ML: A practical overview

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Independent Project Portfolio

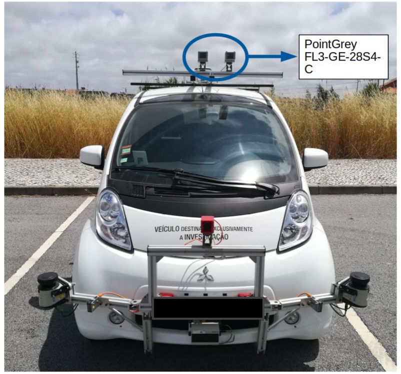
These slides overview my experience in:

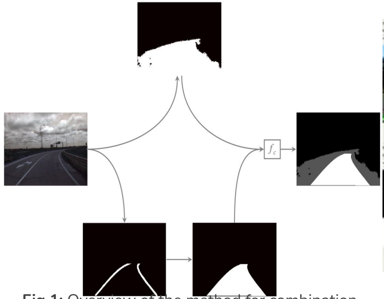
- Perception for **autonomous vehicles** and **mobile robots**
- Working with **sensors** and **electronics**
- Developing classical **computer vision** and **deep learning** algorithms
- **Large scale datasets**

Every described task that follows was or has been developed by myself.

Computer Vision (CV) - 2019

- **First interaction with AI/ML**
- **Autonomous driving**: road lane line detection onboard an autonomous vehicle[1]
    - Multi-algorithm: **classic CV** and/or multiple **deep learning** methods for **semantic segmentation**
    - **Late fusion combination**: the final road representation is a confidence map. It is based on a weighted sum of the multiple segmented areas produced by the methods used for road areas segmentation
    - In Fig. 1, one method is doing road segmentation (top) and the other is doing road lane lines segmentation (bottom). The bottom method's output is converted into a polygon, which is then combined via a weighted sum with the top method's output.





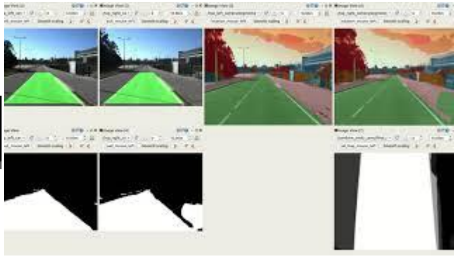
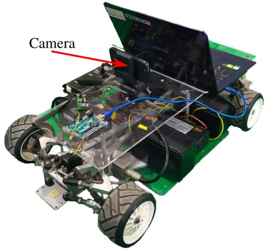


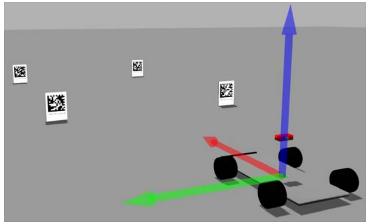
Fig.1: Overview of the method for combination of multiple road areas segmentation

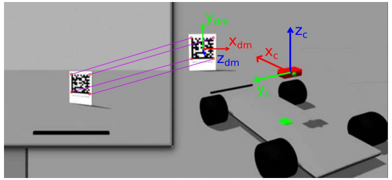
[1] **Tiago Almeida**, Bernardo Lourenço, Vitor Santos, Road detection based on simultaneous deep learning approaches, Robotics and Autonomous Systems, Volume 133, 2020, 103605, ISSN 0921-8890, https://doi.org/10.1016/j.robot.2020.103605.

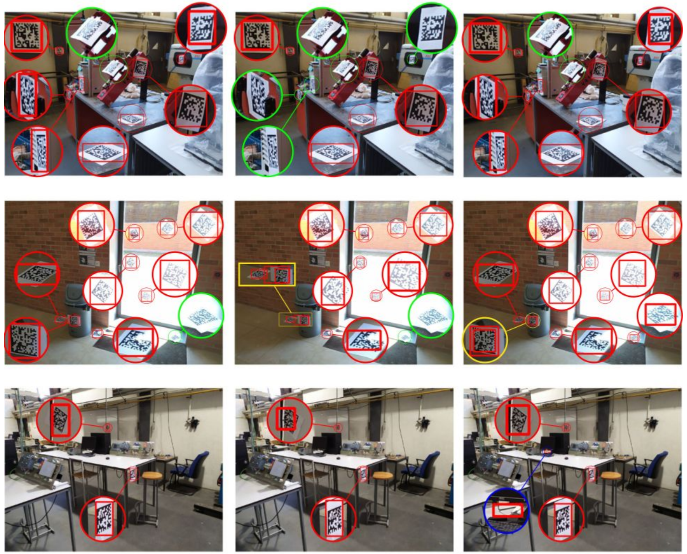
Robotics & CV - 2020

- Research University of Aveiro, Portugal
- Low-cost mobile robot capable of **self-localization** by **detecting** and **decoding landmarks**[2]
    - Dataset collection and labelling
    - Comparative analysis of **deep learning methods for *Data Matrix* detection:** Faster R-CNN, Single Shot Detection (SSD), YOLOv4 with various configurations and data augmentation









red: true positives; **green:** false negatives; **blue:** false positives, **yellow:** ineffective NMS

[2] **Almeida, T.**, Santos, V., Mozos, O.M. et al. Comparative Analysis of Deep Neural Networks for the Detection and Decoding of Data Matrix Landmarks in Cluttered Indoor Environments. J Intell Robot Syst 103, 13 (2021).

CV - 2020

- **Autonomous driving:** road objects detection
  - Edge computing: Nvidia AGX Xavier deployment via Deepstream
  - Training on large scale datasets: BDD100K, Cityscapes, etc.
  - State-of-the-art **deep learning models implementation for object detection**: Faster RCNN, Single Shot Detection (SSD), YOLO

YOLO-v4

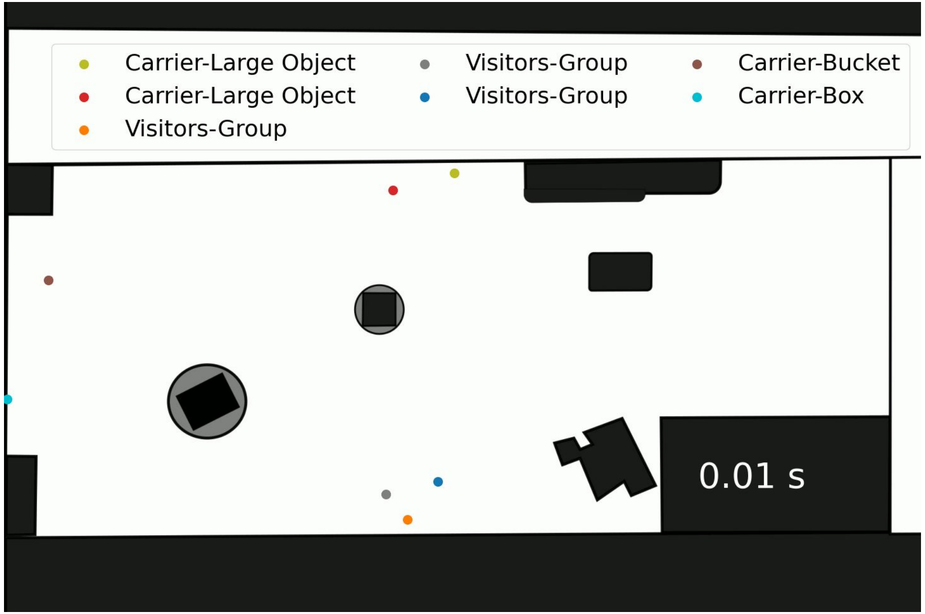
SSD

Faster R-CNN

Code: [deepstream applications] https://github.com/tmralmeida/deepstream-app
[deep learning models] https://github.com/tmralmeida/bag-of-models

Deep learning for human motion prediction - PhD

- Human trajectory clustering
  - Designed Self-Conditioned GAN[1]
  - Time-series k-means and k-means
- Dataset acquisition
  - **Motion capture system for tracking**
  - Experiments design
    - Human-Human Interaction: social interactions and group formation
    - Human-Object Interaction: how ongoing industrial tasks influence human motion
    - Human-Robot Interaction
- [Multimodal Dataset Visualization](): powered by streamlit

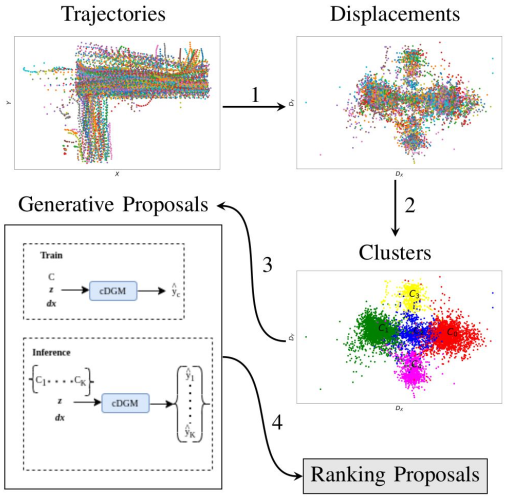


[3] **T. Rodrigues de Almeida**, E. Gutierrez Maestro and O. Martinez Mozos, "Context-free Self-Conditioned GAN for Trajectory Forecasting," 2022 21st IEEE International Conference on Machine Learning and Applications (ICMLA), Nassau, Bahamas, 2022, pp. 1218-1223, doi: 10.1109/ICMLA55696.2022.00196.

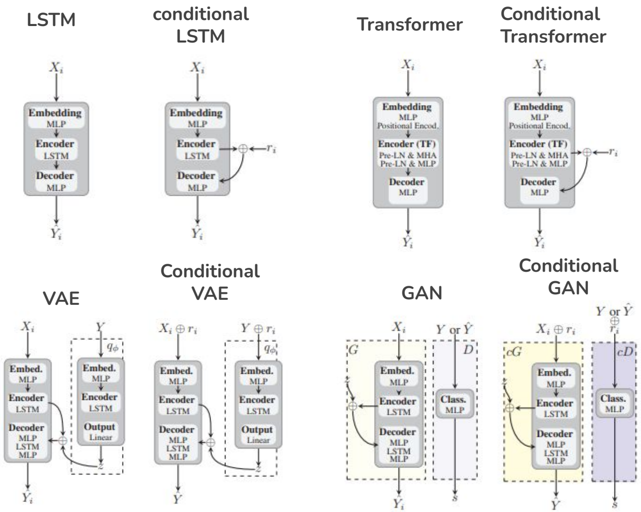
[4] Schreiter T, Rodrigues de Almeida T, Zhu Y, et al. THÖR-MAGNI: A large-scale indoor motion capture recording of human movement and robot interaction. The International Journal of Robotics Research. 2024;0(0). doi:10.1177/02783649241274794

Deep learning for human motion prediction - PhD

Human motion trajectory prediction conditioned on clusters[5]



Human motion trajectory prediction conditioned on ongoing activities[6]

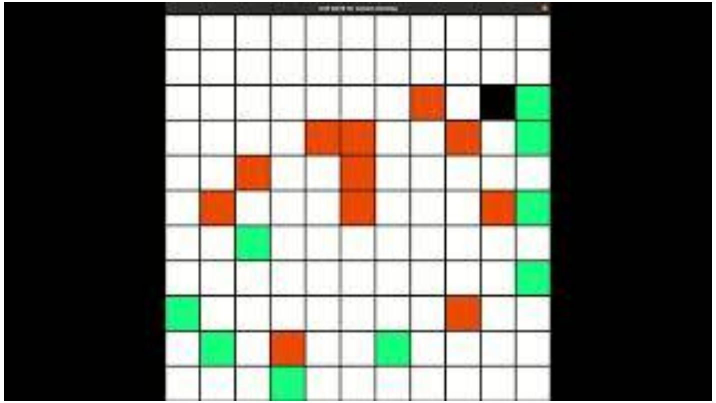


[5] **T. Rodrigues de Almeida**, Oscar Martinez Mozos, Likely, Light, and Accurate Context-Free Clusters-based Trajectory Prediction, IEEE International Conference on Intelligent Transportation Systems (ITSC) '23

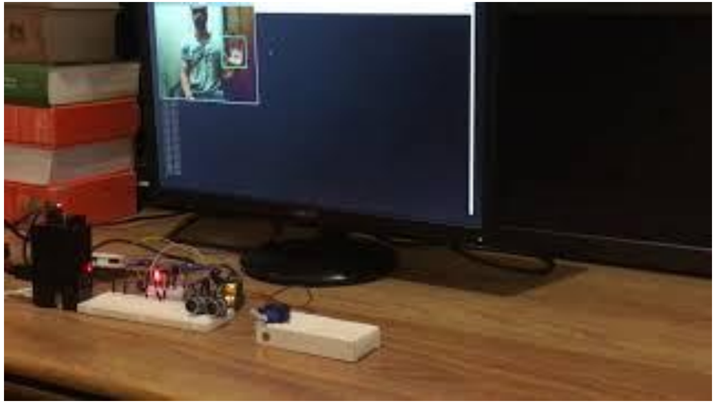
[6] **T. Rodrigues de Almeida**, Andrey Rudenko et al.; Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV) Workshops, 2023, pp. 2200-2209

Other Projects

Vacuum cleaner robot navigation and coverage: **Reinforcement Learning** to learn the navigation policy for optimal spot cleaning in grid representation. Explore more here!



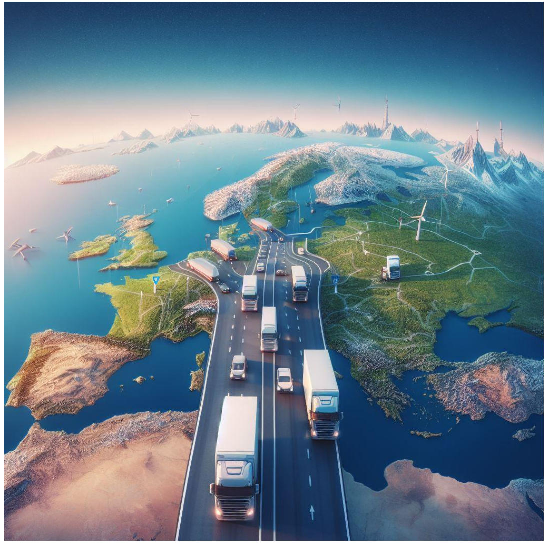
Homemade smart tap: **electronics plus classic CV**. The user controls the water flow and temperature (red and blue lights) according to the hand position with respect to the camera; the motor emulates a tap. Explore more here!



How to use?
- Approach the tap to activate the ultrasonic approximation
- Select the desired water temperature and flow by positioning your hand. Imagine an XY-plane coordinate system in front of the tap sensor, with the X-axis representing the temperature (hotter to the right, red LED and colder to the left, blue LED) and the Y-axis representing the flow (higher above the tap for increased flow, servo position)

Deep learning for transit time estimation - Amazon

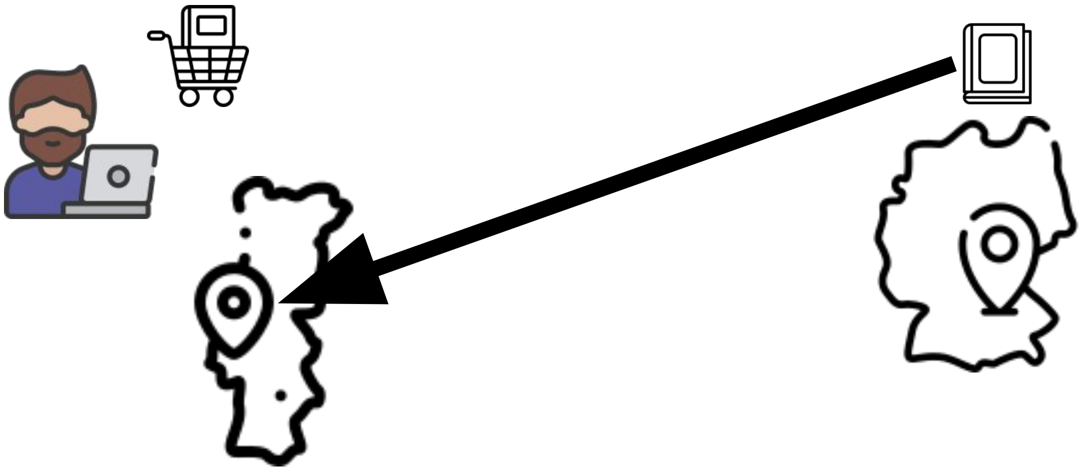
- Trucks transit time estimation from anywhere to anywhere in the EU road transportation network
- **Geospatial data:** preprocessing, visualization, and feature engineering
- **Deep learning** for tabular data: Transformers, ResNets
- **Business** metrics **analysis**
- **AWS deployment: models at beta stage**



Thanks to DALL.E

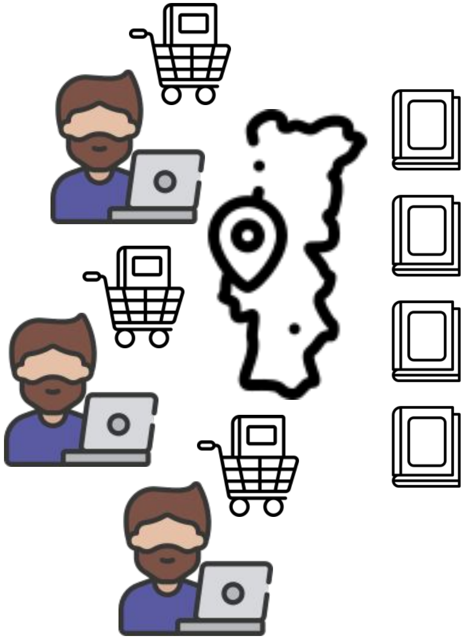
Supply chain on real-world - Amazon case study 1

Demand forecasting: to ensure minimum delivery time



Supply chain on real-world - Amazon case study 1

Demand forecasting: to ensure minimum delivery time



In order to minimize the delivery time, Amazon needs to understand where **demand is highest** in order to **optimally place products in the fulfilment and sort centers** (FC and SC).

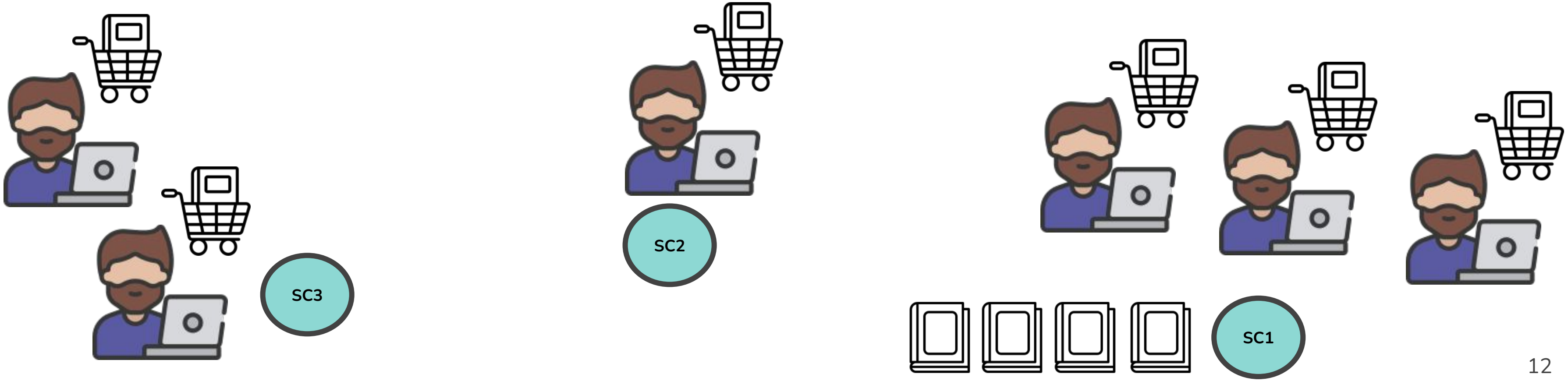
Demand forecasting → FC / SC optimization

Supply chain problem

Supply chain on real-world - Amazon case study 1

FC/SC optimization: to ensure minimum delivery time

Where to place the goods in order to reduce travel distances and delivery time?



Supply chain on real-world - Amazon case study 1

Demand forecasting

- Classical approaches
  - Autoregressive
  - Moving average
  - Autoregressive moving average

→ Very much used in prod

Interpretable and explainable

Easy to implement

- Modern approaches (deep learning)
  - LSTMs
  - Transformers
  - CNNs

https://ts.gluon.ai/stable/

→ Used for complex problems

Require more expertise

Require more energy

Supply chain on real-world - Amazon case study 1

Demand forecasting - classical approaches

- autoregressive $y_t = c + \epsilon_t + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p}$
- moving average $y_t = c + \epsilon_t + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \ldots + \theta_q \epsilon_{t-q}$
- autoregressive moving average $y_t = c + \epsilon_t + \phi_1 y'_{t-1} + \ldots + \phi_p y'_{t-p} + \theta_1 \epsilon_{t-1} + \ldots + \theta_q \epsilon_{t-q}$

Supply chain on real-world - Amazon case study 1

Demand forecasting - modern approaches

- LSTMs
- Transformers
- CNNs

Supply chain on real-world - Amazon case study 1

Demand forecasting - modern approaches

- **LSTMs**
  - not the best for long sequences although use memory
  - vanish gradient (sigmoid)
  - backpropagation through time (BPTT)
  - becoming deprecated due to the transformers boom
- Transformers
- CNNs

Supply chain on real-world - Amazon case study 1

Demand forecasting - modern approaches

- LSTMs
- Transformers
- CNNs

Supply chain on real-world - Amazon case study 1

Demand forecasting - modern approaches

- LSTMs
- **Transformers**
  - more accurate for long sequences
  - query (Q), key (K), value (V)
  - self-attention layers
- CNNs

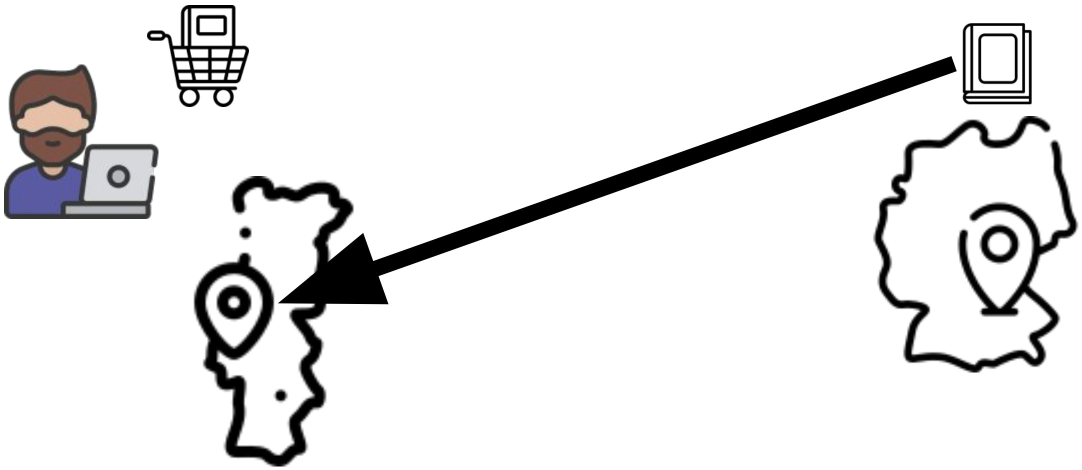
Supply chain on real-world - Amazon case study 1

Demand forecasting - modern approaches

- LSTMs
- Transformers
- **CNNs**
  - work as CNN for images but applied to temporal signals
  - kernel (temporal window) to extract features

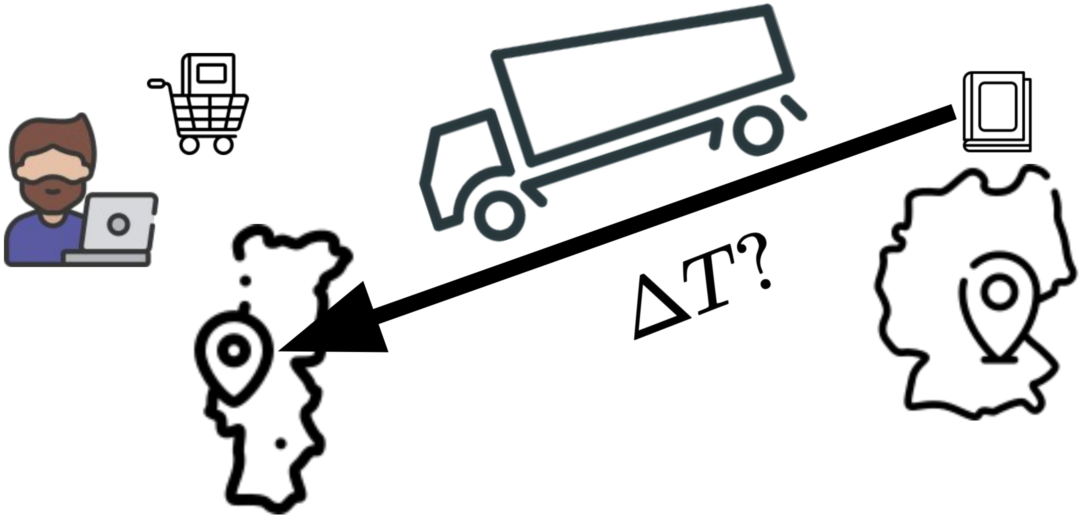
Supply chain on real-world - Amazon case study 2

Transit time estimation: minimum delivery time *without failing the delivery time*



Supply chain on real-world - Amazon case study 2

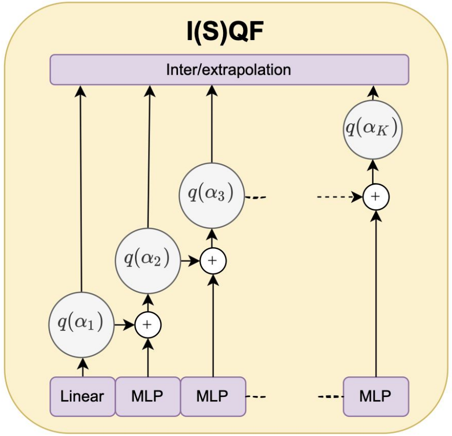
Transit time estimation: minimum delivery time *without failing the delivery time*



Supply chain on real-world - Amazon case study 2

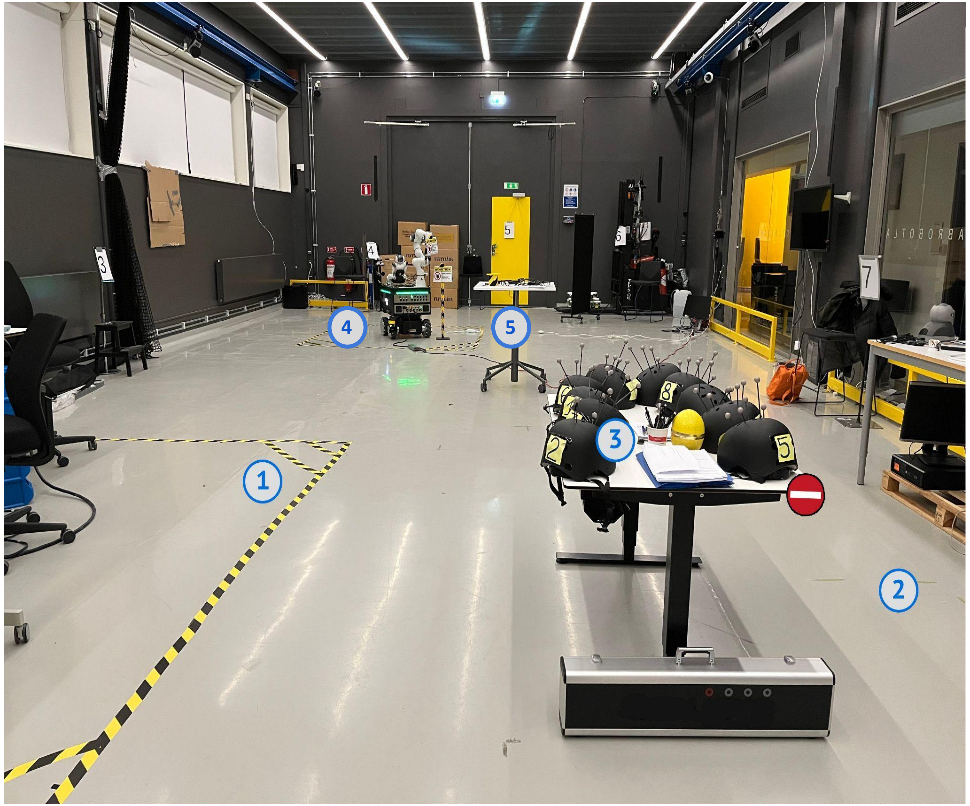
Transit time estimation

- Problem constraints:
  - should be able to estimate from anywhere to anywhere in the EU road transportation network
  - should produce quantiles estimation to be consumed by various stakeholders
  - do not have access to the road transportation network
- Tabular data
  - feature engineering: OD agnostic features (geohash)
  - truck information
- Transformers with ISQF heads
  - attention layer allows *somewhat* explainable estimations
  - ISQF to learn incremental quantiles (quantile regression)



Project - case study 3

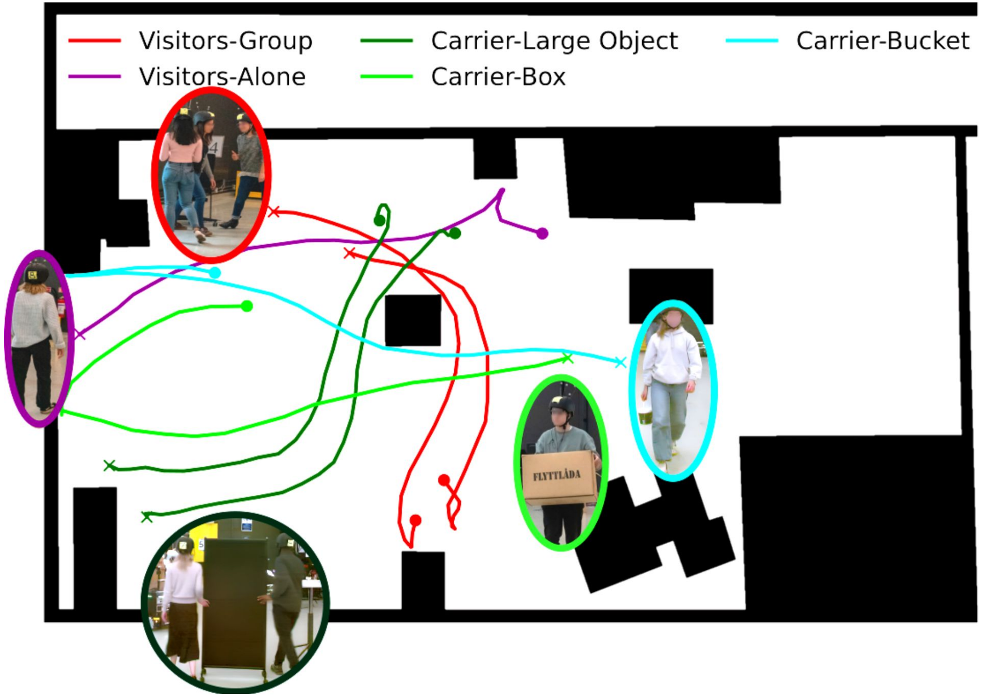
- Efficiency in HRI for inventory management via people tracking 3
- Mobile robot in the scene moving and as static obstacle 4
- Contextual semantics:
  - lane markings 1
  - one way corridors 2
  - static obstacles 5



Project - case study 3

- People with different roles

- Human roles correspond to various activities:
  - Moving in groups of 2 and 3 people (*Visitors-Group*)
  - Moving individually (*Visitors-Alone*)
  - Transporting Objects
    - 2 people moving a poster stand (*Carrier-Large Object*)
    - Box (*Carrier-Box*)
    - Bucket (*Carrier-Bucket*)



Live demo

https://magni-dash.streamlit.app/

- trajectory classification $<x, y>_{0:L}$ -> *role*

- trajectory prediction $<x, y>_{0:t}$ -> $<x, y>_{t:L}$

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