AI applications from Astrophysics to Robotics

Vera Könyves

HUN-REN SZTAKI
(AI Lab.)

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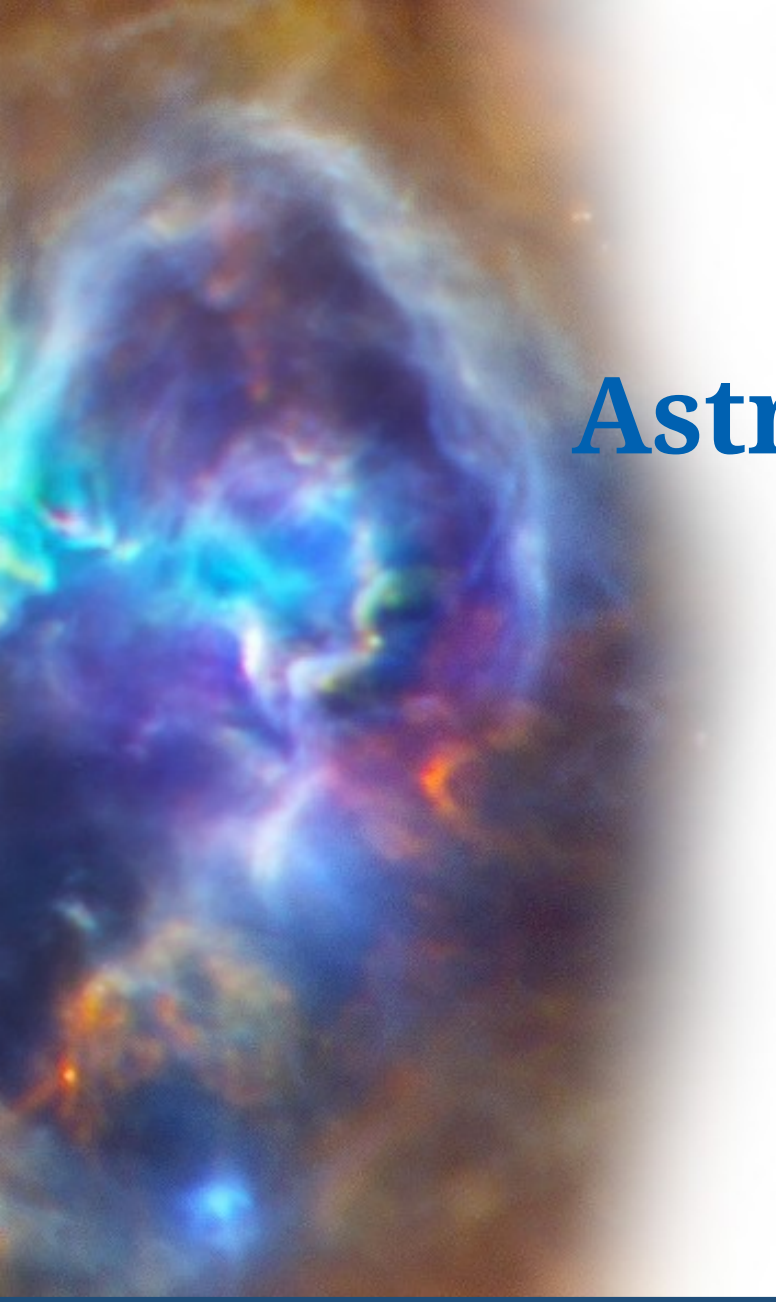
ARTIFICIAL INTELLIGENCE
National Laboratory

GPU Day – May 2025



Astronomy & Astrophysics without/with AI

Star formation – no AI

e.g.: Könyves et al. (2010, 2015, 2020, 2023)

(Solar-type) star formation in a nutshell:

- It takes place in cold, dense regions of **interstellar molecular clouds**.
- Under the influence of **gravity** (+magnetic field, etc.), gas and dust are arranged in long "**filaments**".
- Within the filaments, the matter collapses into "**prestellar cores**".
- The cores become denser, heat up and undergo **nuclear fusion**.
- Eventually, **new stars** (+planets) form.

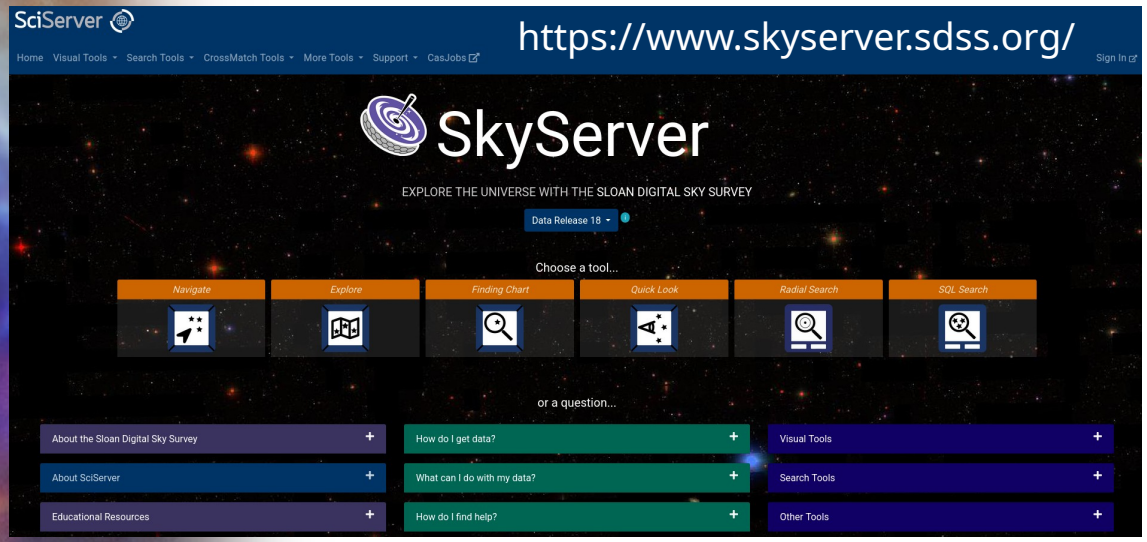
Star formation – no AI

The process of –my– astrophysical data analysis:

- Earth- or space telescopes provide raw data.
- Image processing results in sky maps, spectra, etc.
- Extracion of point sources, diffuse objects, etc.
- Calculation of physical parameters, statistics, correlations,...
- Discussions (observations vs theory), writing papers...

Text-to-SQL framework for the SDSS SkyServer database

Co-Authors: Péter Zsoldos (SZTAKI/ELTE IK), Benedek Székács (TU Delft), István Csabai (ELTE TTK)



SDSS (Sloan Digital Sky Survey)

- Detailed 3D skymap of >3 million objects.

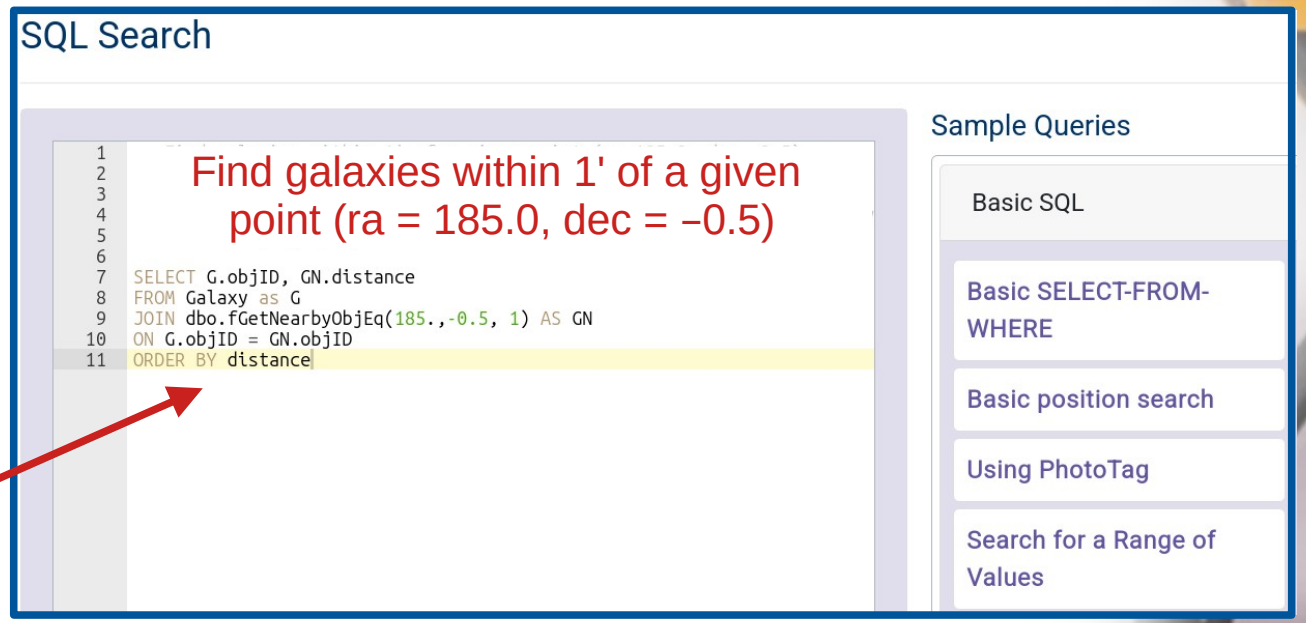
SkyServer

- Web-based data platform for data query and analysis.

Database

tables + functions

SQL query



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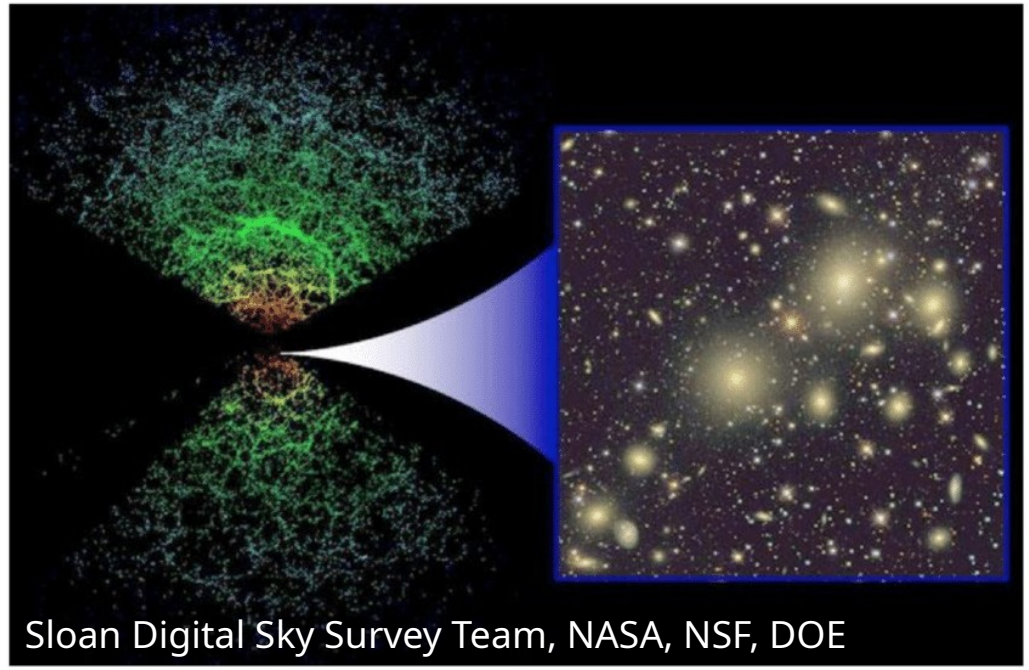

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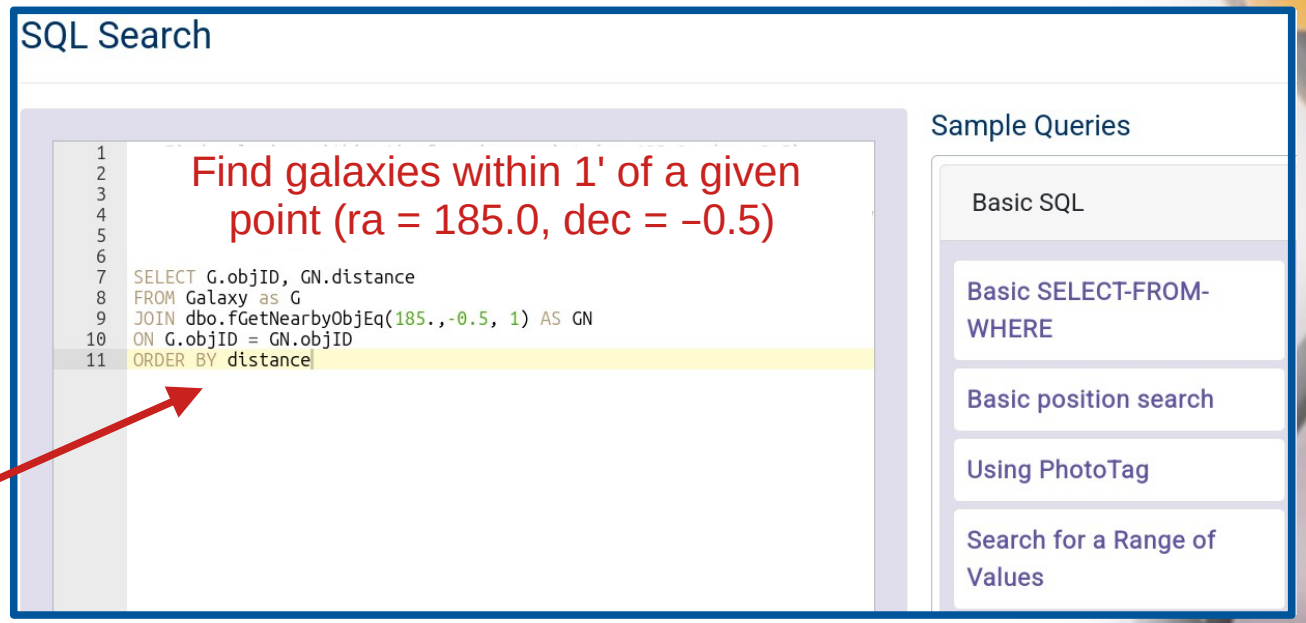

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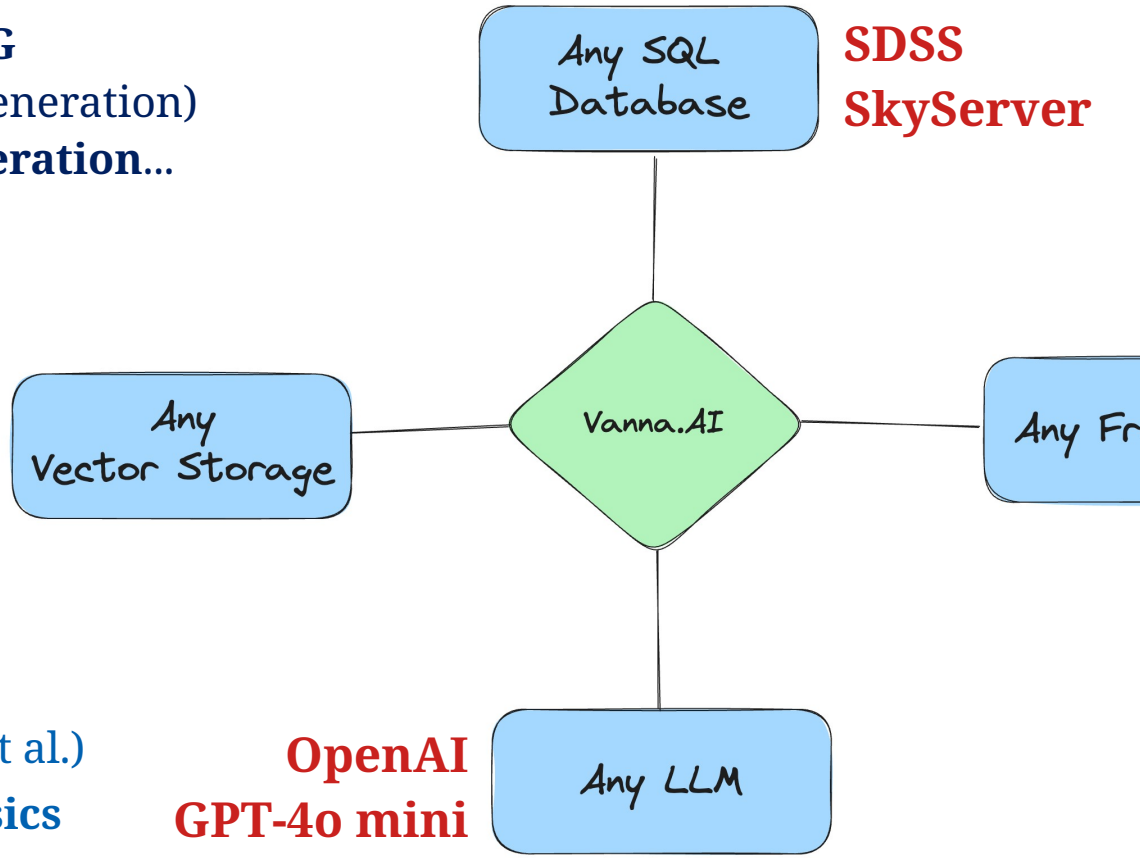
Vanna (https://vanna.ai/)

- Open-source Python **RAG** (Retrieval-Augmented Generation) framework for **SQL generation**...



SDSS SkyServer

all-MiniLM-L6-v2 (sentence embedding model)

FAISS (similarity search library)

VannaFlask App (Streamlit, Slack bot, ...)

OpenAI GPT-4o mini

Paper in prep. (P. Zsoldos et al.)

Astronomy & Astrophysics journal

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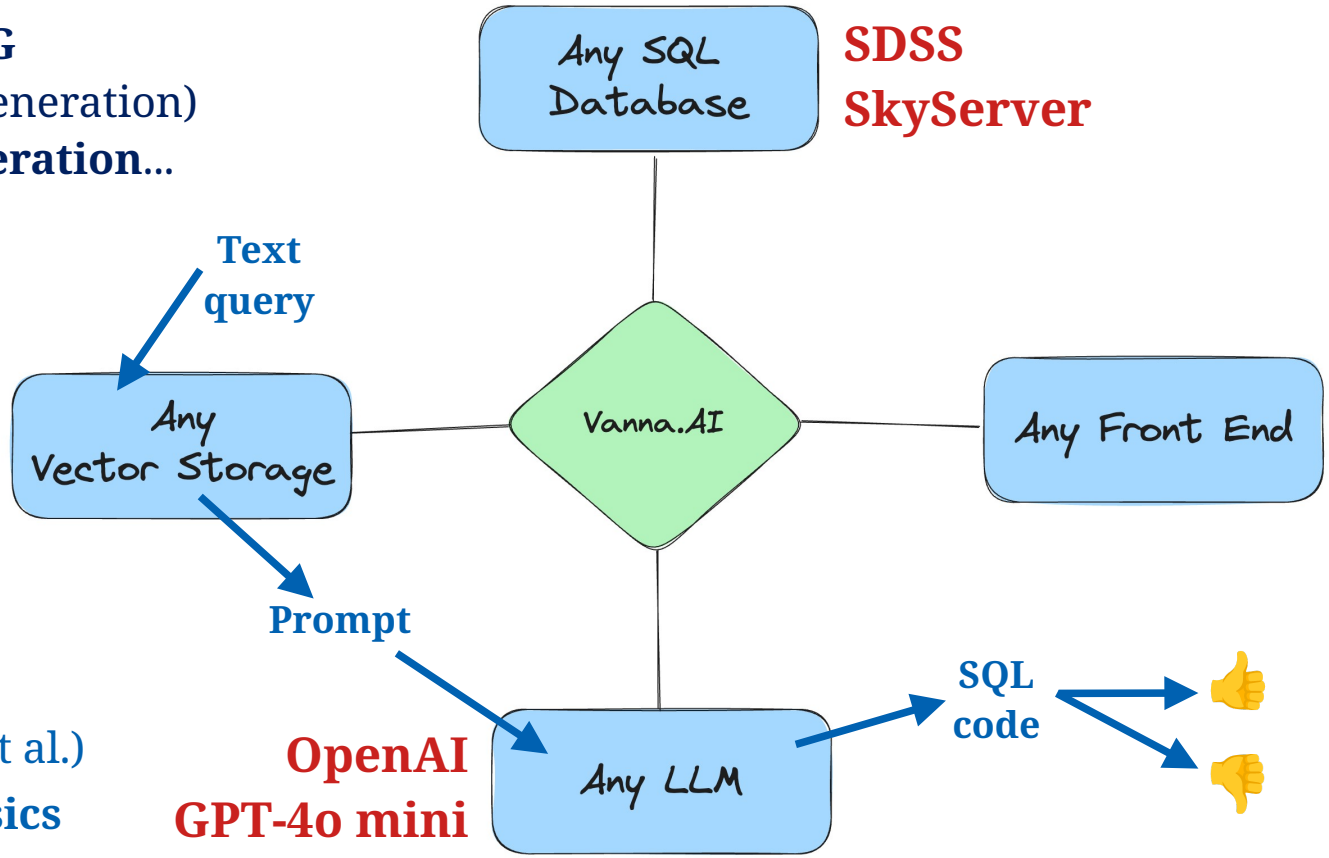

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Astronomy & Astrophysics journal

Energetics

Improving power network forecasting

Day-ahead forecasting of transmission network loss

Co-Authors: Ferenc Béres (SZTAKI), András Benczúr (SZTAKI), Bálint Sinkovics (BME), István Vokony (BME), Bálint Hartmann (BME), Kristóf Juhász (BME)

https://mavir.hu/
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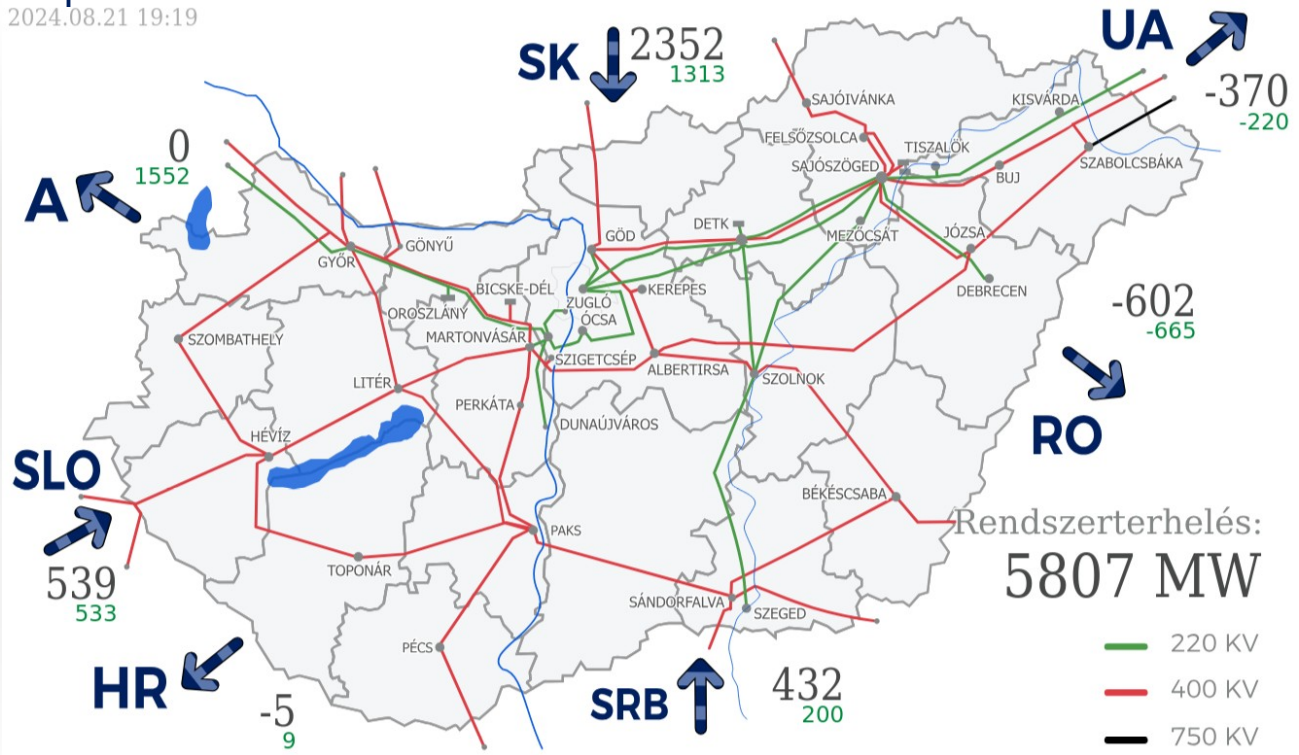

MAVIR

FASTER
Future 4 Zrt.

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Accepted paper (K. Juhász et al.):
2025 IEEE Kiel PowerTech Conf.

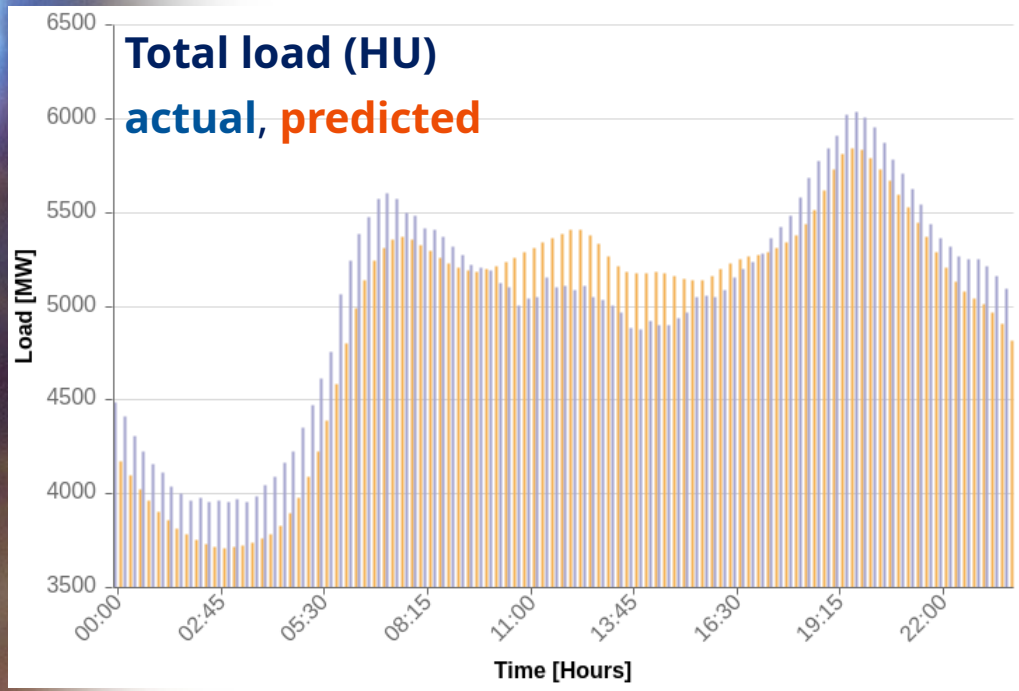
In this task, the best predictive supervised learning method was **XGBoost**

Power network load forecasting (on public data)

Co-Authors: Ferenc Béres (SZTAKI), András Benczúr (SZTAKI)

ENTSO-E platform

European Network of Transmission System Operators for Electricity (https://transparency.entsoe.eu/)



Feature Engineering

Electricity network info:

- System Load and Scheduled Int. Transmissions at hourly resolution.
- Data Transformation: Moving averages for the past few hours, days, weeks, weekends, and weekdays.

Date information:

- Identifying months, working days, holidays

Weather data:

- Daily measurements from HungaroMet stations (temp., wind speed, humidity, evap., precip, global radiation, ...)
- Data Transformation: National daily average meas.

Power network load forecasting (on public data)

Co-Authors: Ferenc Béres (SZTAKI), András Benczúr (SZTAKI)

Data:

- 2019 – 2023 (train-test: 80% – 20 %)
- Day-ahead pred. in hourly resolution

Chosen model:

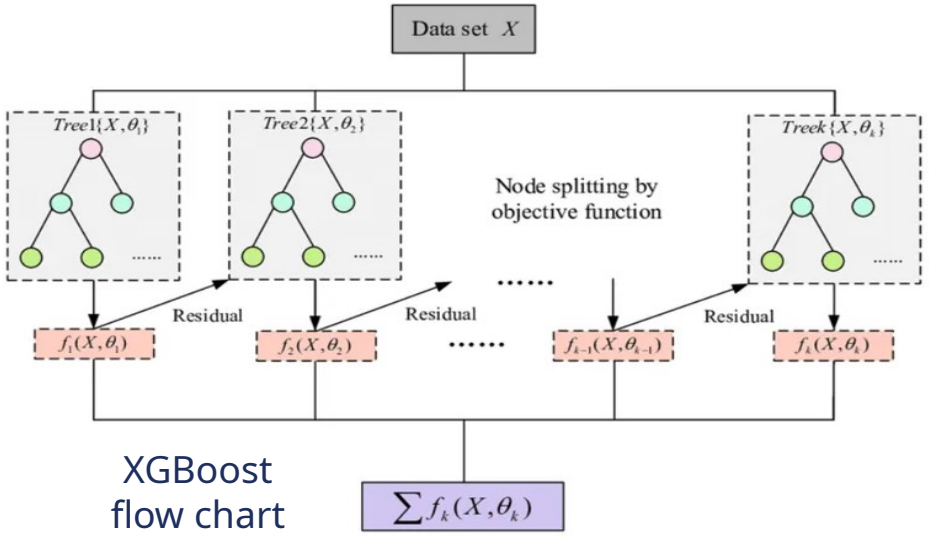
- **XGBoost**, decision tree-based hybrid method

Interpretation of results:

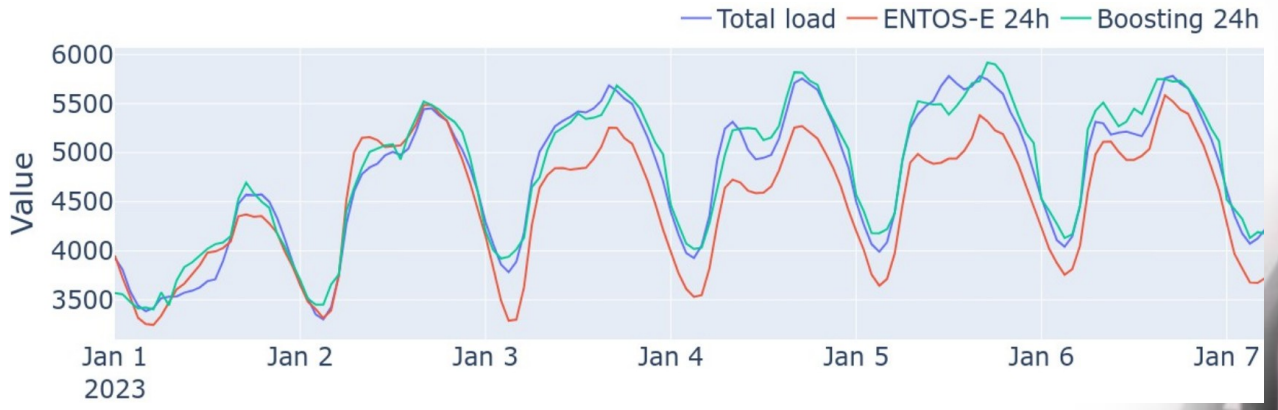
- Multiple metrics/criteria in evaluation
- Explanatory power of input variables (**SHAP**, **feature importance**)

Sensitivity analysis:

- Change in performance considering different feature sets, e.g., importance of weather forecasts:
  - **pessimistic case** (historical data only)
  - **optimistic case** ("weather oracle")



XGBoost flow chart

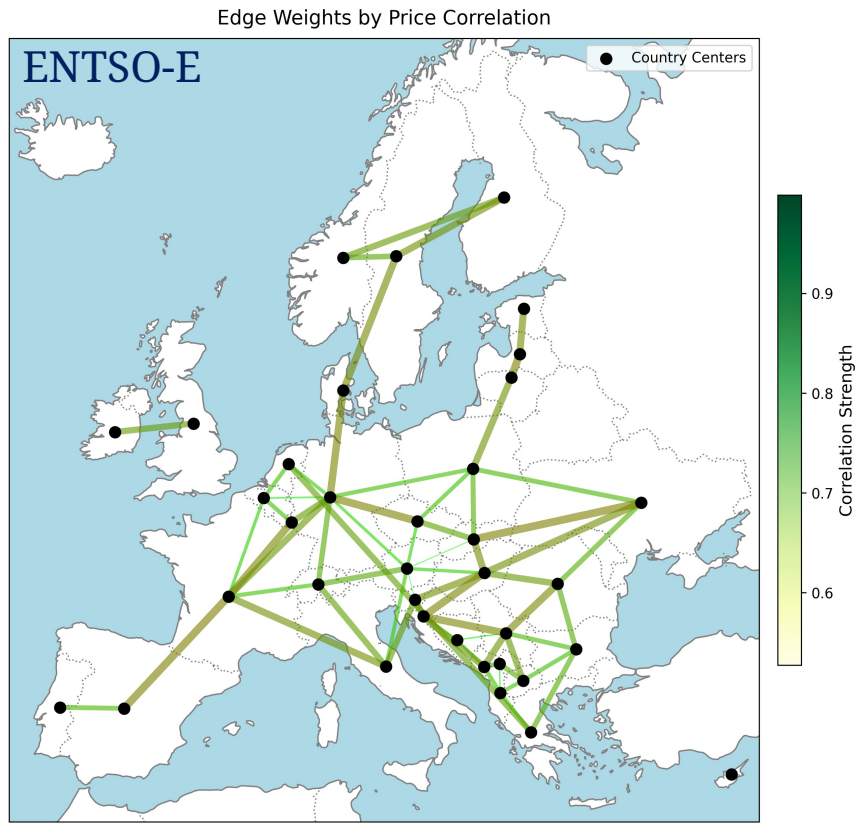


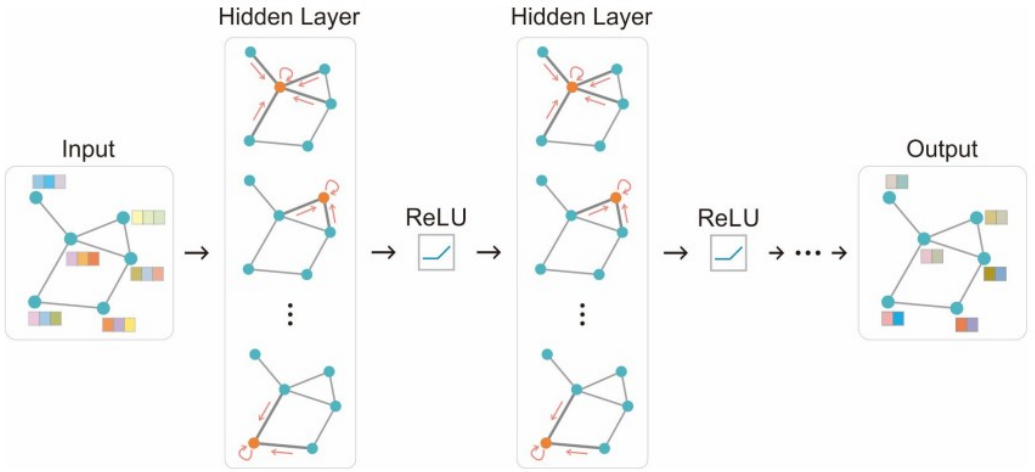
Electricity price forecasting with graphs (MSc)

Authors: Samer Makni (MSc, SZTAKI/ÓE), Ferenc Béres (SZTAKI)

Task:

Forecasting day-ahead electricity prices with hourly resolution.



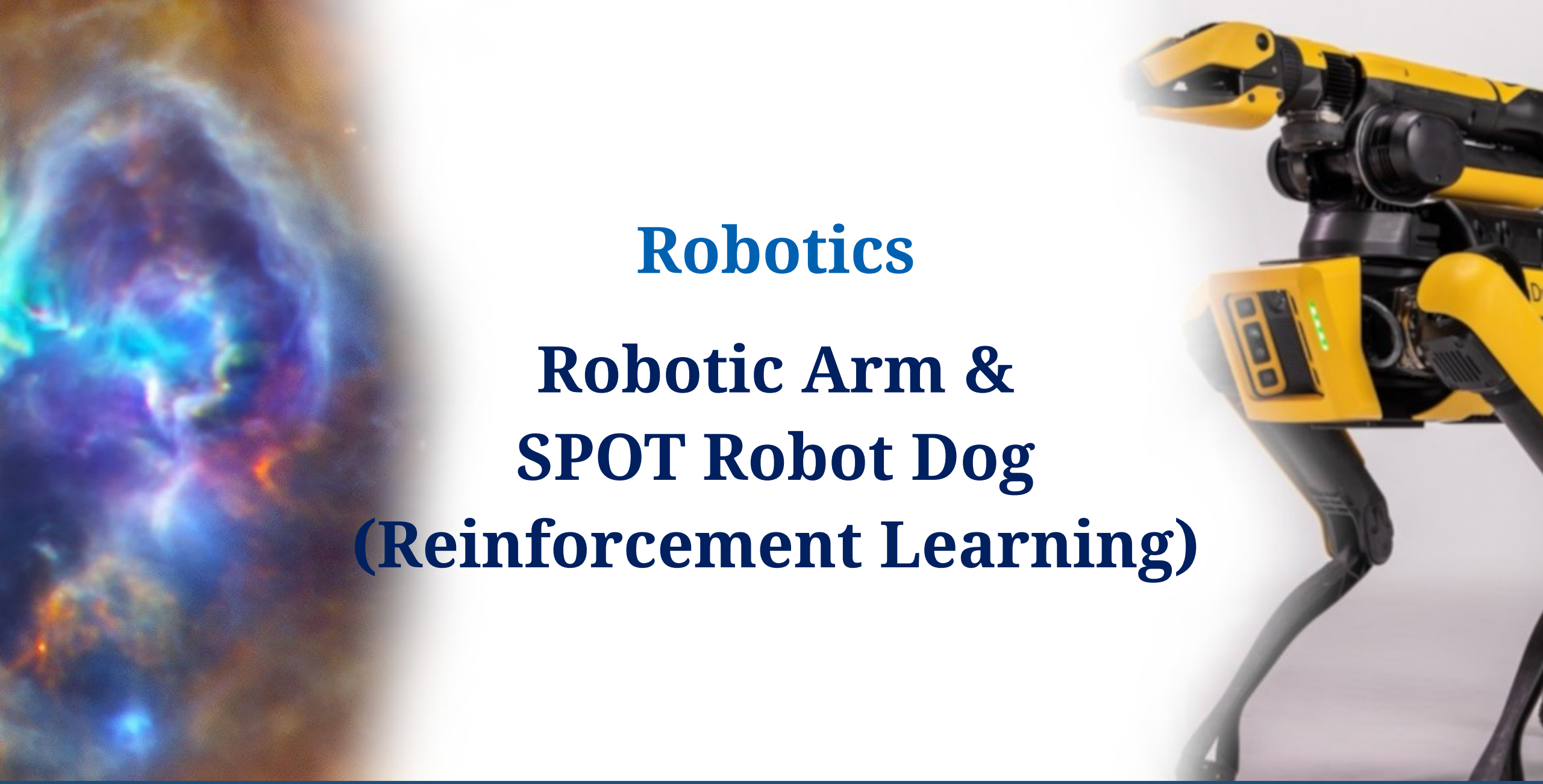


Architecture of the
Graph Convolutional Network (GCN) model

Graph topology: fixed

Edge features: unweighted (stat.), euclidean distance (stat.), energy flow (dynam.), price correlation (stat./dynam.).

Node features: historical prices, power generation, weather info, etc.



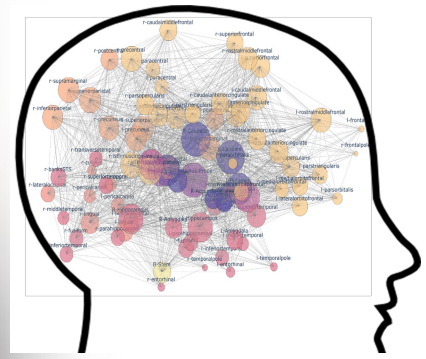
Robotics

Robotic Arm & SPOT Robot Dog (Reinforcement Learning)

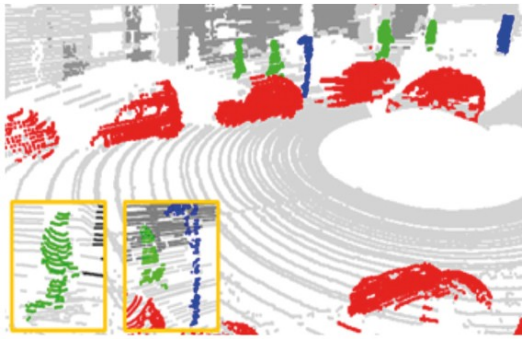
QUANSER QArm Robotic Arm

Robotic Arm in the Ligeti **Kindergarten**
in Pilisvörösvár (4–6 year olds, Oct. 2024)

AI National Lab. (MILAB) – Research Areas

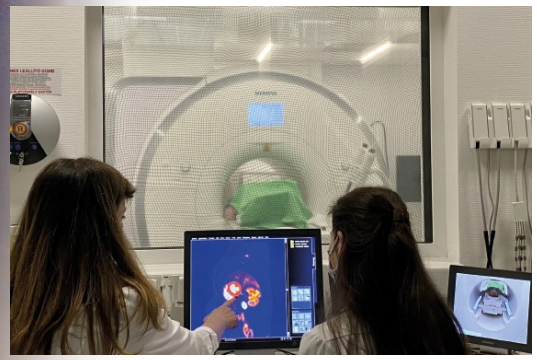


WP1: Foundations of AI

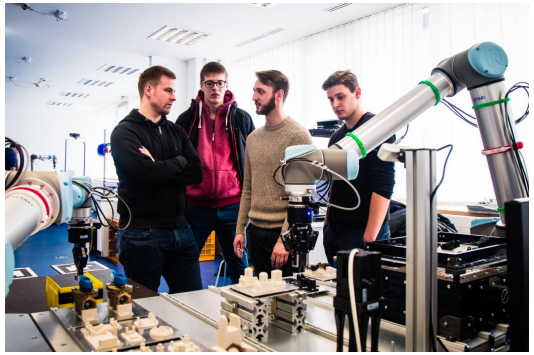


WP2: Machine Perception

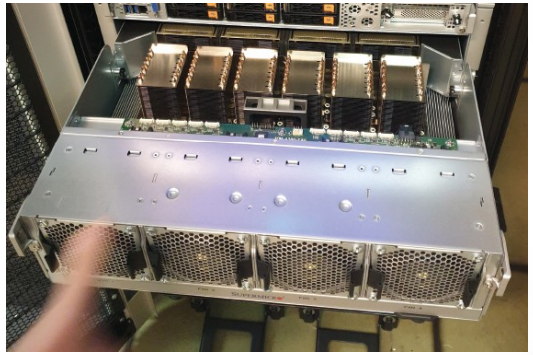
WP3: Human Lang. Proc.



WP4: Medical, Health, and Bio Applications



WP5: Sensors, IoT, and Telecomm.



WP6: Security and Privacy

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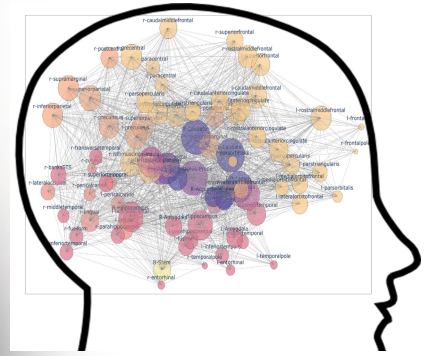

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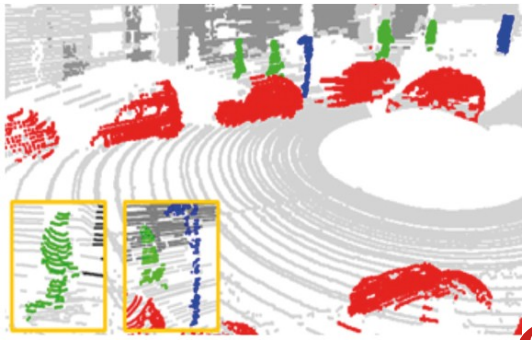
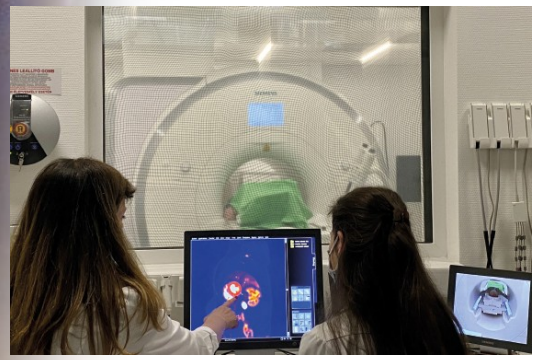


WP2: Machine Perception

WP3: Human Lang. Proc.

our robotic tasks



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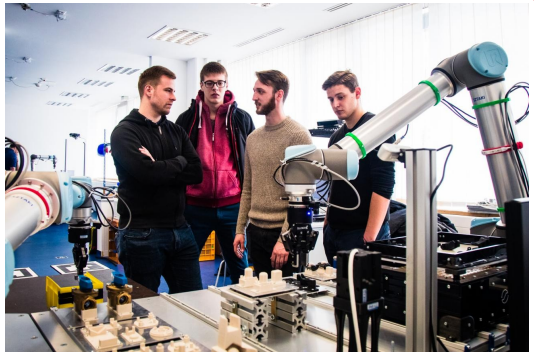

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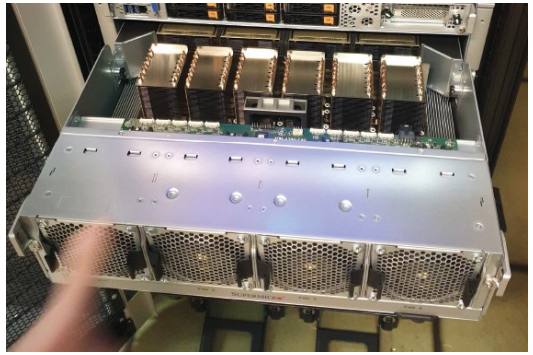

WP6: Security and Privacy

QArm – Block tower building with RL

Co-Authors: Levente Kocsis (SZTAKI), Tamás Selmeczi (SZTAKI/BME)

Block tower building with Reinforcement Learning

Reinforcement Learning (RL):

- Intelligent **Agent** interacts with its **Environment**
- The **State** is a snapshot of the environment (e.g.: position, speed, field of view)
- The agent makes **Actions** to influence the env.
- Depending on these actions, it receives a **Reward** (or penalty) at each **Timestep**.
- The aim is to develop a decision strategy (**Policy**), that maximises long-term rewards.

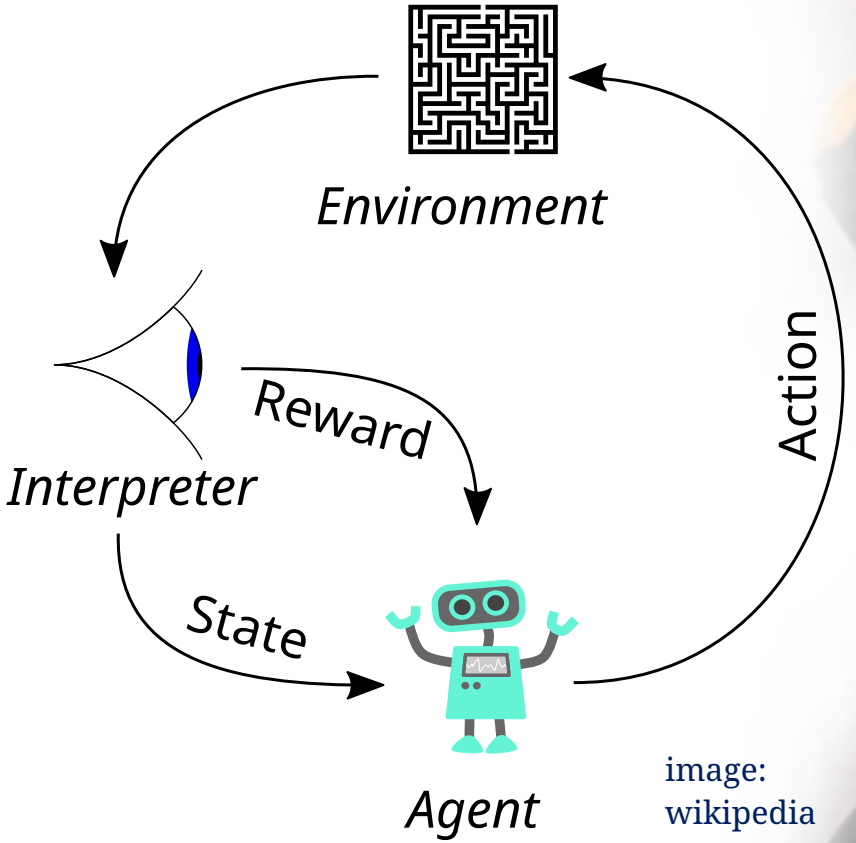

image: wikipedia

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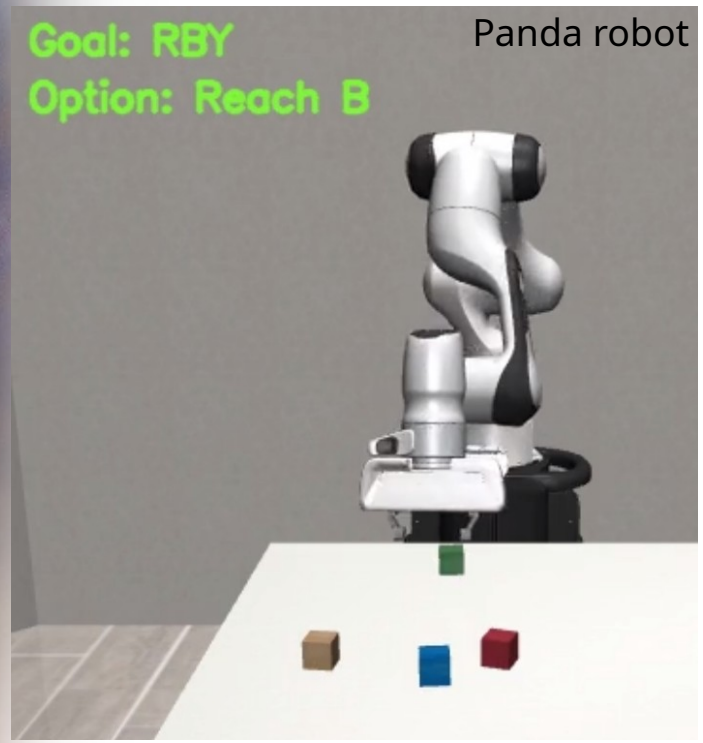
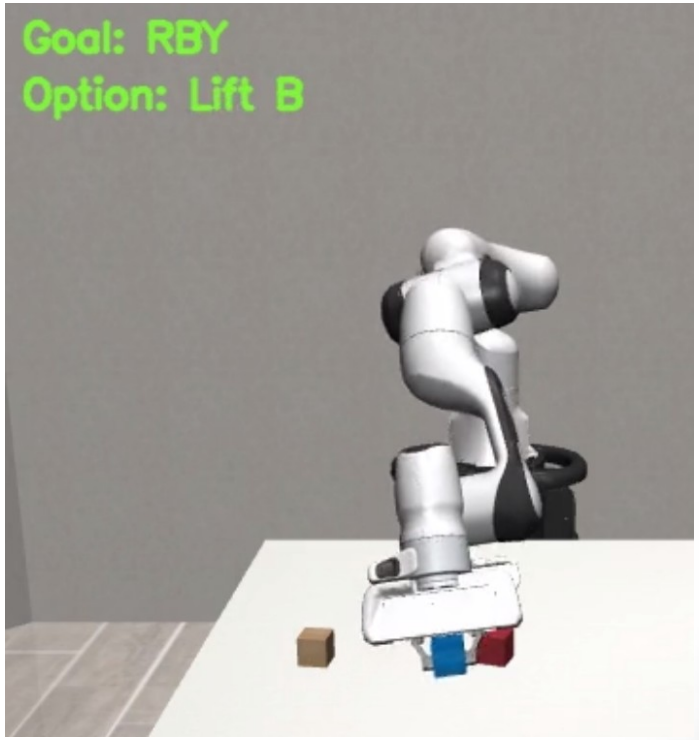
Block tower building with –Hierarchical– Reinforcement Learning

- **Sub-goals** of the **Target Task** **(Options)**: Reach, Grasp, Lift, Align, Stack





Simulations in the **Robosuite** framework (Zhu et al. 2020)

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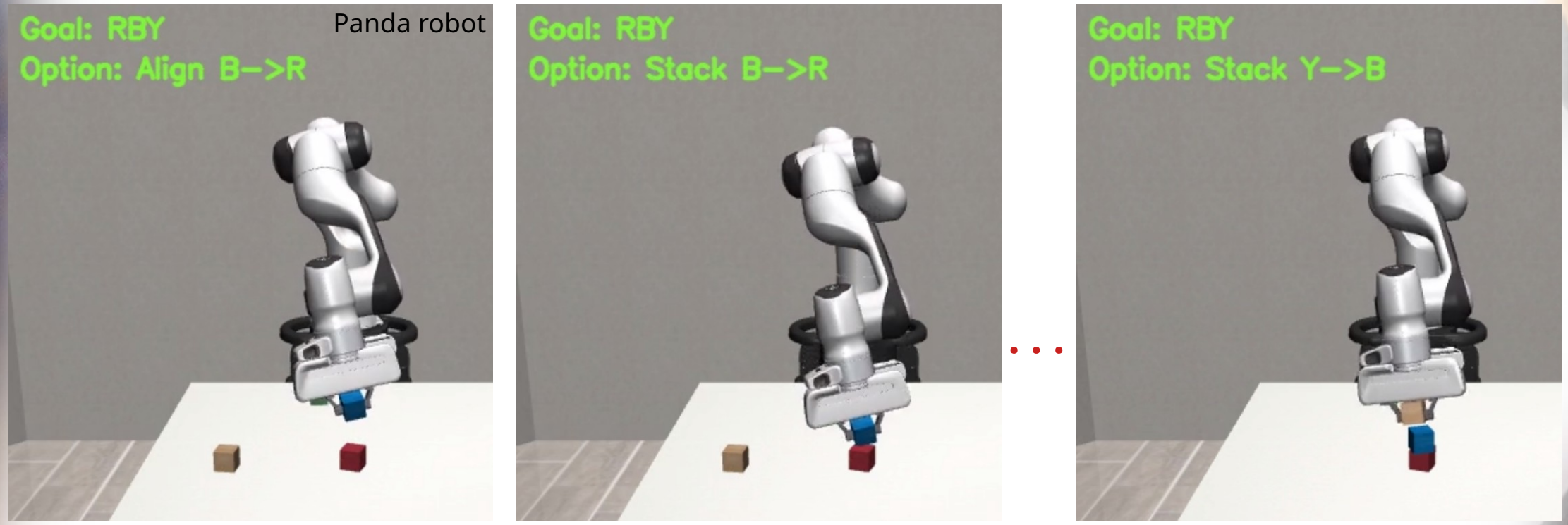

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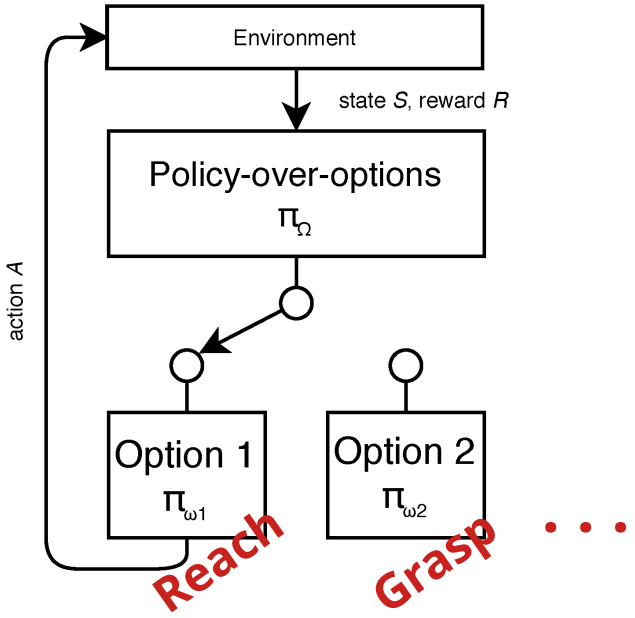

Simulations in the **Robosuite** framework (Zhu+ 2020)
Panda robot

SPOT, AKA „MACSKAFOGÓ”

Co-Authors: Levente Kocsis (SZTAKI), Erzsébet Frigó (SZTAKI), Péter Zsoldos (SZTAKI/ELTE IK), Tamás Selmeczi (SZTAKI/BME), Bálint Daróczy (SZTAKI), Endre Hamerlik (SZTAKI/ComeniusUni), Judit Ács (SZTAKI), Botond Barta (SZTAKI)

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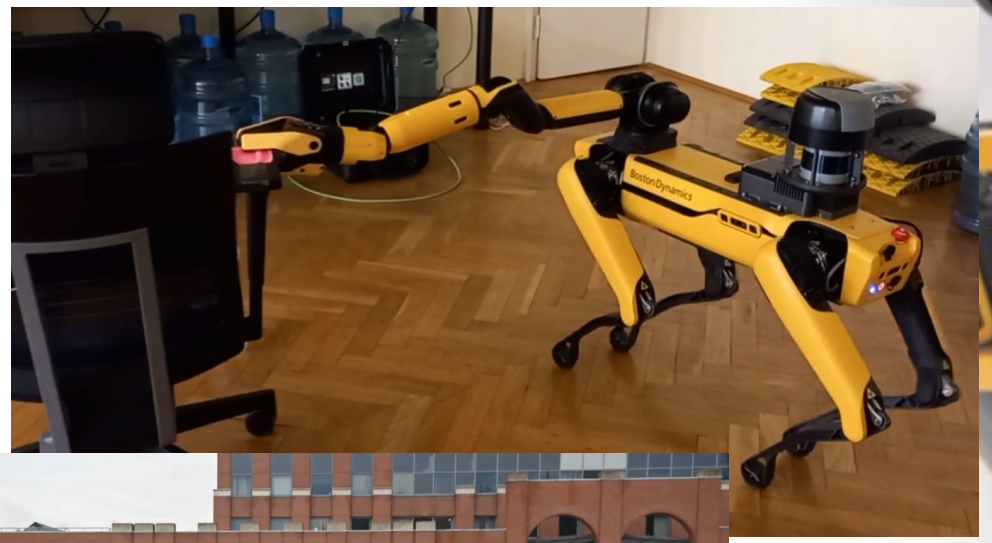

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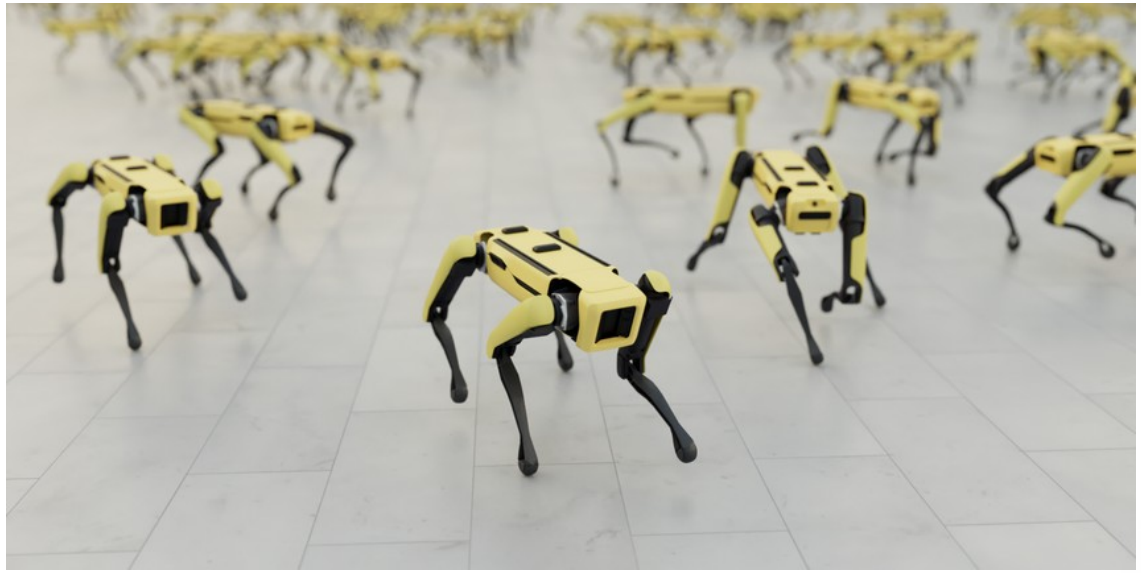
The Boston Dynamics’ SPOT robot dog is also trained with (hierarchical) RL for different tasks:

- **Challenging tasks:**
  - Interaction with the environment
    - LLMs, VLMs, cameras, sensors
  - Safe-RL integration
- **Well-demonstrable exercises:**
  - Spectacular
  - Unique



Simulation environment: NVIDIA Isaac Lab / Isaac Sim (PhysX, RTX)

Infrastructure: HUN-REN Cloud, Apr – Jun (8 vCPU, 32 GB RAM, 16 GB GPU RAM)

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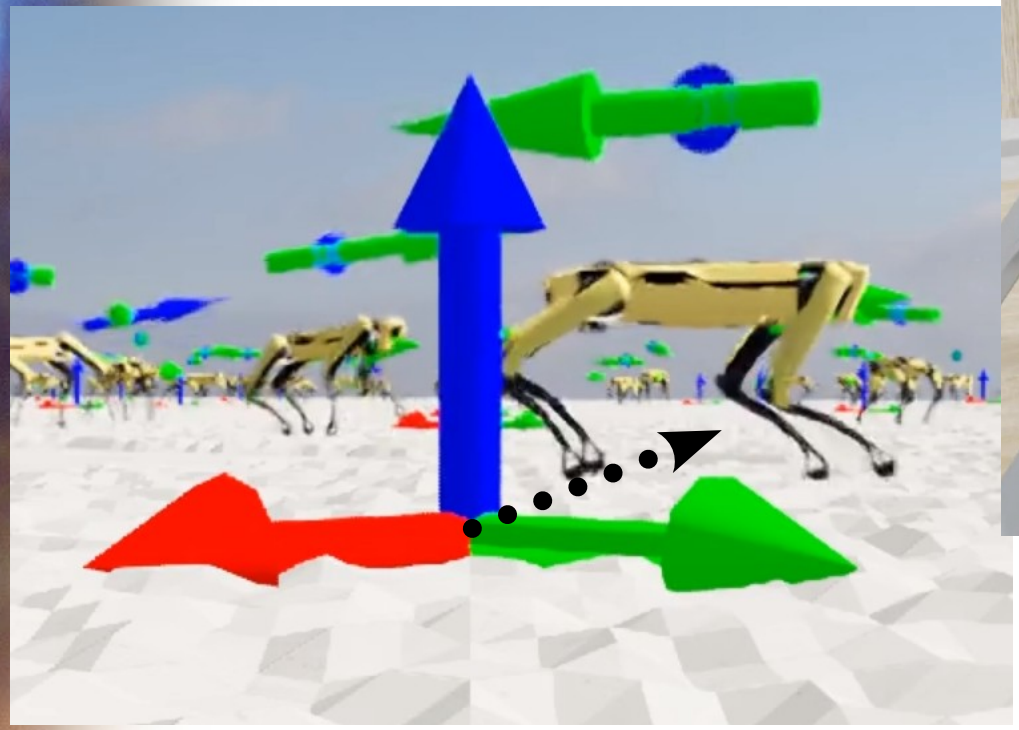
Simulated elementary tasks moments



Thanks for the Attention!