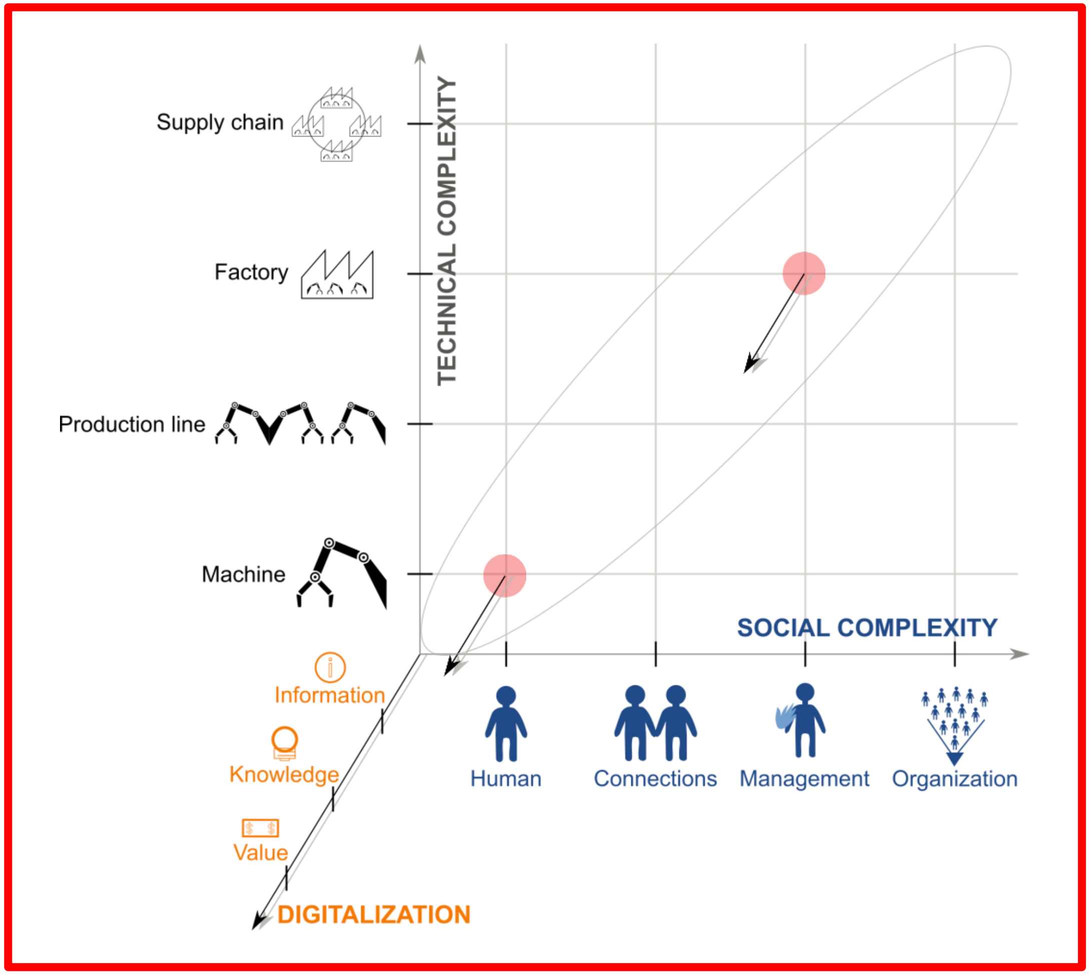
Hoshin Kanri Tree (HKT):

- The process owner tracks his process through a standard communication form
- Direction for improvement is set
- Tree like structure displays the relationships between goals, objectives, strategies, and tactics

IMPROVING STRATEGIC ALIGNMENT

Industry 4.0 framework:

- Interaction point of management and factory
- Interaction point of human and machine (explanation follows)



IMPROVING STRATEGIC ALIGNMENT

- Achieving strategic alignment is highly influenced by the management tools used

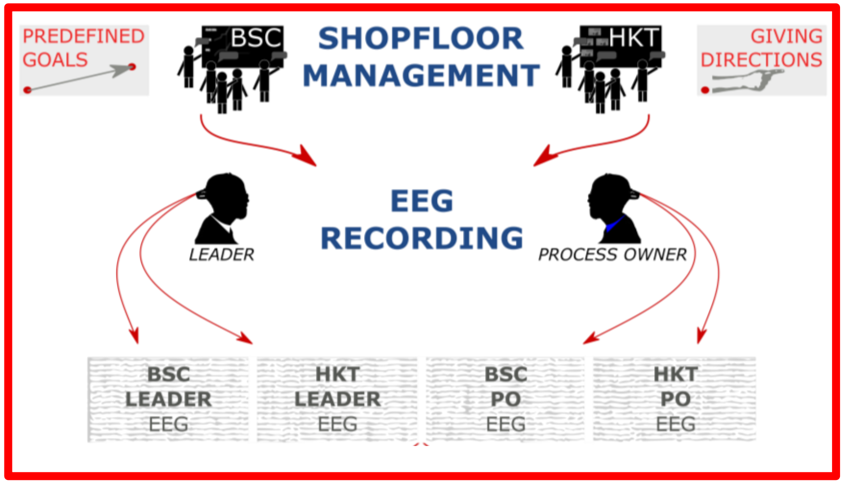
- Better understanding of the differences needed

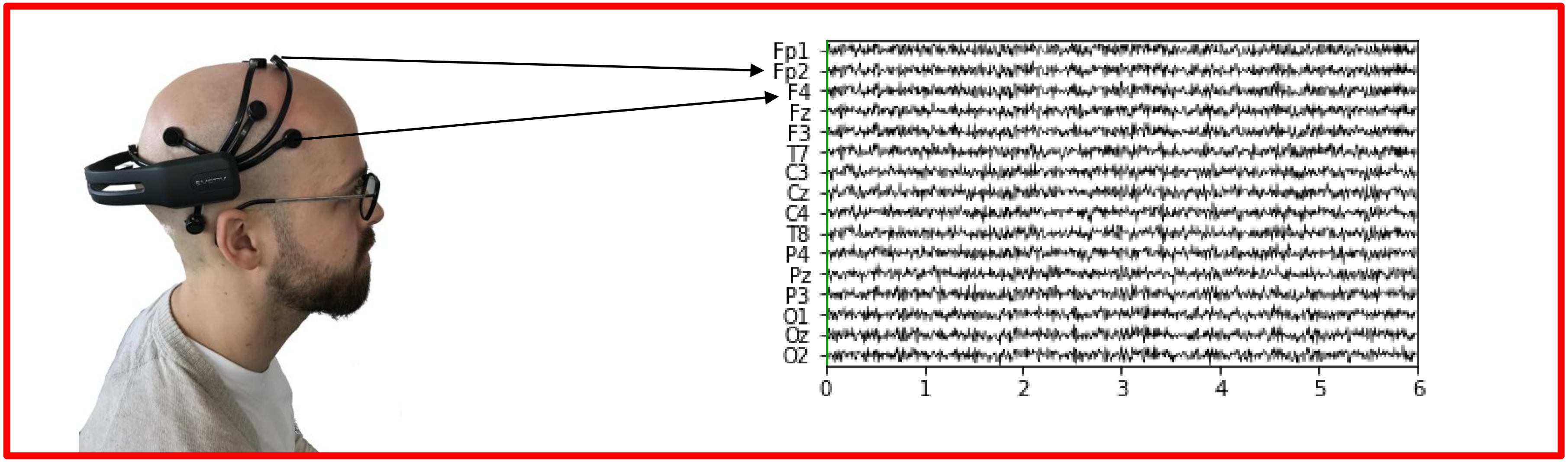
- Predefined Goals: **Balanced Score Cards (BSC)**
- Giving Directions: **Hoshin Kanri Tree (HKT)**

- Case studies cannot give comparative results, as many more factors come into play for the results

IMPROVING STRATEGIC ALIGNMENT

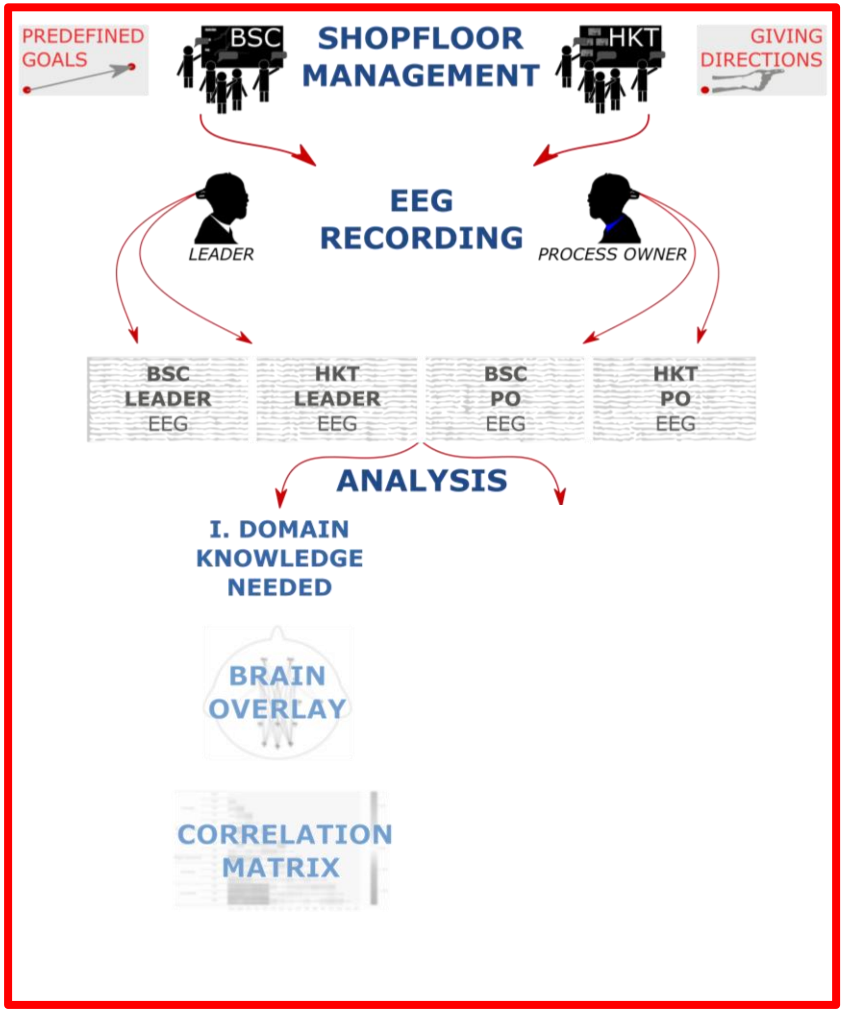
- Understanding what is happening in the brain of practitioners could help
- **EEG-Devices** can give this insight
- BSC Leader vs HKT Leader vs BSC PO vs HKT PO





IMPROVING STRATEGIC ALIGNMENT

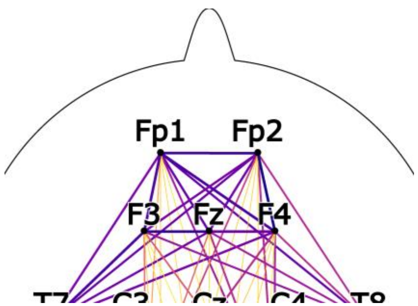
- Correlation of sensor recordings help understand which brain regions are communicating
- High correlations → High interaction
- Meaning of interplay is known for many areas:
  - **Prefrontal Cortex** is responsible for the ability to form internal goals and to pursue these
  - **Left Temporoparietal Junction** (TPJ) involved in strategic planning of choices concerning humans
  - **Right TPJ** plays a pivotal job for empathy, sympathy and perception



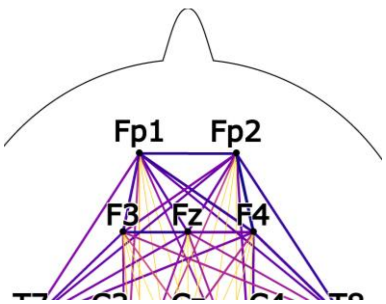
IMPROVING STRATEGIC ALIGNMENT

It was proven that:

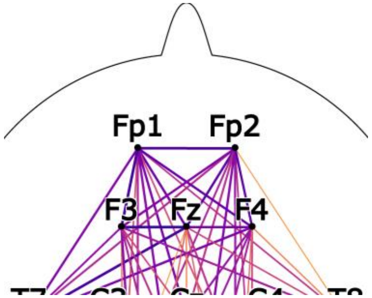
- Both HKT and BSC practitioners show executive behavioural patterns



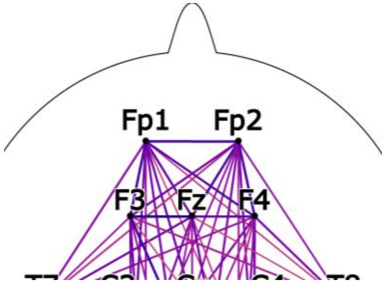
Average correlations for BSC Process Owner



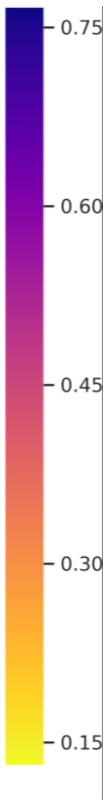
Average correlations for HKT Process Owner



Average correlations for BSC Leader



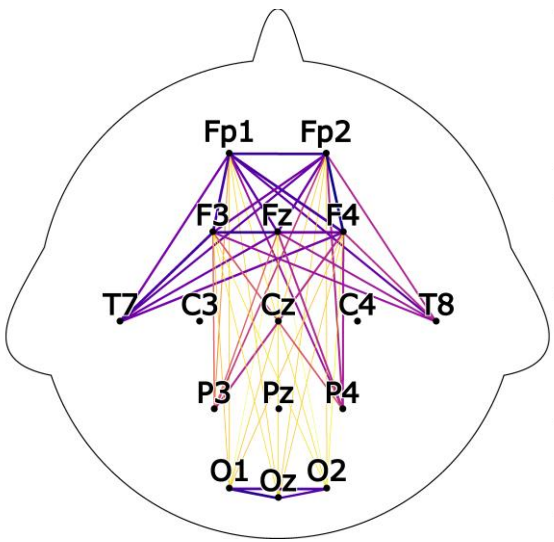
Average correlations for HKT Leader



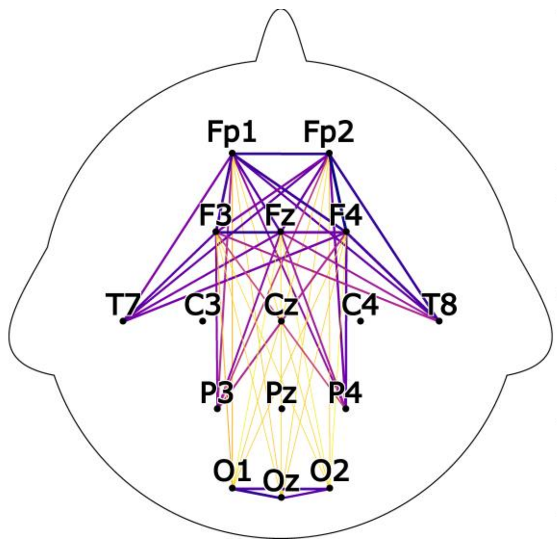
IMPROVING STRATEGIC ALIGNMENT

It was proven that:

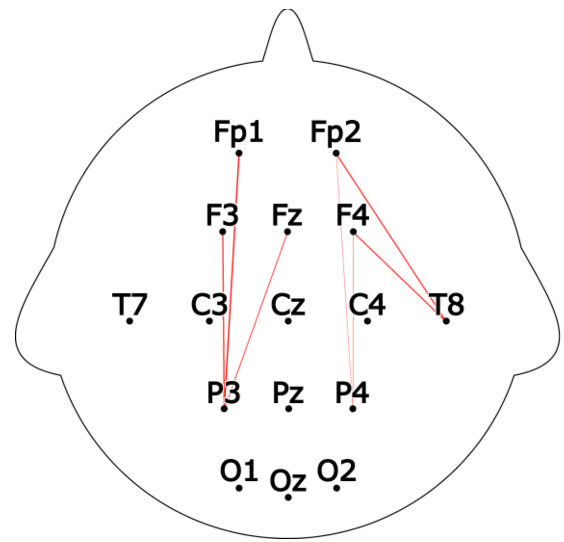
- HKT shows **context-independent** problem-solving brain patterns
- BSC shows **context-dependent** problem-solving brain patterns



Average correlations for BSC Process Owner



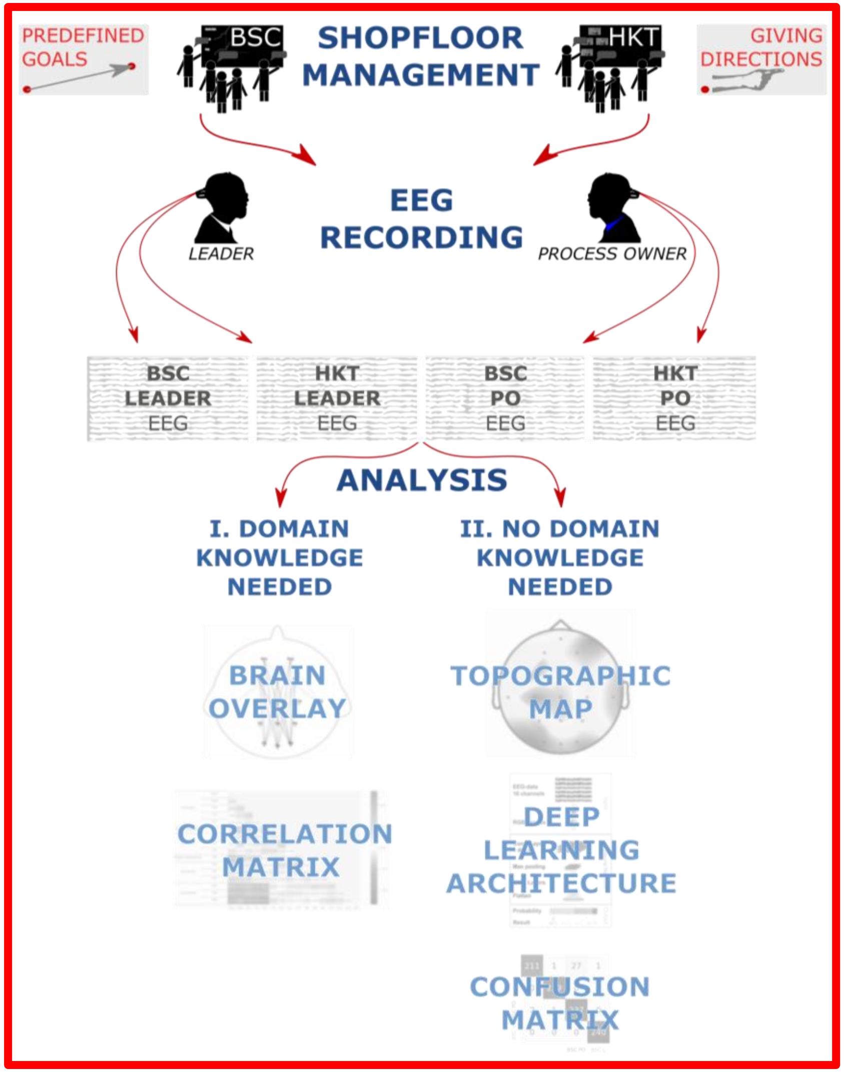
Average correlations for HKT Process Owner



Difference between HKT PO and BSC PO

IMPROVING STRATEGIC ALIGNMENT

- Classification could be used to automatically recognize the management system applied
- Classification needs to take a complex rule system into account
- If complex dependencies exist → Deep Learning-based algorithms (short introduction following)
- Advantages:
  - Complex dependencies are **detected**
  - No domain-knowledge necessary



SUPERVISED NEURAL NETWORKS - Basics

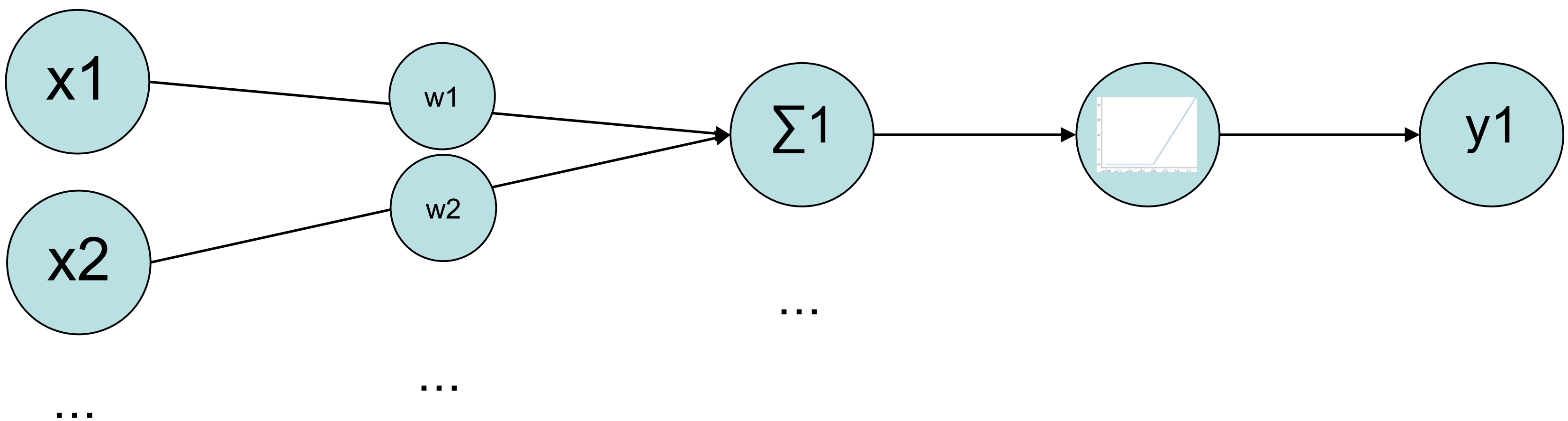
Input
List of numbers
→ e.g. Image, …

Weights
Starts with random numbers

Summation

Activation
e.g. ReLU

Output

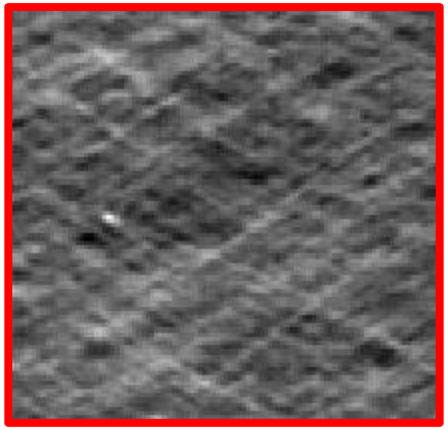


Backpropagation: Through difference with expected results weights are adjusted

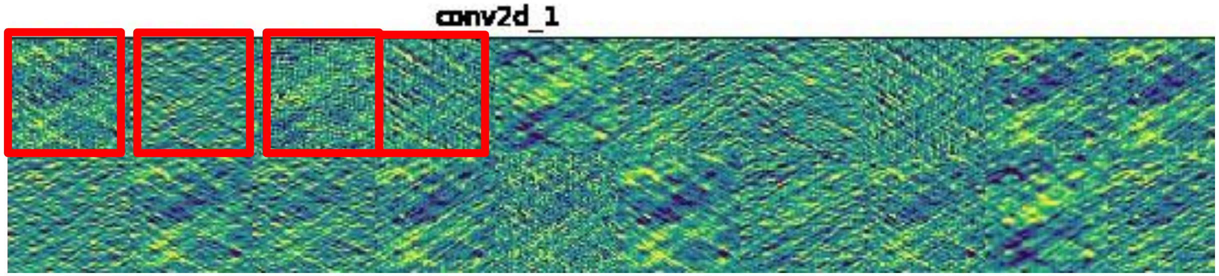
SUPERVISED NEURAL NETWORKS - Basics

- Convolutional layer: Finding relevant feature/activation maps

Input



Outputs Convolutional layer



SUPERVISED NEURAL NETWORKS - Basics

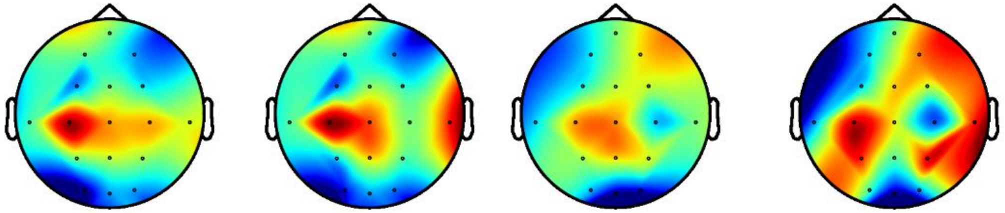
- Max-Pooling: Taking the maximum of a specific area

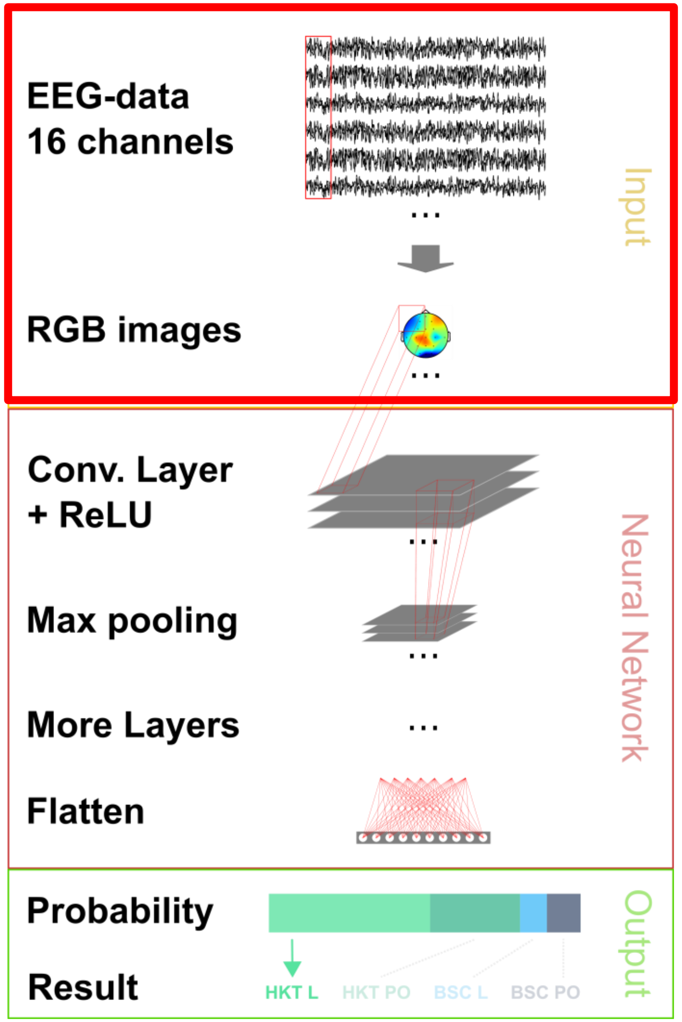
0.2	0.3	0	0.5
0.1	0.2	0	0
0.3	0.1	0.2	0.3
0.3	0.2	0.2	0.1

0.3	0.5
0.3	0.3

IMPROVING STRATEGIC ALIGNMENT

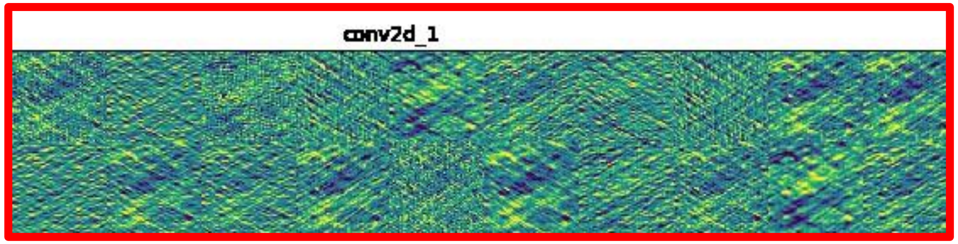
- EEG-Data is transformed to images
- 0.5 seconds of EEG-Data for one brain activity image





IMPROVING STRATEGIC ALIGNMENT

- Convolution → Detecting features

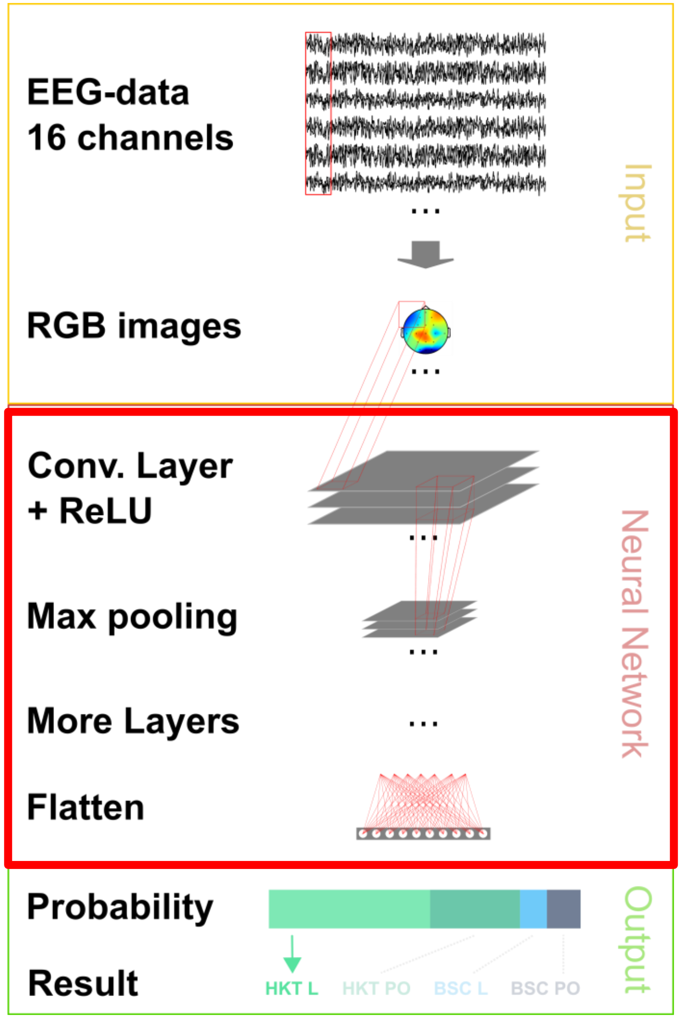


- Max pooling → Reducing dimensions

0.2	0.3	0	0.5
0.1	0.2	0	0
0.3	0.1	0.2	0.3
0.3	0.2	0.2	0.1

0.3	0.5
0.3	0.3

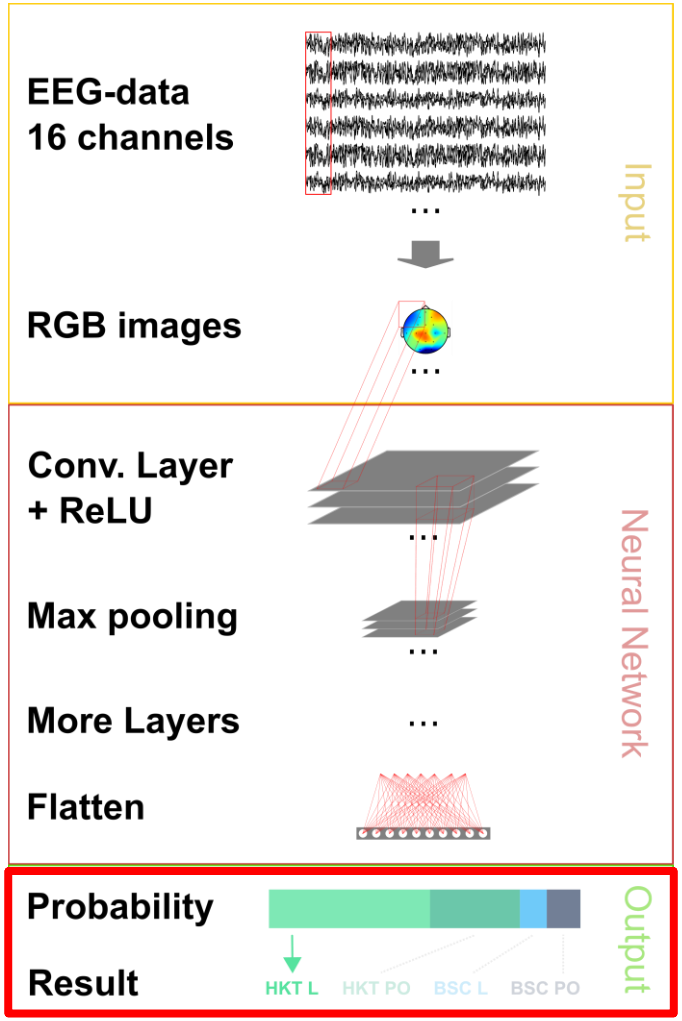
- Multiple stacks (Conv., Max Pooling, Conv., Max Pooling, …) → **Deep** Learning



IMPROVING STRATEGIC ALIGNMENT

- Probability → Calculated through the learned weights

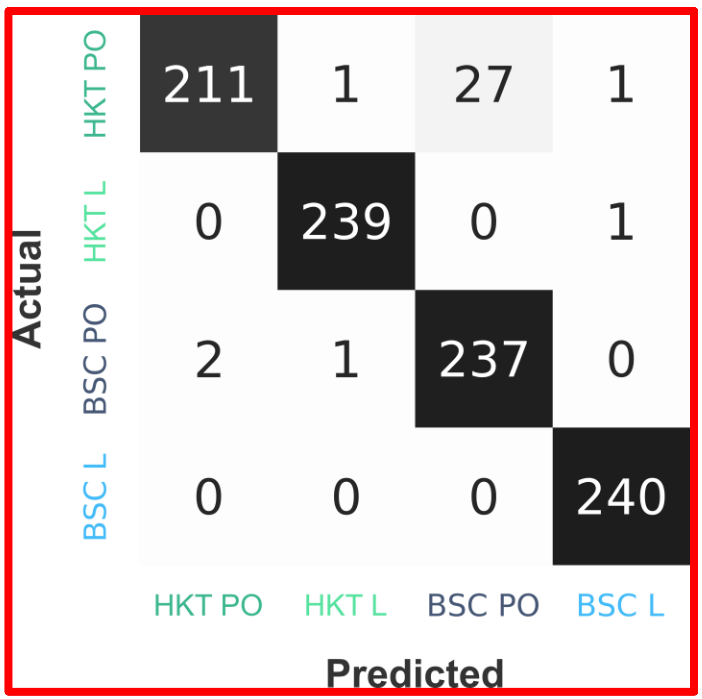
- Which category should it be



IMPROVING STRATEGIC ALIGNMENT

- A classification accuracy of **96.5%** was able to be achieved through the brain activity images and a convolutional neural network (CNN)

→ Different Shopfloor Management systems have noticeable effects on the brain patterns of practitioners



IMPROVING STRATEGIC ALIGNMENT

- EEG-Devices and data analysis offer possible tools for management
- Both HKT and BSC show core requirement for any kind of improvement in the brain activity
- The direction-focused approach of HKT seems to enable a wider view, allowing diverse positions to be taken into perspective
- The contemplated perspectives during the usage of BSC are restricted and the focus on predefined goals limits the aspects that are taken into consideration to receive a goal

REDUCING COSTS AND ADDING VALUE

Research Question 2:

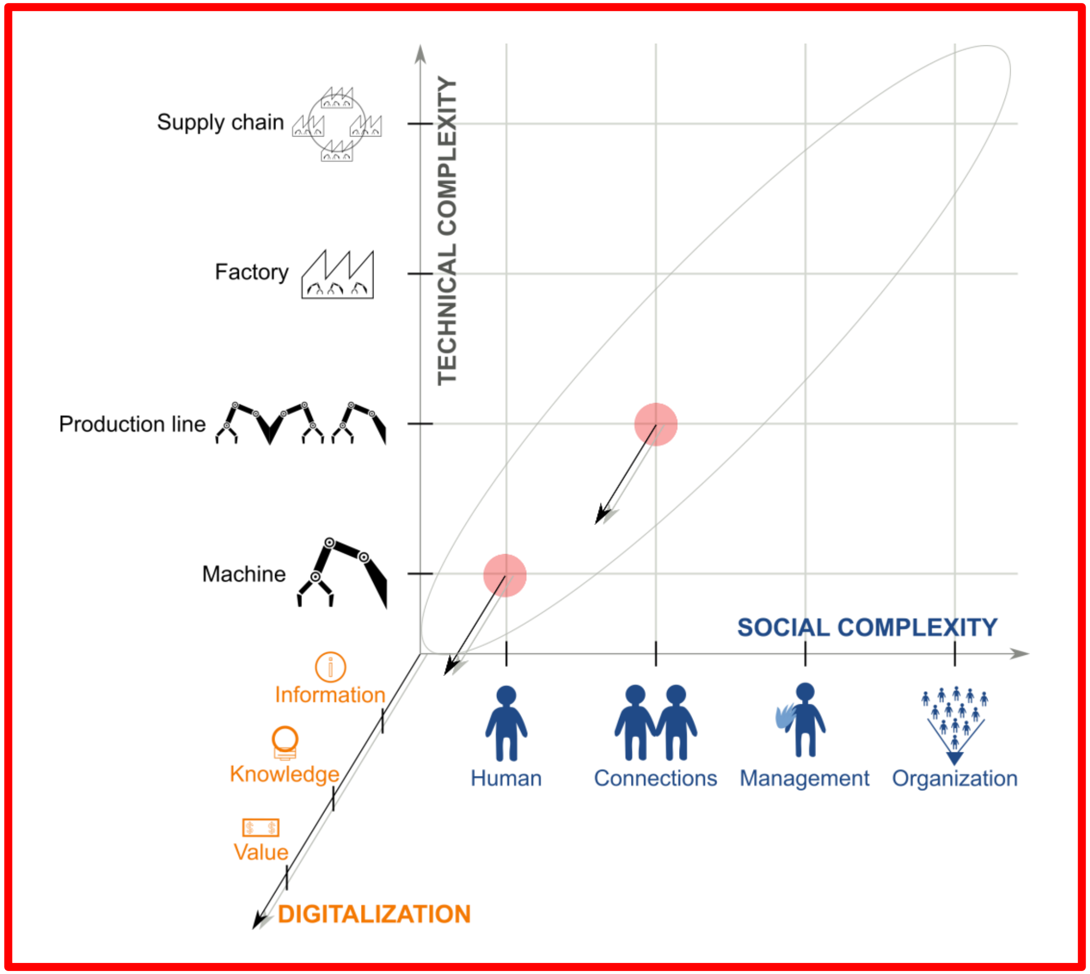
How can data and algorithms be used to reduce costs and add value to a manufacturing line?

- Defects cause high costs in manufacturing
- Better quality control and improvement could decrease these costs dramatically
- Example based on rotogravure manufacturing (printing industry)

REDUCING COSTS AND ADDING VALUE

Industry 4.0 framework:

- Interaction point of human and machine
- Interaction point of connections and the production line



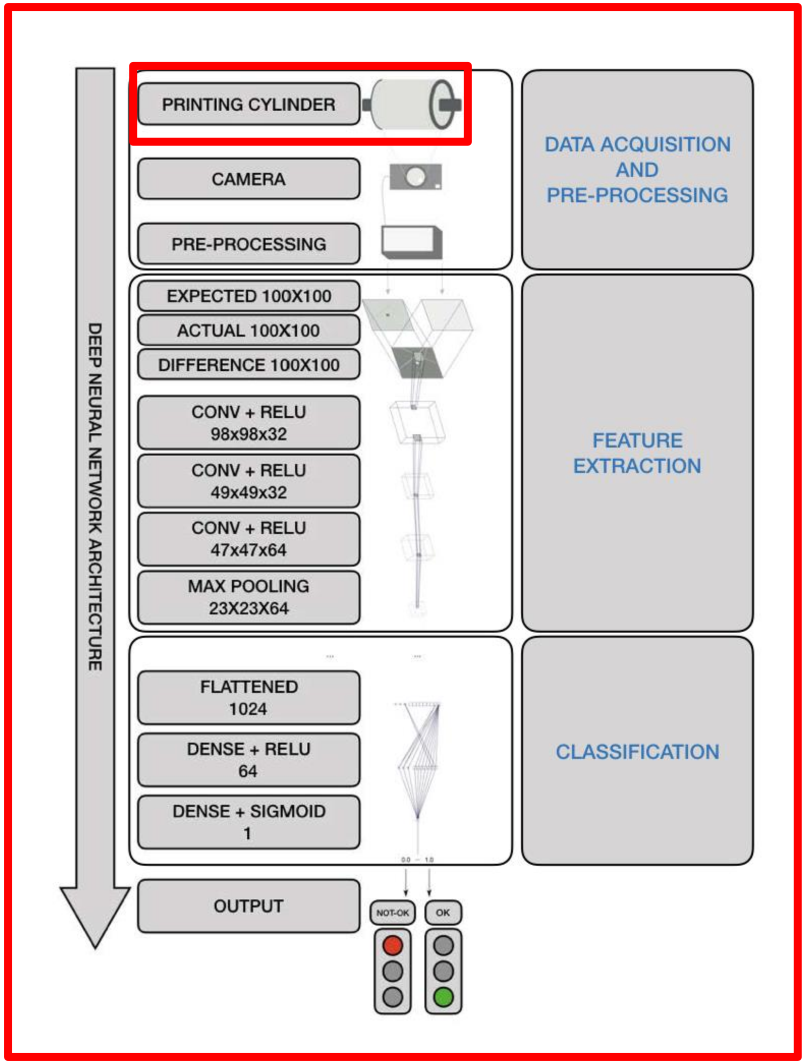
REDUCING COSTS AND ADDING VALUE

- Digitalisation steps taken by Saueressig to improve the quality control

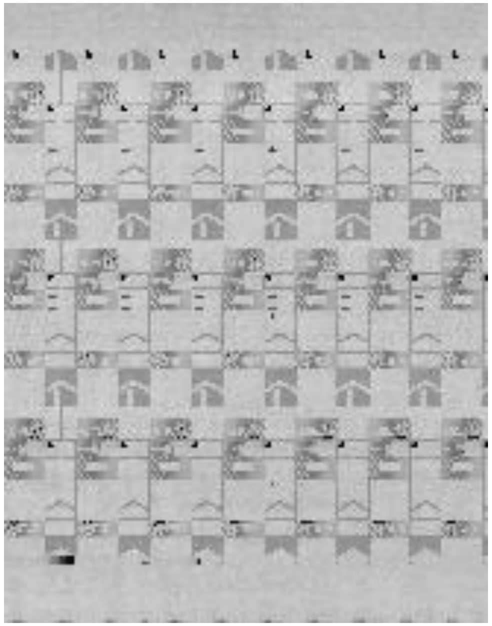
REDUCING COSTS AND ADDING VALUE

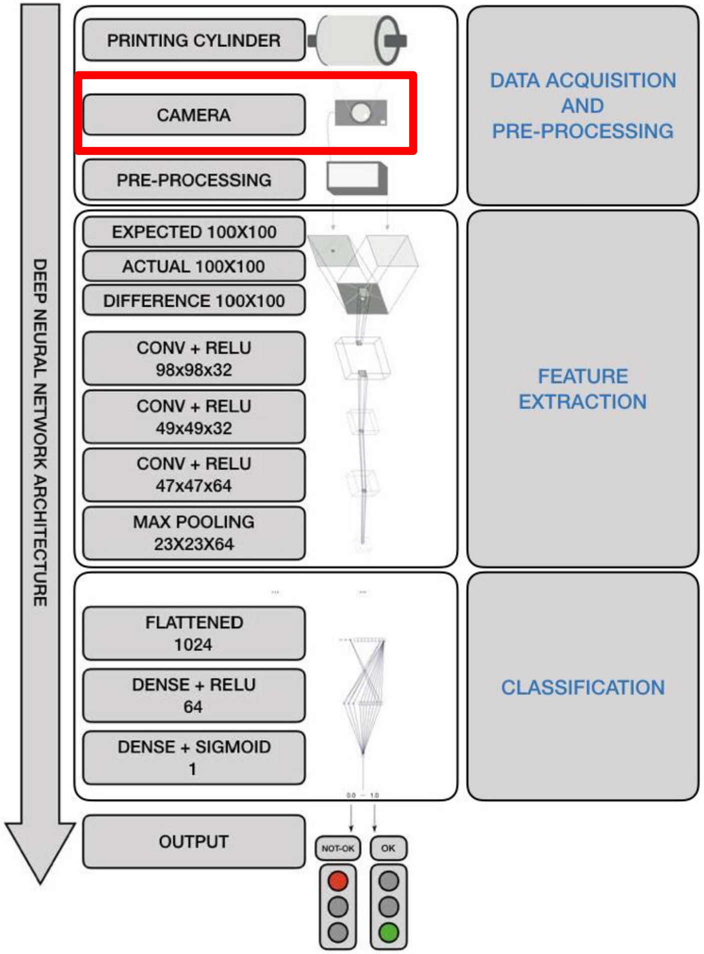
- Lead time was reduced from 6 to under 5 days
- Control time was reduced by >60%
- Capacity for quality control was doubled (previous bottleneck)
- Overall claim rate reduced to a third of the previous
- But expert knowledge was still needed to make a decision if it is a defect → Deep Learning for image classification

REDUCING COSTS AND ADDING VALUE - Results



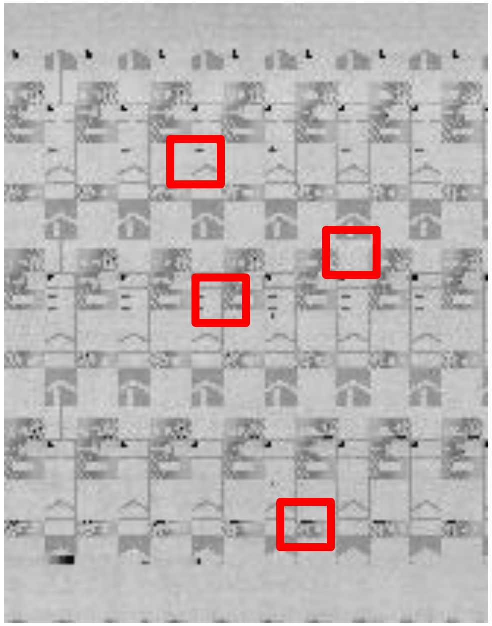
REDUCING COSTS AND ADDING VALUE - Results

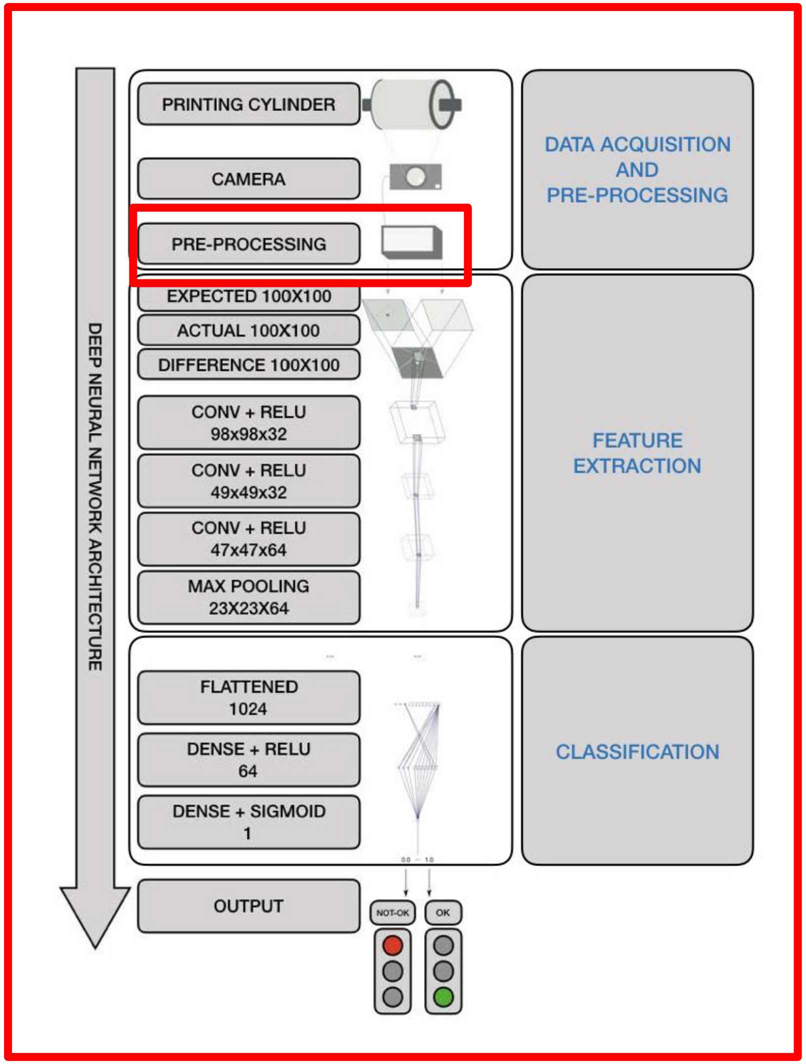




REDUCING COSTS AND ADDING VALUE - Results

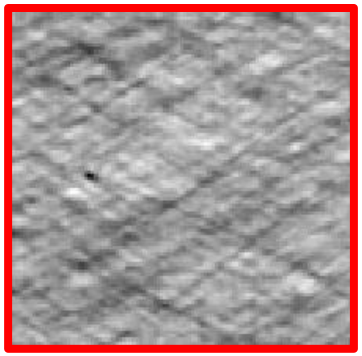
- Pre-processing is the rule-based defect-detection
- Possible defects are detected

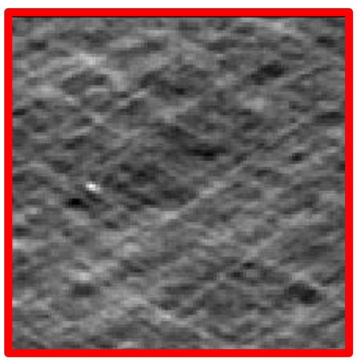


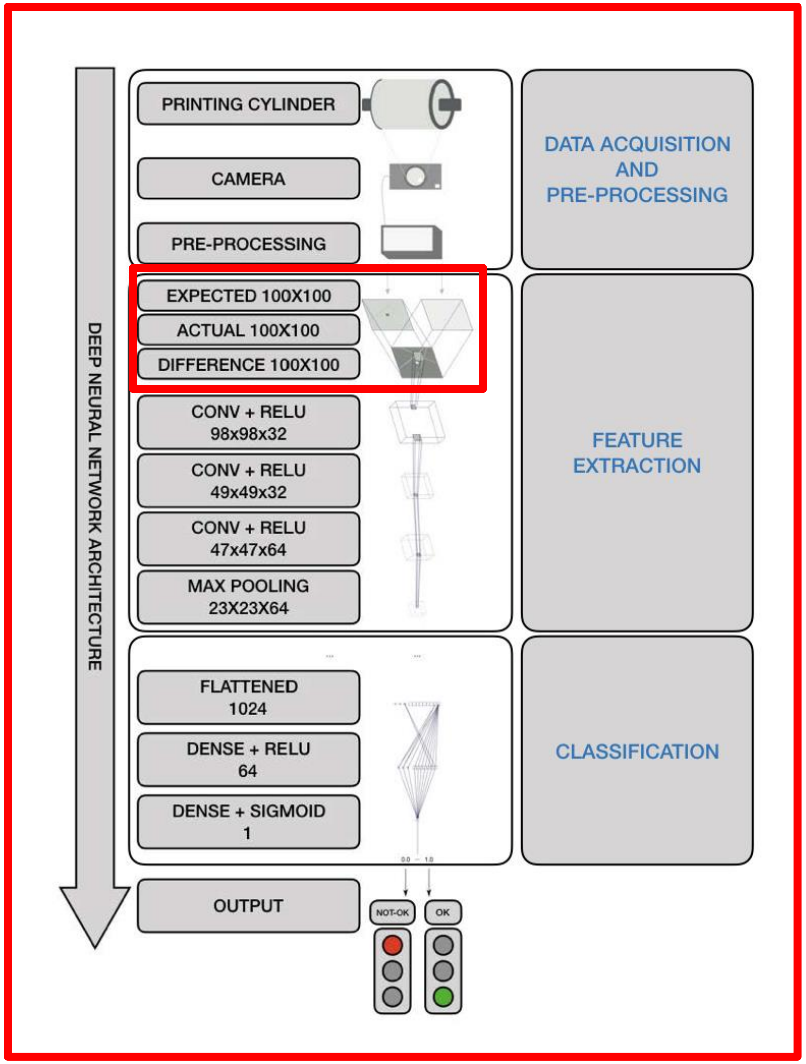


REDUCING COSTS AND ADDING VALUE - Results

- Difference is calculated for the possible defects

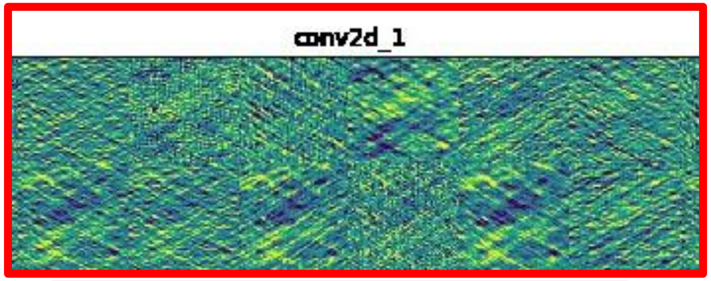


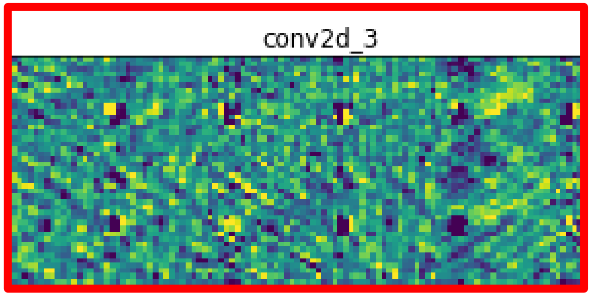


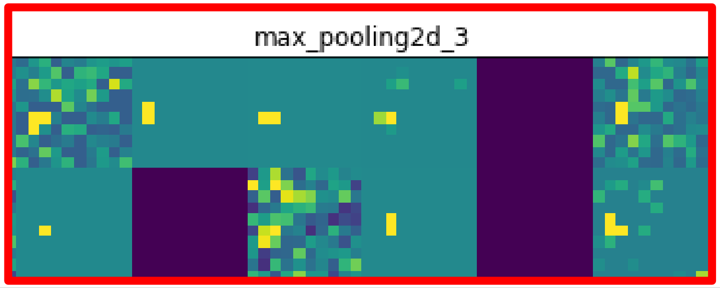


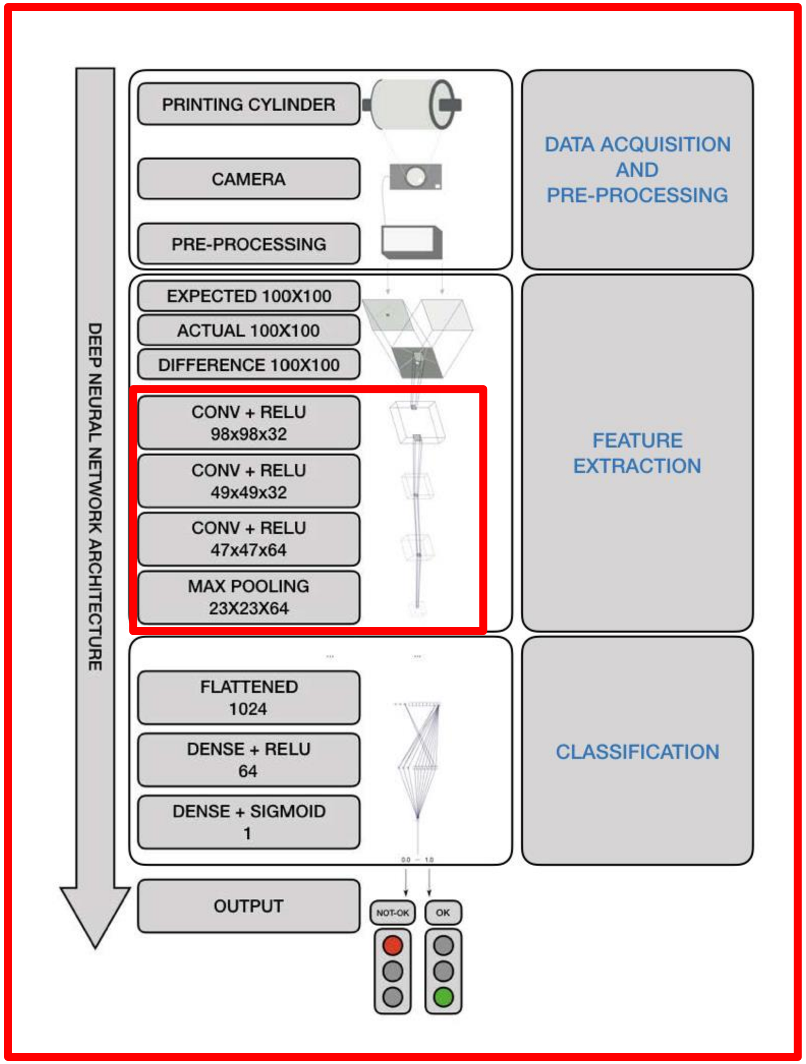
REDUCING COSTS AND ADDING VALUE - Results

- Convolution to find features
- Maxpool to concentrate on important features and reduce output



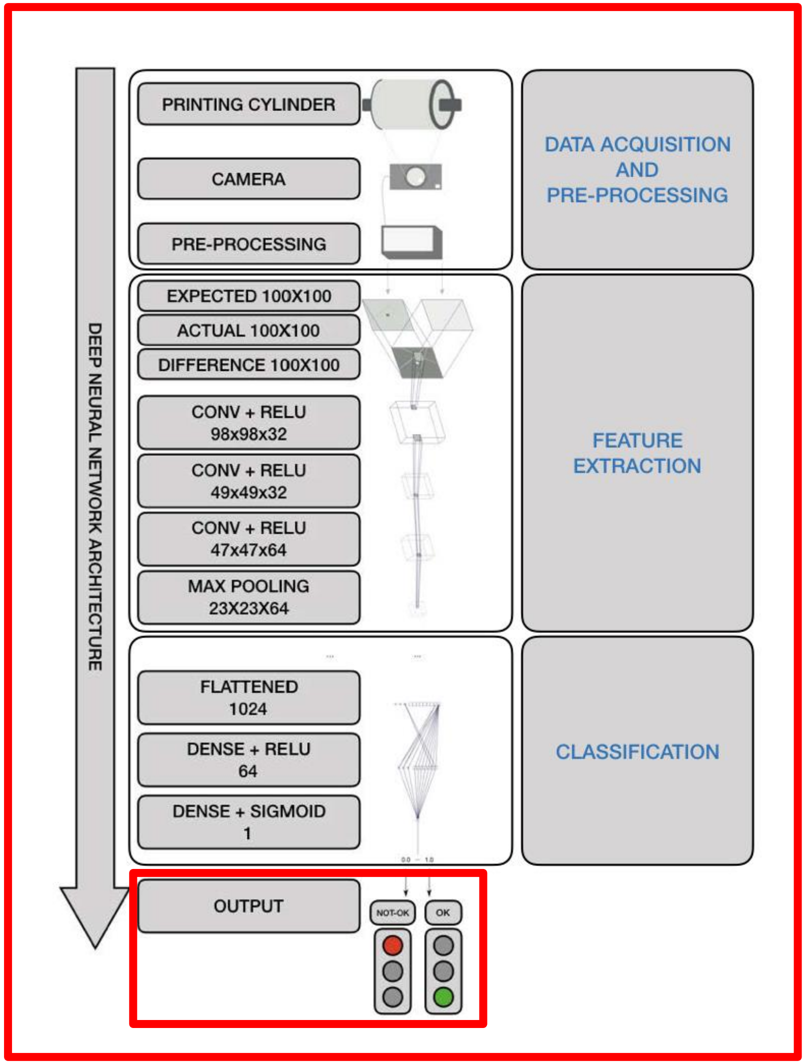






REDUCING COSTS AND ADDING VALUE - Results

- Defect probability is calculated
- 0% - 100%



REDUCING COSTS AND ADDING VALUE

- Automatic defect classification for rotogravure cylinders can be achieved with **98.4%** accuracy

- Existing data from machines could be used to find correlations with the detected defects in produced items

→ Deep Learning offers functionality to reduce costs and add value by **detecting** and **preventing** defects in manufacturing

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

Research Question 3:

How can data and algorithms be used to reduce the complexity of the customer-manufacturer interaction?

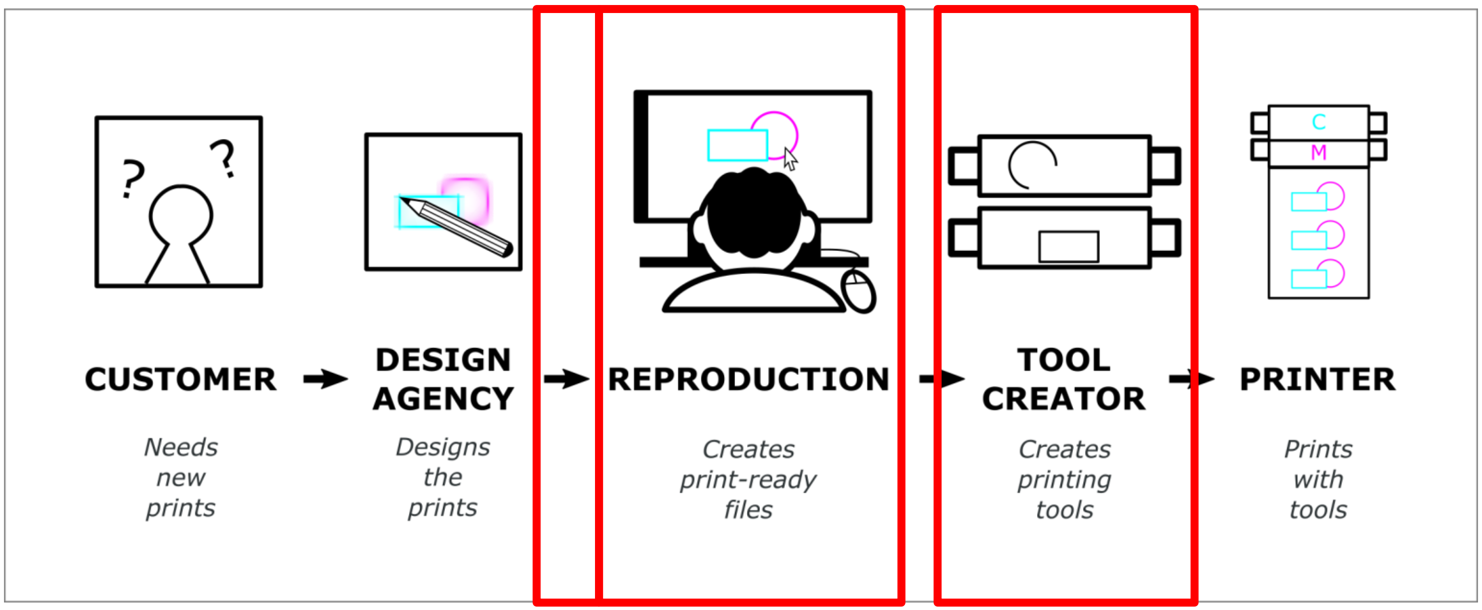
- Reducing the complexity for the customer interaction has been one of the biggest factors for success of the biggest digital companies (e.g. Amazon: Ease of finding products and getting them delivered, Google: Finding information through simple search-box)

- If this first hurdle is too high, further business is lost
→ Reducing complexity increases the usage

- Uncertainties or errors at this point can lead to massive problems in the following value-stream

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

Following work based on the example of the printing industry



Information needs to be known

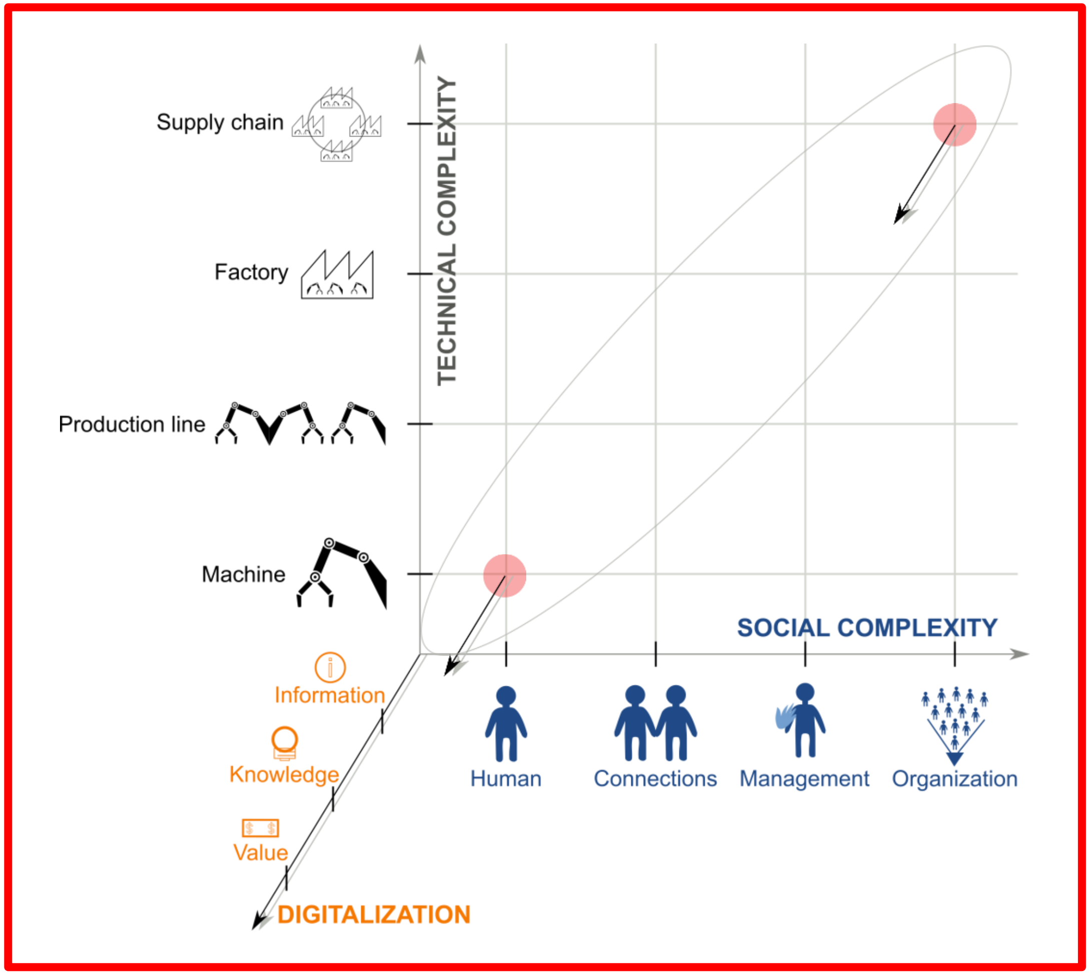
Needs to know how to prepare the image data

Needs to know the parameters to manufacture the print tools

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

Industry 4.0 framework:

- Interaction point of human and machine
- Interaction point of organization and supply chain (explanation later)



REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Current interaction is very complex
  - Necessary information exists in different files, programs, papers
  - Often just in the head of employees

→ **Time-consuming, error-prone, expensive process step**

- Algorithms and data can massively reduce the complexity of the customer-manufacturer interaction

- Data can be used to learn from previous decisions made
- Algorithms can map the technical rules (not always known by all)

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Deep Learning could be a tool to help
  - Advantages:
    - Can be quickly adapted and trained with new data
  - Disadvantages
    - Reasoning behind a result is often a black-box
    - Lots of training data necessary

- Rule-based and simpler machine learning algorithms
  - Advantages:
    - Deterministic behaviour
    - Clear rules and reasons for decisions can be communicated
  - Disadvantages:
    - Rules need to be defined first

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- PDF is delivered by customer
- This is created by a designer and needs to be adapted for printing
- This contains the image needed to be printed + further information in the image
- Already contains “separations”

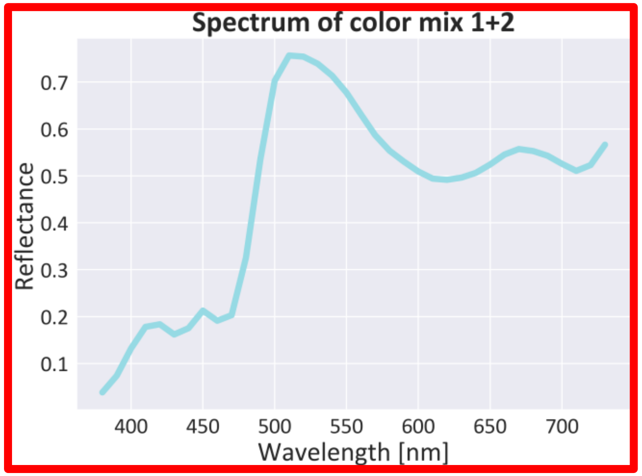
REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

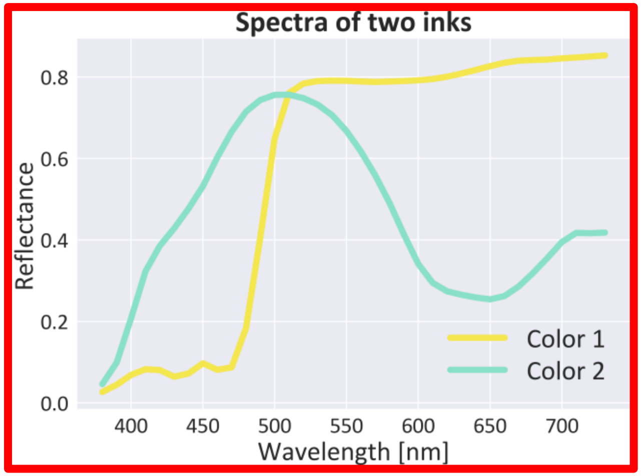
- Relevant information is calculated by rule-based algorithm, showing 88% accuracy
- User can accept the automatic selection or change it manually
- This is the basis for further calculations

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Perception of color is based on spectrum

- Similar spectrum could be created by multiple different combinations of ink





REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Specific colors can be printed with multiple combinations of colors
- If all colors of a print job can be achieved with less separations

→ Less print tools necessary

→ Reduction of complexity and costs

→ Increase of print quality

Displayed color for [45, 51, 135]

78% Cyan,
69% Magenta,
7% Yellow,
13% Black

Displayed color for [45, 51, 136]

81% Cyan,
72% Magenta,
16% Yellow

Displayed color for [44, 51, 135]

77% Cyan,
66% Magenta,
22% Black

Displayed color for [40, 57, 165]

83% Cyan,
69% Magenta

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- CMYK parts can sometimes be printed with less colors (CMY, CMK, CYK, MYK)
- A rule-based algorithm calculates the existing visual differences for using less inks
- If the difference is very low, the user can accept these changes

Original — Reduced (MYK) — Color-coded differences

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Many parts of the image are printed with multiple inks

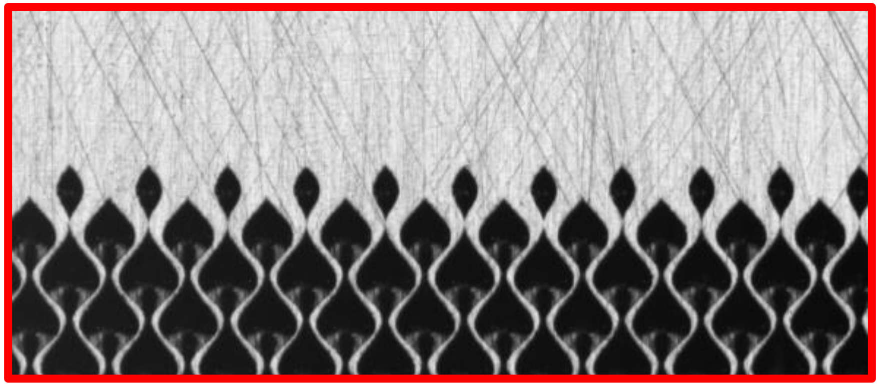
- This can lead to unwanted effects due to tolerances during printing

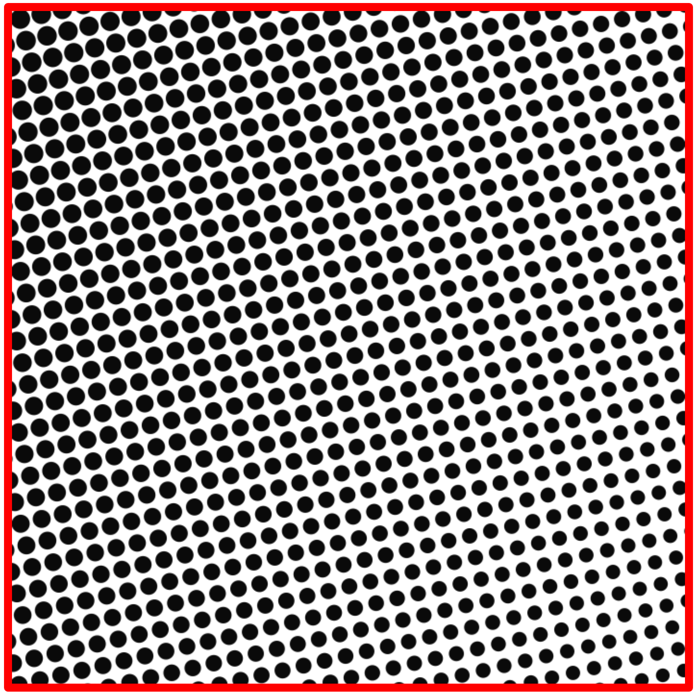
REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- To achieve better printing results, single ink printing tools can be added to the process
- This comes with a higher cost for the customer and must therefore be justified
- By implementing the thought process of the experts, the best options can now be directly displayed for the user
- The user has the final call, as he takes other factors into account, but all necessary information is made available

REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Finally, production parameters are calculated for all separations based on implemented expert rules using image processing and previous data
- Example parameters:
  - Printing order
  - Grid angle
  - Grid width
  - Best production method





REDUCING CUSTOMER-MANUFACTURER INTERACTION COMPLEXITY

- Algorithms and data play an important role in reducing the complexity of the customer-manufacturer interaction by **simplifying the decision making processes for the user**
- This decreases costs and increases quality
- Knowledge can be applied with near zero cost
- Allows new business models
  - SaaS: Offering the knowledge
  - Platform: Using the knowledge to become platform for printing jobs

THESIS CONCLUSIONS

- The focus of an Industry 4.0 integration needs to be placed more on the human side and the integration with the technical aspects

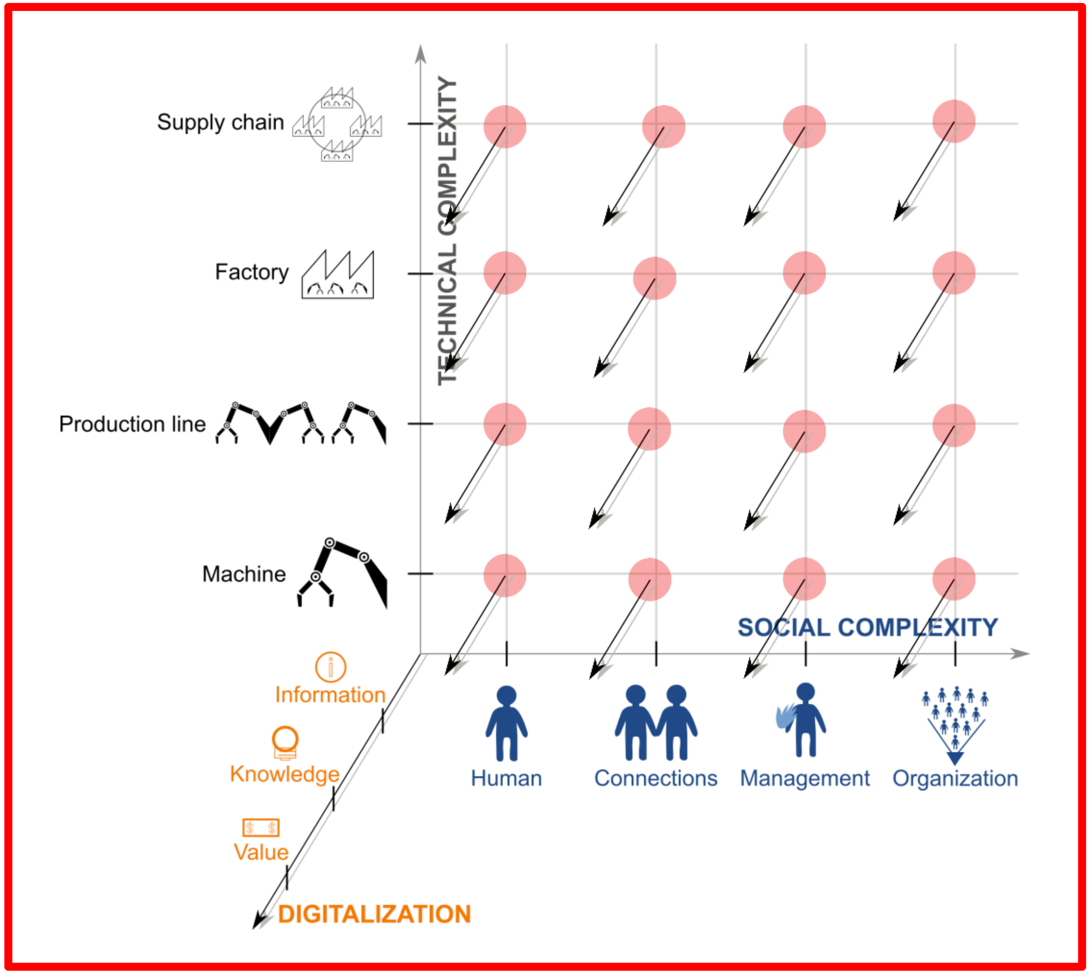
- Algorithms and data have shown to be essential tools for this challenge

FUTURE RESEARCH LINES

- Gap can't be filled with one thesis

→ Industry 5.0 as a model from the European Commission to better include social topics for Industry 4.0

- A lot more connection points outside linear growth line



FUTURE RESEARCH LINES

- Examining the effects of using EEG devices for management

- Integration of Deep Learning in manufacturing to prevent defects

- Comparison of deep-learning vs rule-based algorithms for the reduction of customer-manufacturer interaction **on the user**

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FROM DATA AND ALGORITHMS TO VALUE CREATION IN THE INDUSTRY 4.0

Doctoral Thesis Defense

Economía y Gestión de la Innovación

Author: Daniel Schmidt

Directors: Prof. Dr.-Ing. Joaquin Ordieres-Meré,
Prof. Dr.-Ing. Dr.-Ing. habil. Javier Villalba-Diez

13.05.2022