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Learning and Reasoning Approaches in Logistics

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This Talk

- An input from the industry side
- The problem that we are trying to tackle
- Magazino proposed solution
- Examples of how we use reasoning and machine learning in our products

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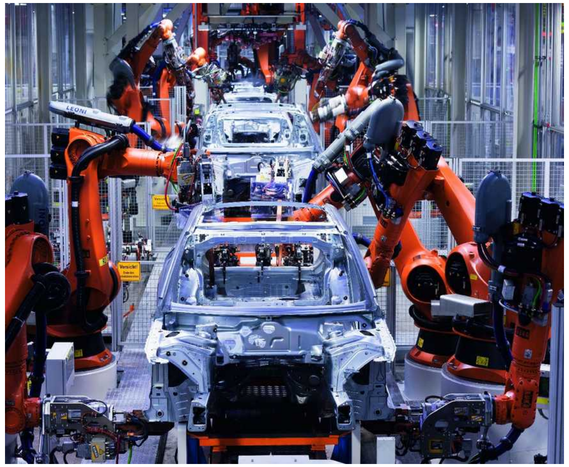
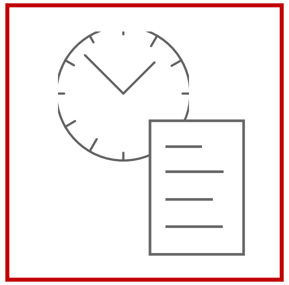
Problems in the fulfillment sector

Uncertainties set limits for automation

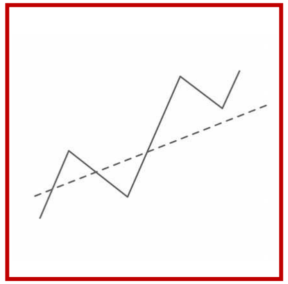


Highly automated and fast production at Audi today

Almost completely manual intralogistics in the same factory today



Short contract periods



Handling order peaks

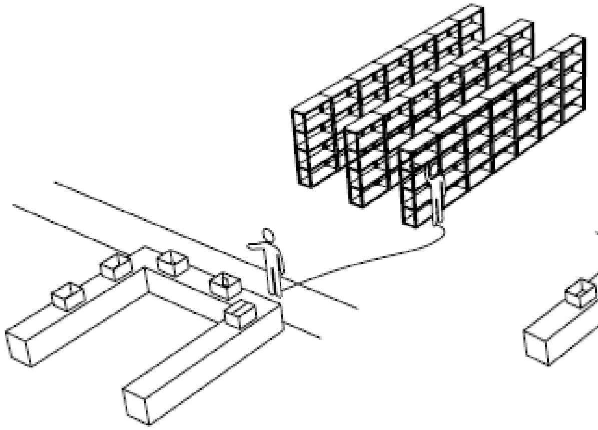
Unergonomic tasks

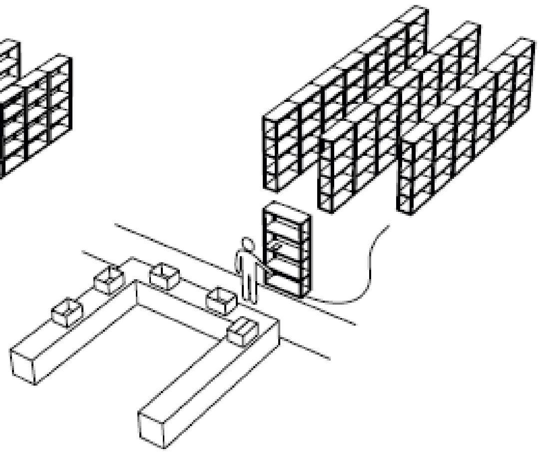
Lack of qualified personnel

Problems in today’s logistic-concepts

None of the currently established concepts meet the requirements for flexible, cost-efficient and scalable intralogistics automation

Currently: two conventional warehouse systems

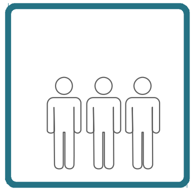




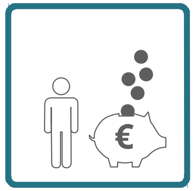
man-to-goods
A worker commissions a product directly at a storage location mostly without automated aiding systems

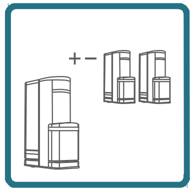
goods-to-man
Containers (e.g. pallets, boxes, entire shelves) are sent to
an employee, who then retrieves the required article

Problems of current intra-logistics concepts:

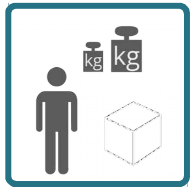

High Dependence on staff

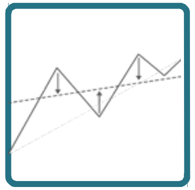

High labor and process costs

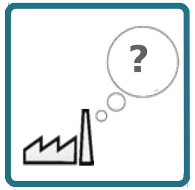

Missing flexibility


Missing scalability


High initial investment


Non-ergonomic work conditions


Long driving cycles lead to high inventory stock



Low transparency of material flows

A new kind of robotics is on the rise

A huge step compared to traditional robotics

+ High precision & performance
- Repetitive , predefined jobs
- Deterministic tasks

Camera- and sensor-based

Behavior adaption and decisions at runtime

Learning with artificial intelligence

Cloud-based

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What is Magazino?

Flexible, mobile picking robots for warehouses

Start-Up in the center of Munich

In live operation at several customer sites

Flexible robot solutions for intra-logistics

AI & robotics team
>
100 employees

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TORU Pick-by-Robot

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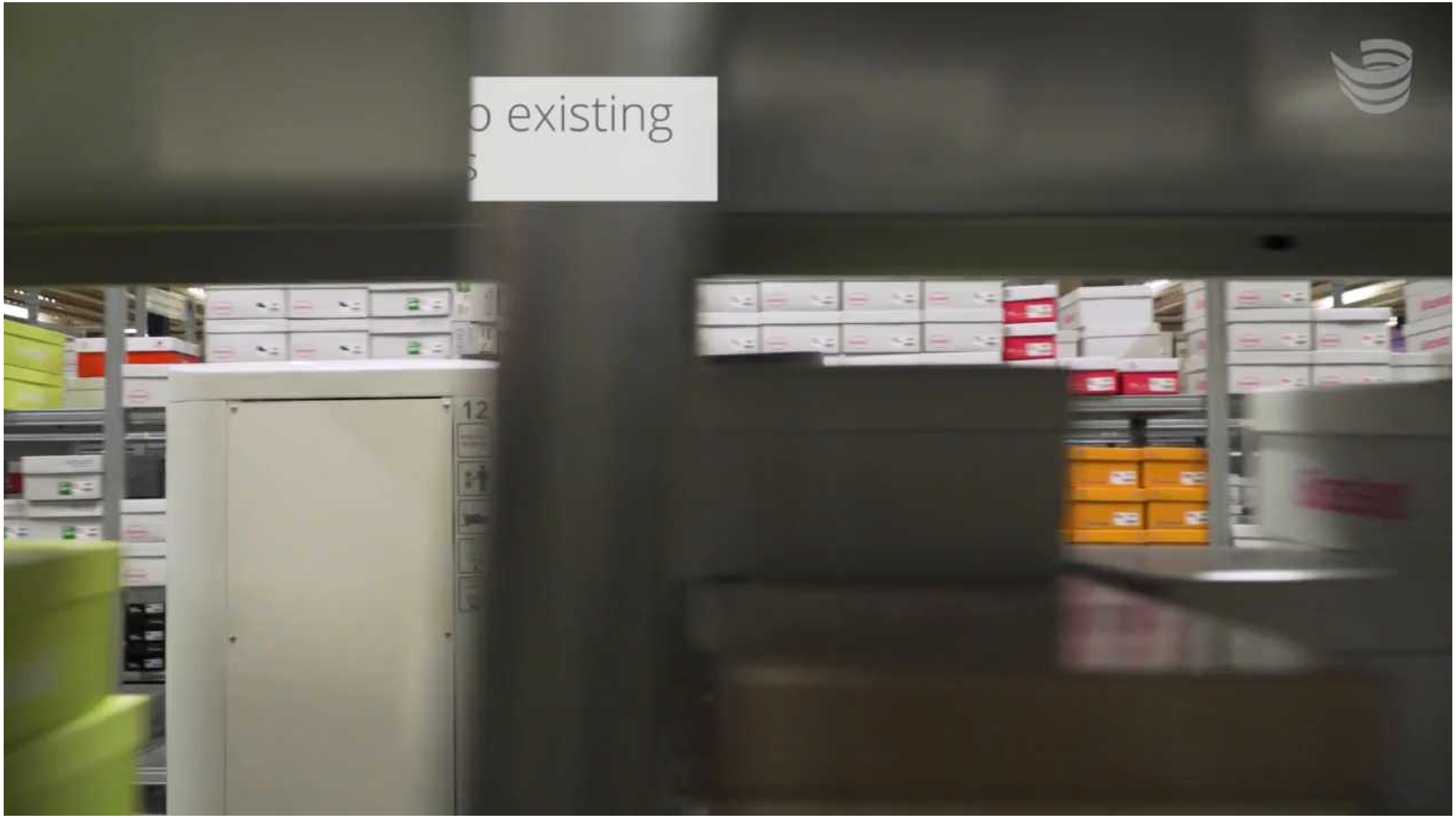
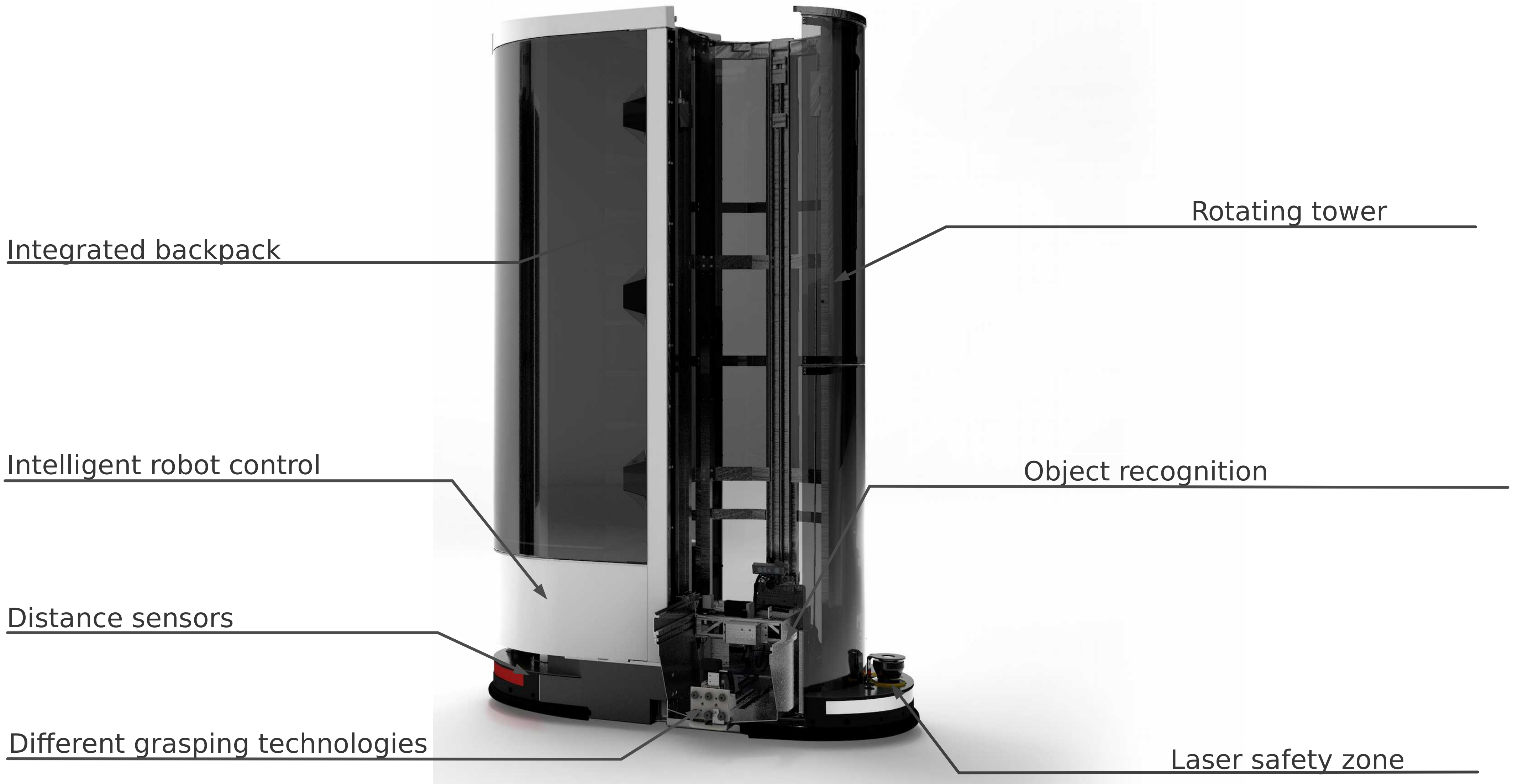


TORU

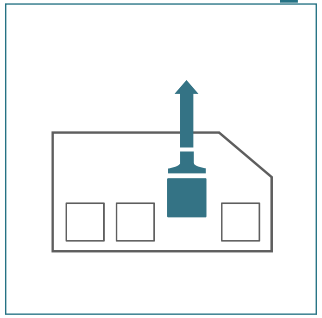
The robot for the E-commerce sector



Advantages of TORU

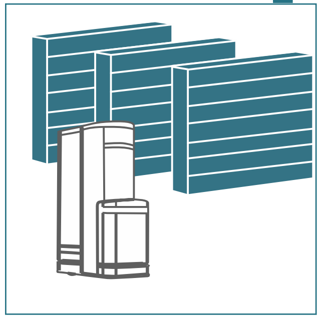
Flexible automation to save pick-costs

1



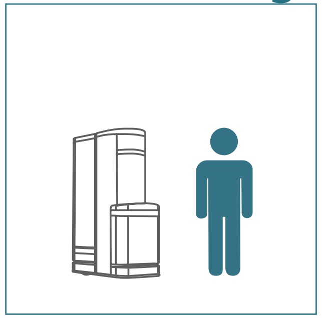
Item-specific handling

2



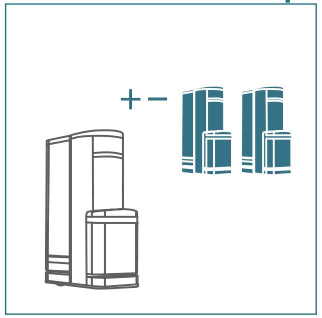
Integration into existing warehouse

3



Working parallel to humans

4



Flexibility

5

Reduced labor- and process-costs

6

New logistics concepts possible

Robots can benefit from all kinds of AI methods

Symbolic AI helps with planning, coordination and reasoning

Machine learning solves (self-) supervised and reinforcement learning problems

Model-based Software Architecture

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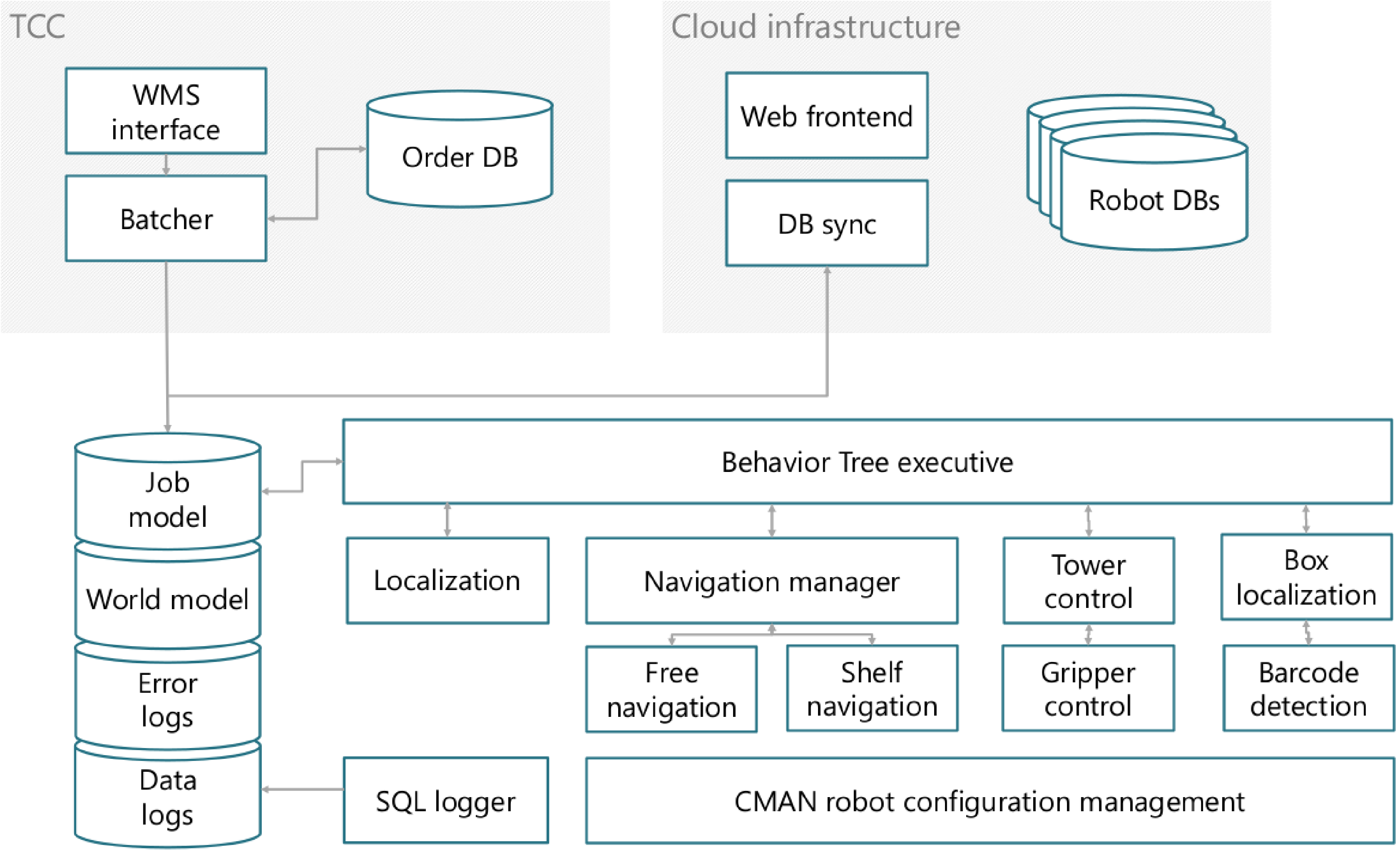
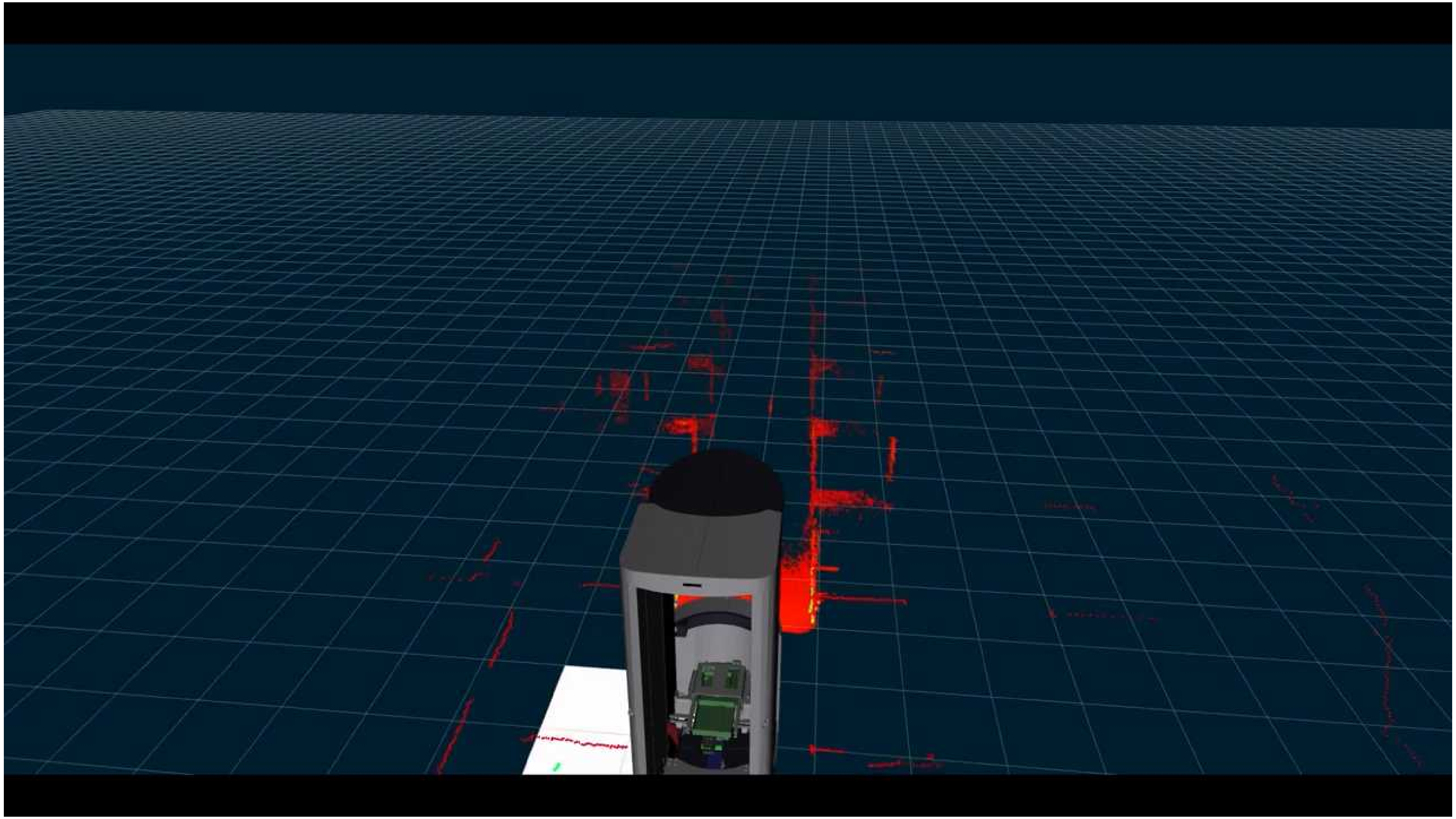


Strongly model-based architecture:

- Environment model
- Order representation
- Behavior model
- Robot configuration management

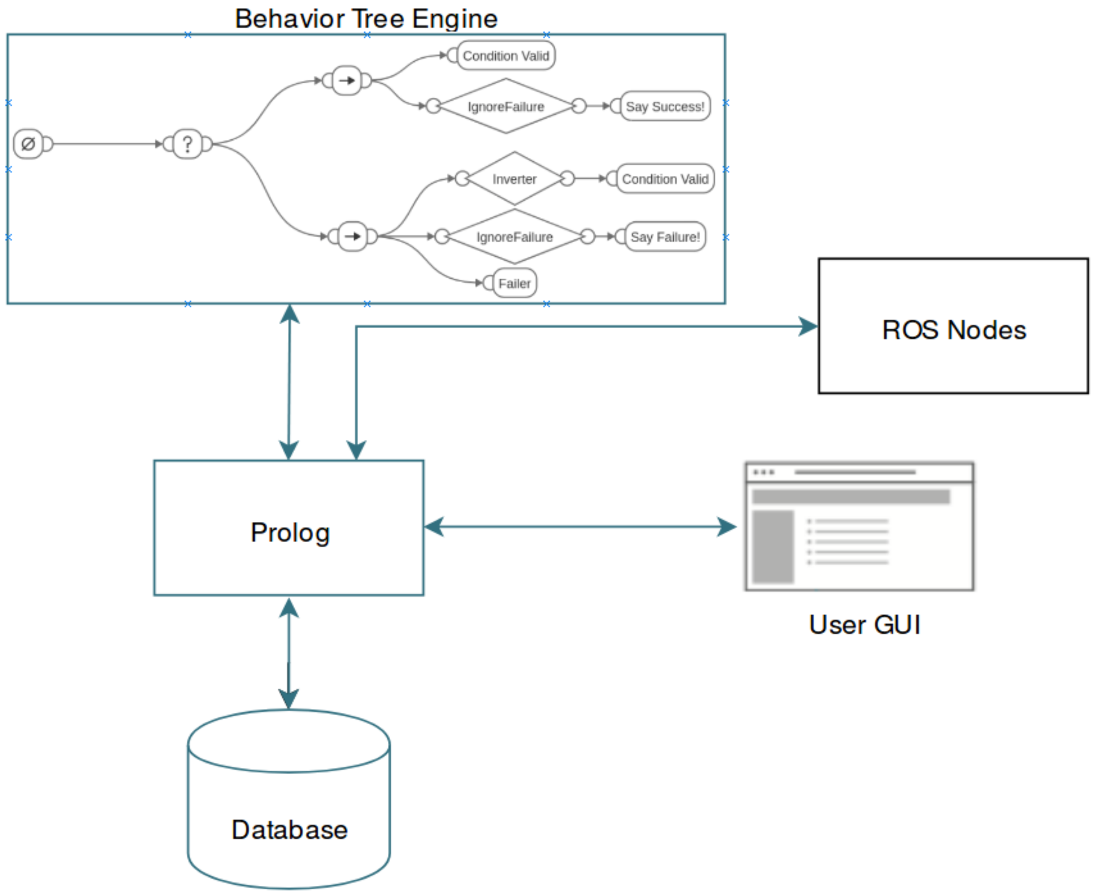
So far manually created models that can serve as starting point for integrating Machine Learning techniques

The world as seen by TORU



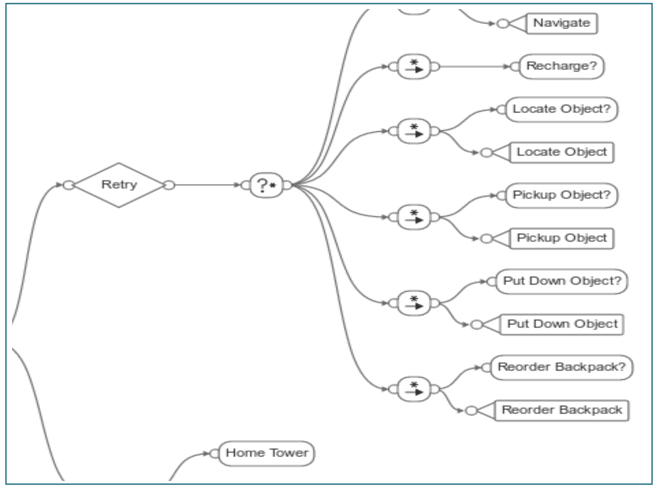
Reasoning as part of task execution

Extending the data representation with logical inference methods



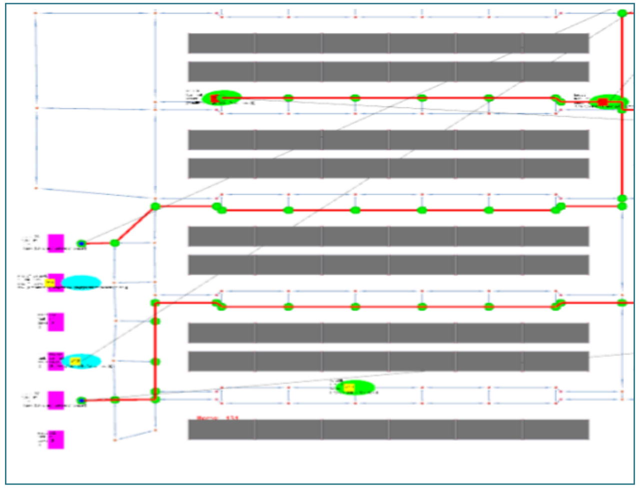
- Environment-, object-, robot-, task- and execution-related information is stored in a structured database
- A logical inference layer on top allows advanced queries on this data, e.g.
  - Spatial reasoning on warehouse model representation
  - Capability reasoning in case of hardware errors
  - Diagnostic reasoning for classifying errors and suggesting solutions

Some AI projects at Magazino



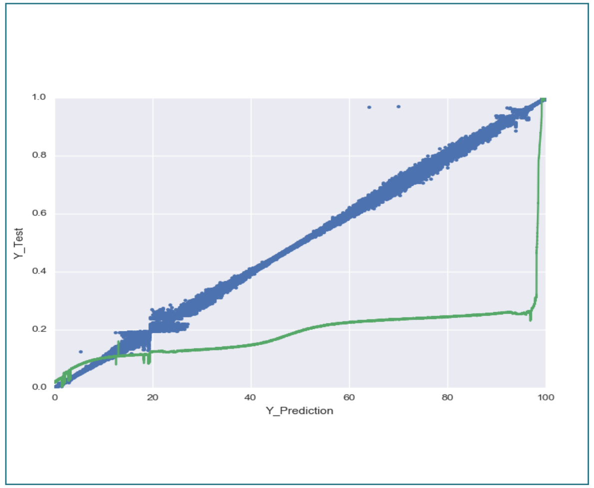
Behavior Tree as abstract execution model

- A good model of the robot‘s behavior helps to manage the complexity in real-world manipulation tasks
- Behavior trees as execution model allow for easy creation, modification, visualization, execution, introspection and debugging



Learned cost models for multi-robot task allocation

- The decision which robots perform which picks in which order has huge impact on the overall performance
- Learning models in a data-driven approach can increase cost prediction accuracy by up to 96%



Learned models for estimating the battery state

- Battery discharge profiles are nonlinear, so a prediction of the remaining charge is difficult
- Better predictions of the remaining charge improve operation time and reduce the risk of empty batteries

Magazino current focus is on reliability

A non-reliable robot means a non-viable product

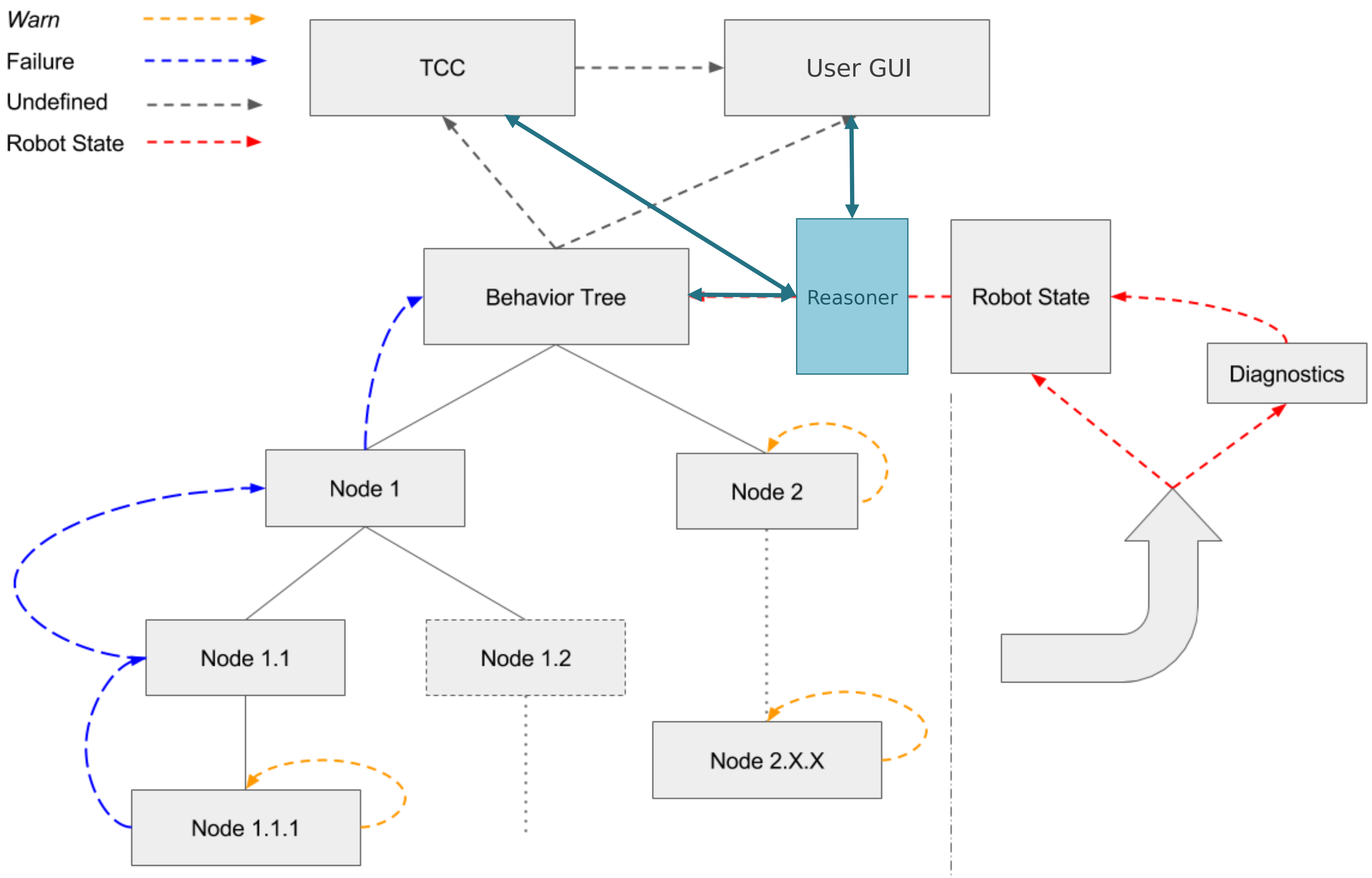
What can go wrong?

Our robots have to carry item i from a to b

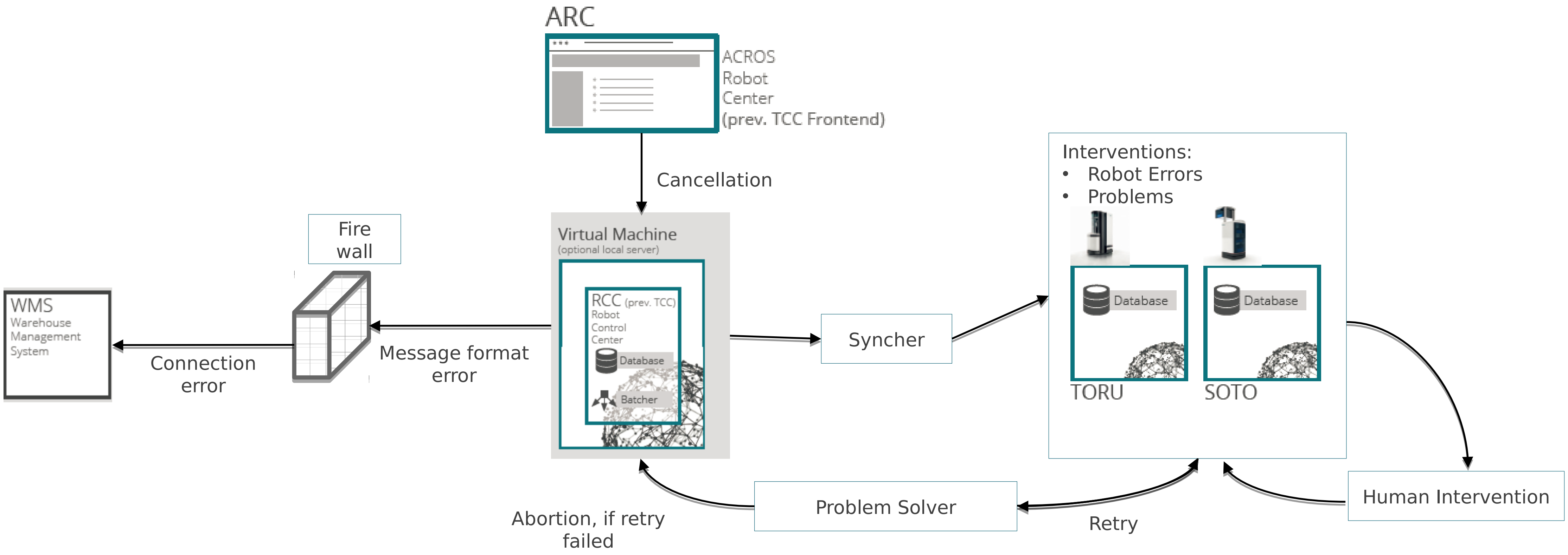
- Robot related exceptions:
  - Errors that can be monitored over time (e.g, motor not responding)
  - Events that happen at a given point in time (e.g., robot bumped into a shelf)
- Process related exceptions:
  - Fleet manager related (e.g., a shelf cannot be temporarily reached)
  - Warehouse Management System related (e.g., a box is not where it should be)

Robot Related Exceptions

What has happened, what can the robot still do, and who should be informed?



Process Related Exceptions



If you can’t measure it, you can’t improve it

Improving robustness of an autonomous system
requires a deep understanding of its inner workings

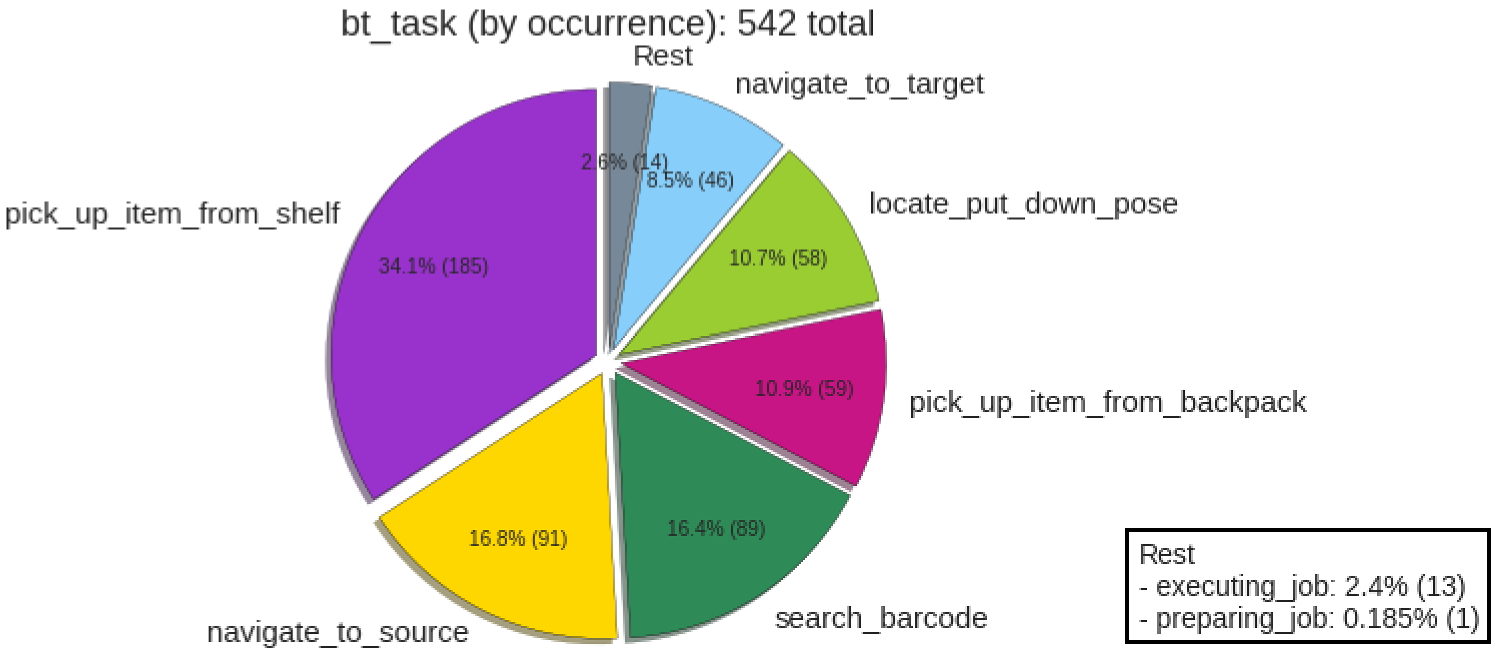
Live introspection and statistics generation

Performance monitoring & developer support for deciding what to improve first

Modeling Exceptions Allows Deep Introspection

Introspection Enables Data Driven Development

- We aggregate data about robot actions
- Post analysis allows to understand the most frequent problematic actions
- Understanding the problems of the system allows for steering development



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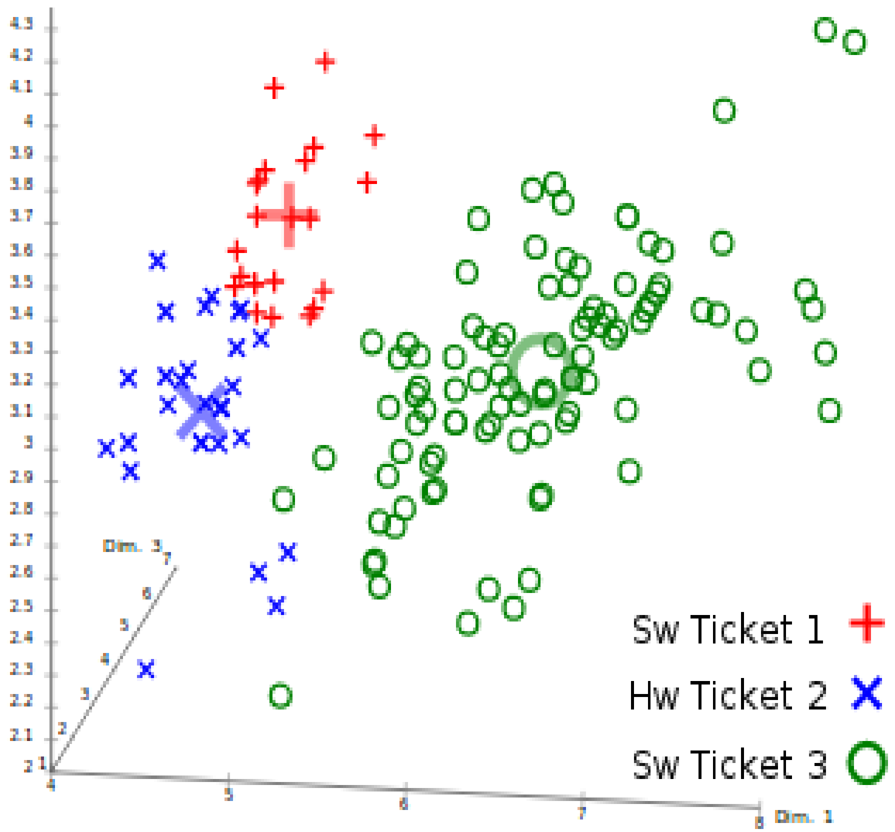
From Data to Concrete Problems

Clustering exceptions for quicker analysis



- Analysing exceptions manually is tedious and time consuming
- Hard to estimate which exception has more impact on robustness
- Given the data, exception analysis is translated into a clustering problem were labels are actionable tickets
- More points, more frequent, more impact on robustness

Gathered data can be used to solve problems

How solutions can be found via self-supervised machine learning

Tackling one of the most common problems

Tackling one of the most common problems

What data do we have?

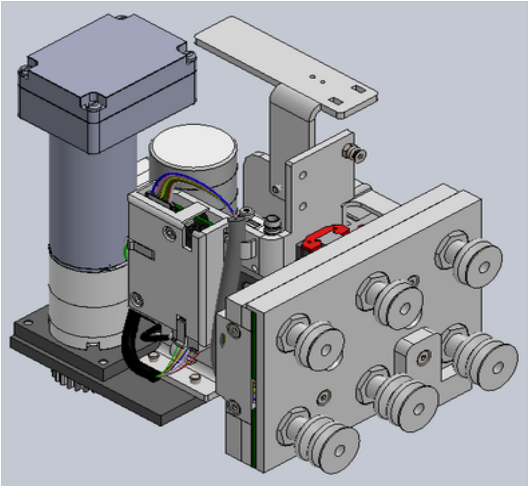
+

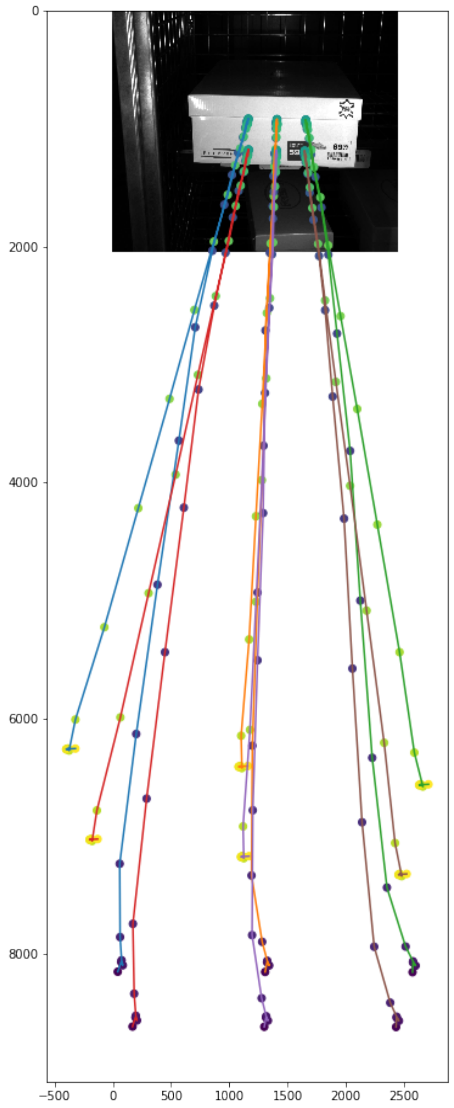
- Manipulation data:
  - Position of boxes
  - Position of robot
  - Grasping successful or not
  - Robot geometry
  - Pump state
  - Valve state
  - Pressure sensor readings
  - …

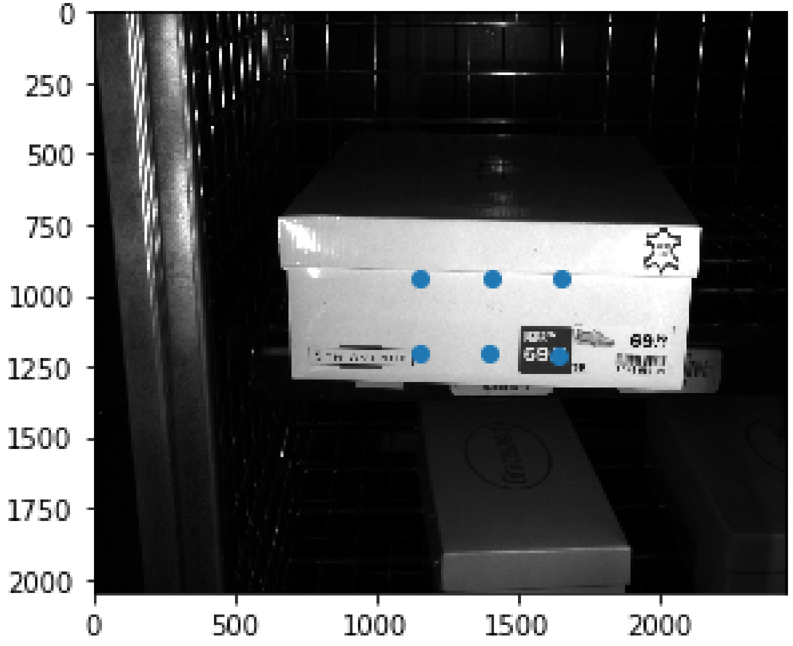
Deep Learning for Robust Grasping

Combining:
- Images
- Robot poses
- Object poses
- Gripper geometry

For every attempted grasp we extract the contacts points between the vacuum cups and the boxes



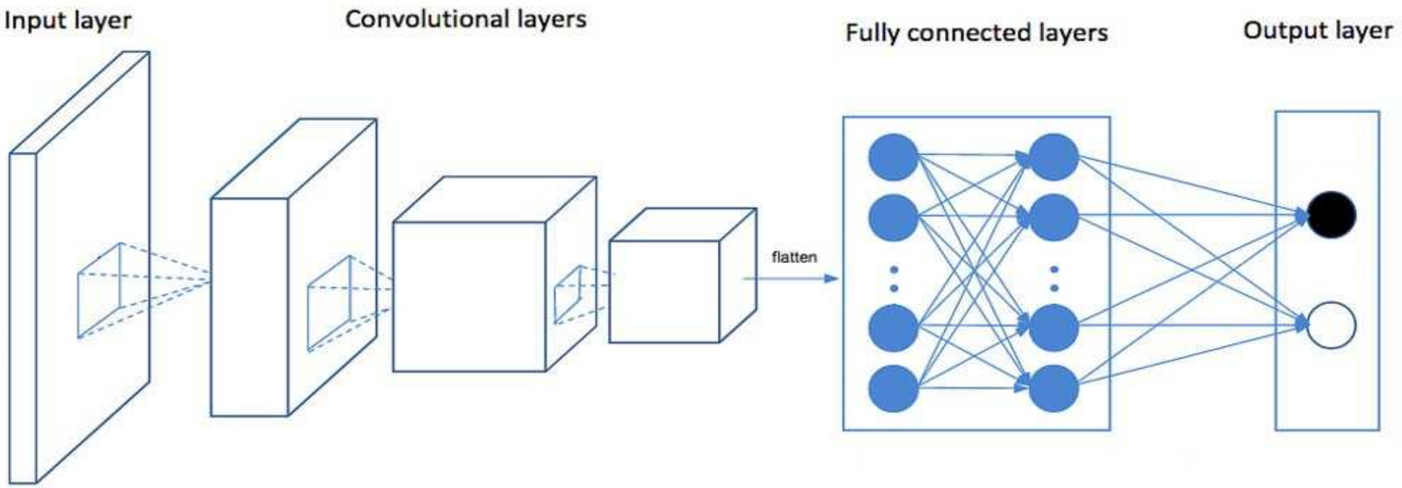


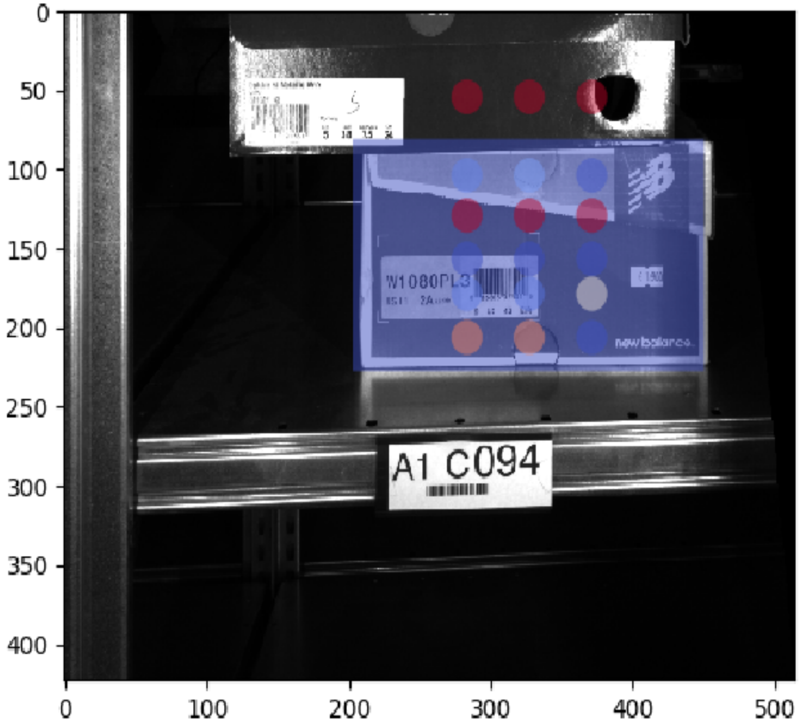


Building a Grasping Probability Model

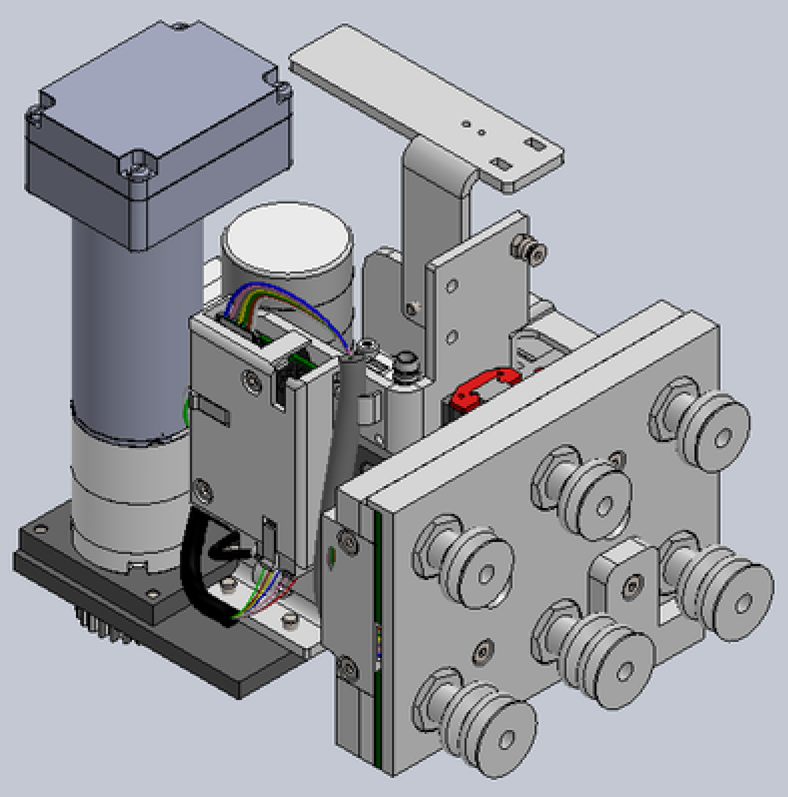
Combining the grasping points information and the history of the past grasped boxes we trained a CNN.

The CNN is able to give a probability of building vacuum for every contact point of a given box





Combining Expert Knowledge with the Model



```
def grasp_probability_from_suction_probabilities(probabilities):
    knowledge = "\n".join([str(float(p))+"::"+l+"."
                           for p, l in zip(probabilities, short_link_names)])
    model = """
            both_center :- tc, bc.
            outer_top :- tl,tr.
            outer_bottom :- bl,br.
            diagonal :- tl,br; tr,bl.
            left :- tl,tc; bl,bc; bl,tc; bc,tl.
            right :- tr,tc; br,bc; br,tc; bc,tr.
            success :- both_center; outer_top; outer_bottom; diagonal;left;right.
            """
    query = "query(success)."
    command = knowledge + model + query
    result = get_evaluatable().create_from(PrologString(command)).evaluate()
    return result.values()[0]
```

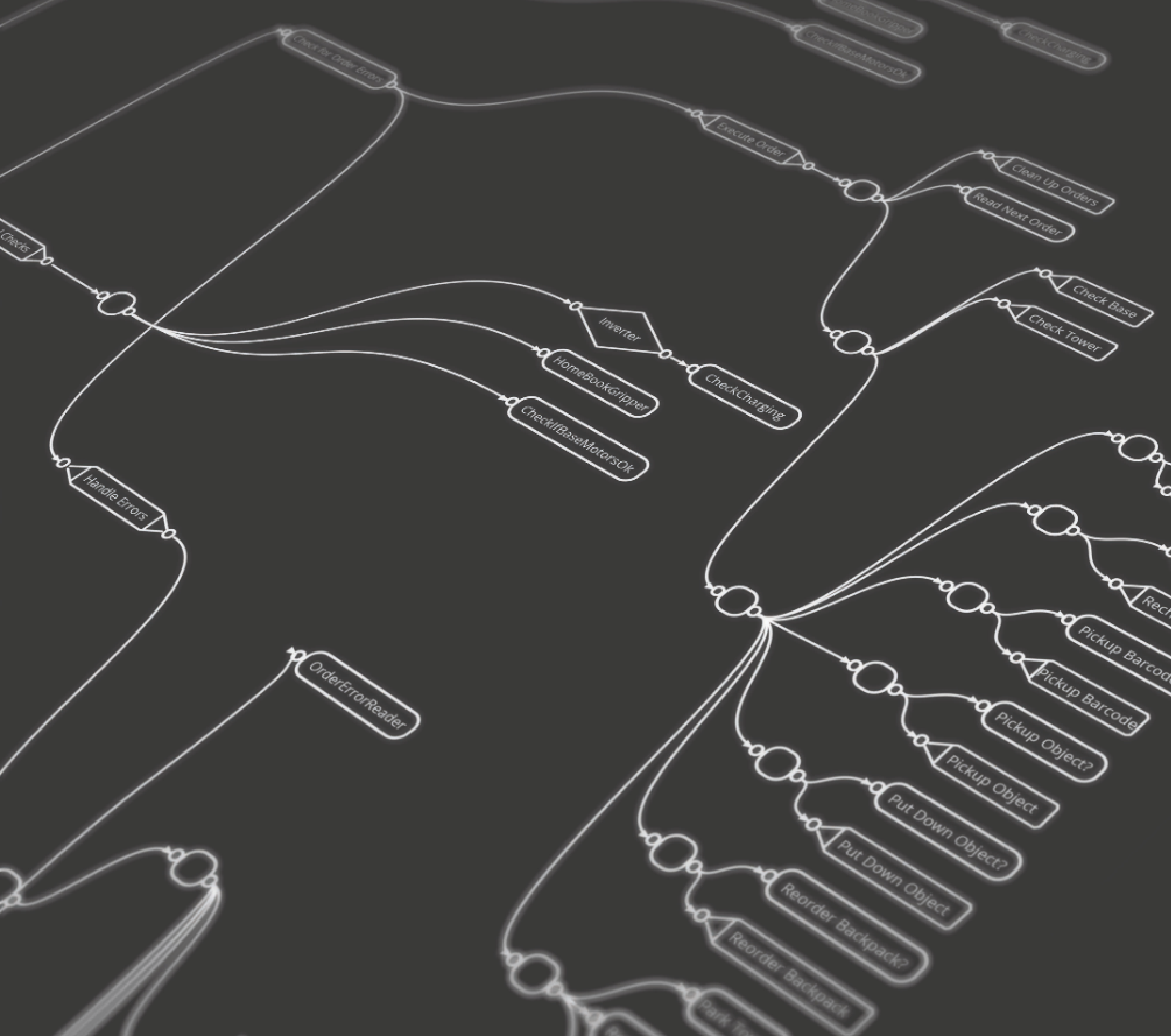
For every new grasping attempt we choose the best scoring choice for grasping using Problog[1]

[1]D. Fierens, G. Van den Broeck, et al. **Inference and learning in probabilistic logic programs using weighted Boolean formulas**. Theory and Practice of Logic Programming, 15:3, pp. 358 - 401, Cambridge University Press, 2015.

Current Grasping Status

Take Home Messages

- Logistic robots operating alongside humans require strong perceptual and decision-making abilities to perform their tasks robustly
- A non-reliable robot means a non-viable product, reliability and robustness is the main requirement
- A proper modeling of the robot state and possible exceptions allow for in depth understanding of robotic systems
- Learning allows to leverage knowledge acquired during operation to improve robot robustness



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What we believe in

… is that the robots of the future need a brain!

What we do

- Magazino builds this brain
- We need a simple but complex enough industry which is scalable as a use-case
- Logistics is the best industry to start with building the robots brain

… and we are hiring!

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