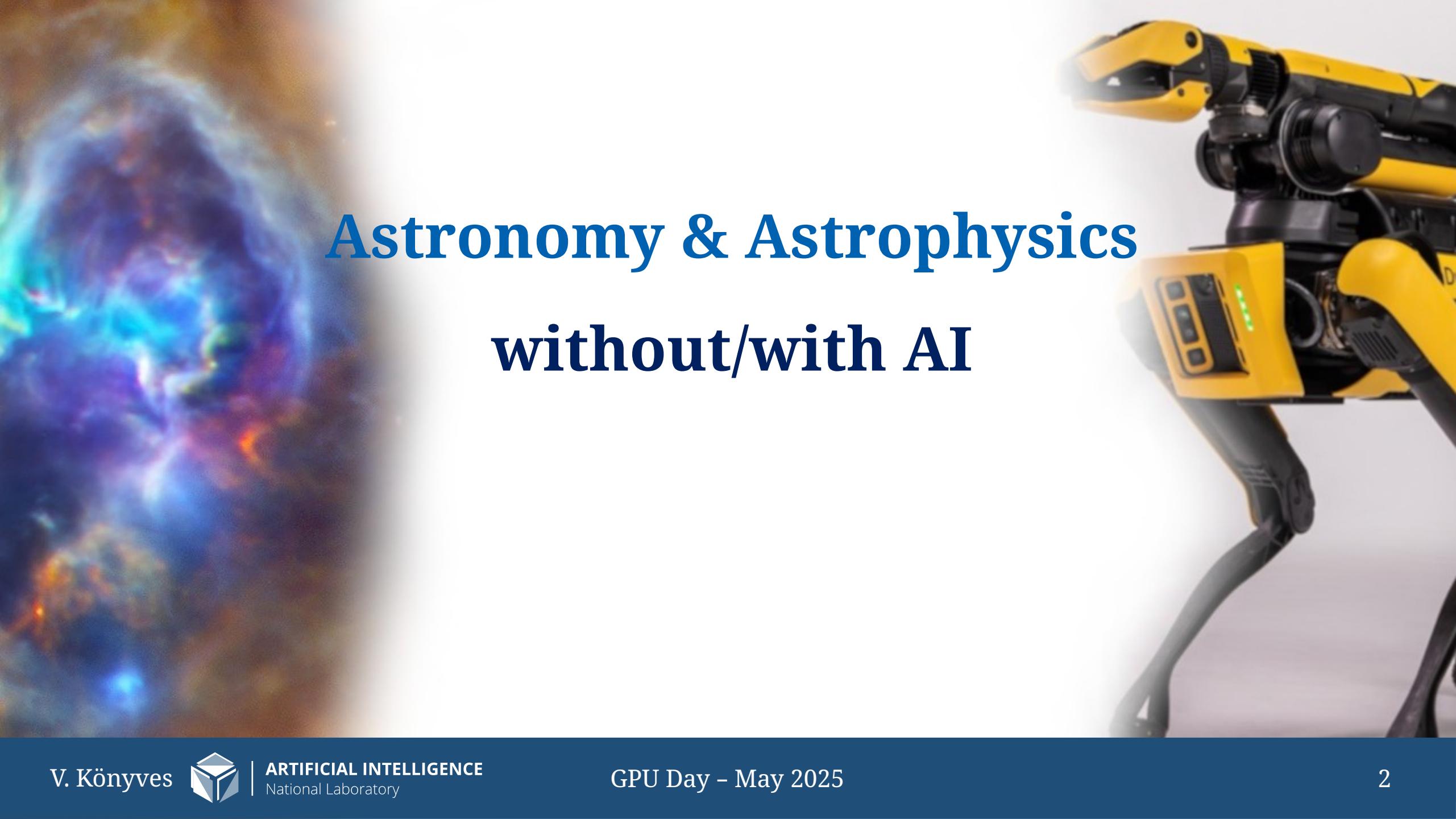


AI applications from Astrophysics to Robotics

Vera Könyves

HUN-REN SZTAKI
(AI Lab.)





Astronomy & Astrophysics without/with AI

Star formation – no AI



(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.
- Extraction 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)



Database
tables + functions

SQL query

SDSS (Sloan Digital Sky Survey)

- Detailed 3D skymap of >3 million objects.

SkyServer

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

A screenshot of the SDSS SkyServer SQL Search interface. The title 'SQL Search' is at the top. On the right, there's a 'Sample Queries' sidebar with categories like 'Basic SQL', 'Basic SELECT-FROM-WHERE', 'Basic position search', 'Using PhotoTag', and 'Search for a Range of Values'. The main area shows a code editor with a red background for the query text. The query is:

```
1
2
3
4
5
6
7
8
9
10
11
```

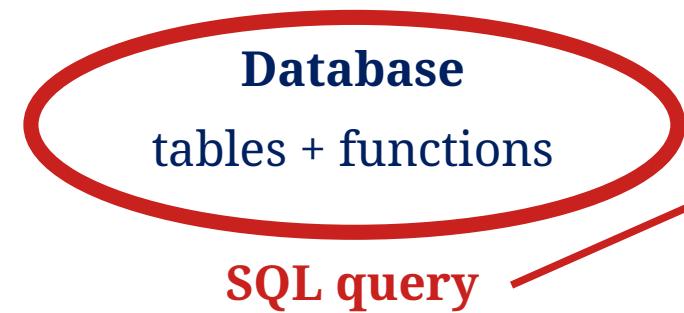
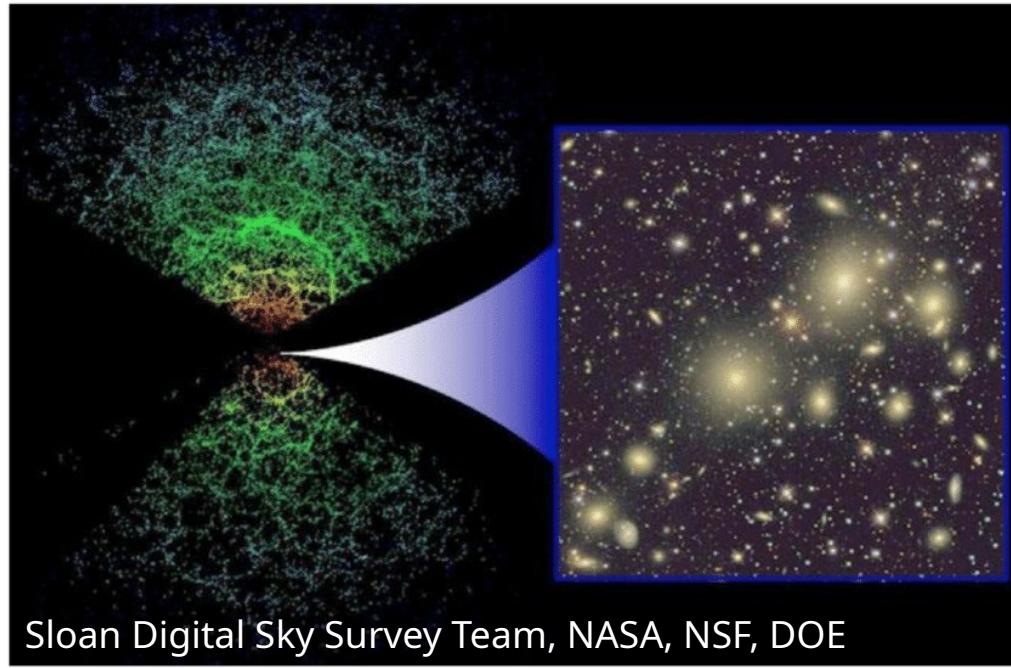
Find galaxies within 1' of a given point (ra = 185.0, dec = -0.5)

```
SELECT G.objID, GN.distance
FROM Galaxy as G
JOIN dbo.fGetNearbyObjEq(185., -0.5, 1) AS GN
ON G.objID = GN.objID
ORDER BY distance
```

A red arrow points from the word 'SQL query' in the text above to the code editor.

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SQL Search

```
Find galaxies within 1' of a given point (ra = 185.0, dec = -0.5)

1
2
3
4
5
6
7 SELECT G.objID, GN.distance
8 FROM Galaxy as G
9 JOIN dbo.fGetNearbyObjEq(185.,-0.5, 1) AS GN
10 ON G.objID = GN.objID
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```

Sample Queries

- Basic SQL
- Basic SELECT-FROM-WHERE
- Basic position search
- Using PhotoTag
- Search for a Range of Values

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Vanna (<https://vanna.ai/>)

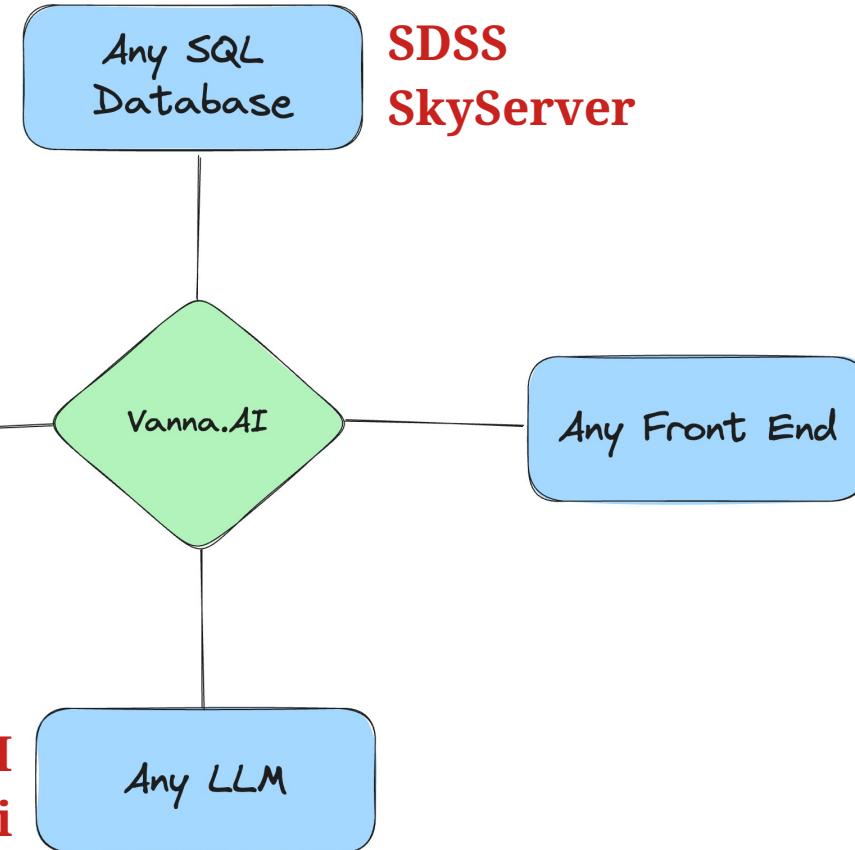
- Open-source Python RAG
(Retrieval-Augmented Generation) framework for **SQL generation...**

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

FAISS
(similarity search library)

Paper in prep. (P. Zsoldos et al.)
Astronomy & Astrophysics
journal

OpenAI GPT-4o mini



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

Text-to-SQL framework for the SDSS SkyServer database

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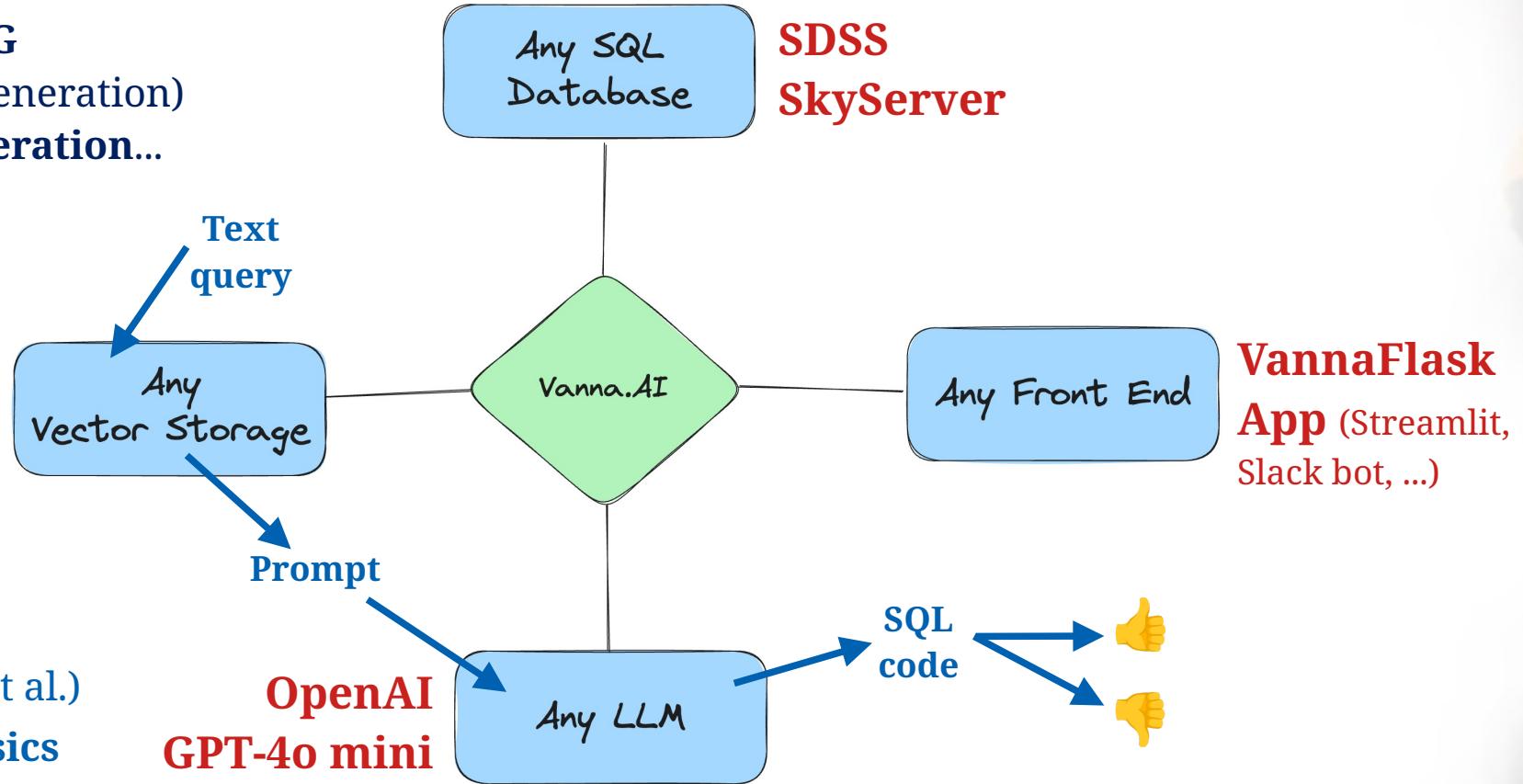
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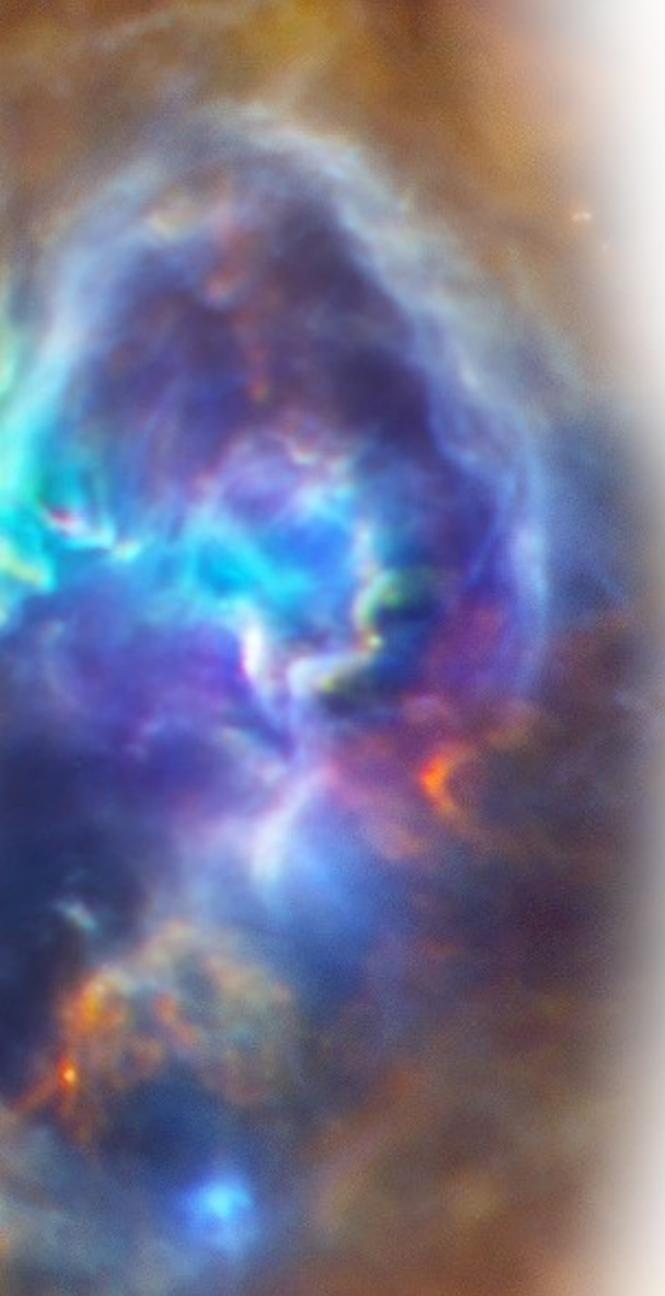
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journal



SDSS
SkyServer

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



Energetics

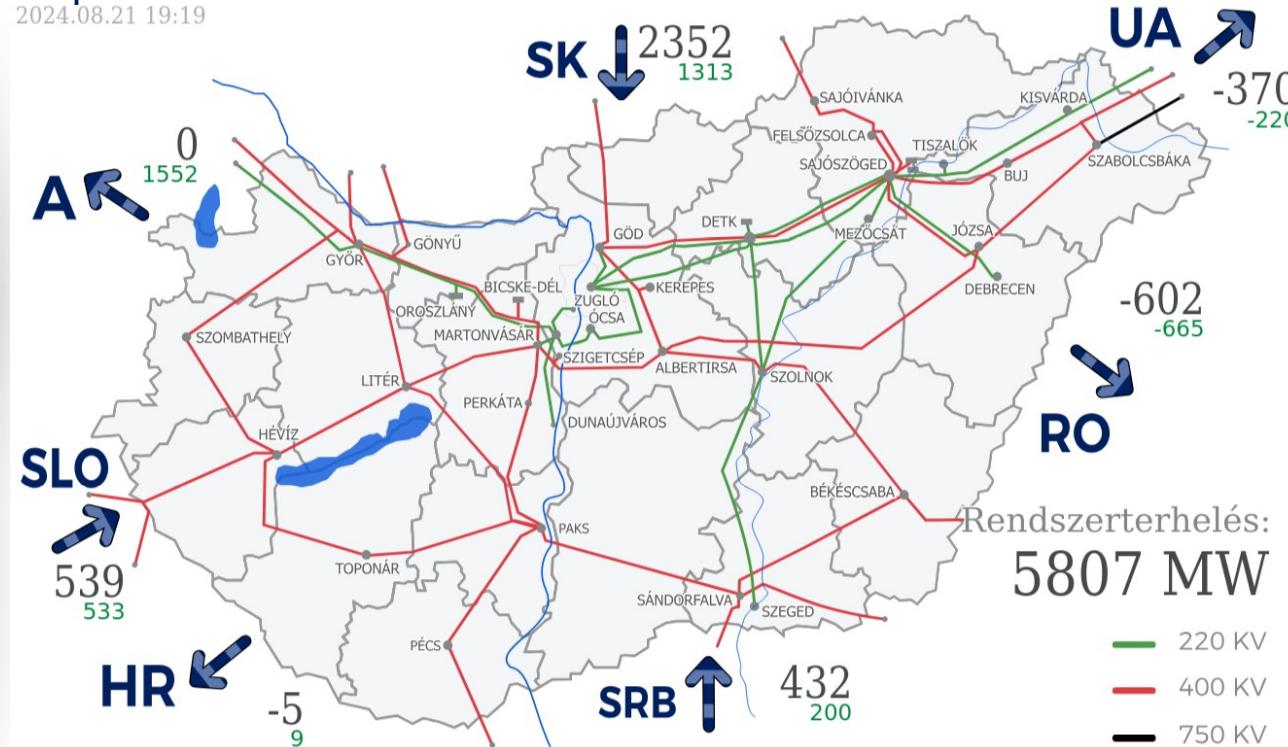
Improving power network forecasting

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/>

2024.08.21 19:19



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

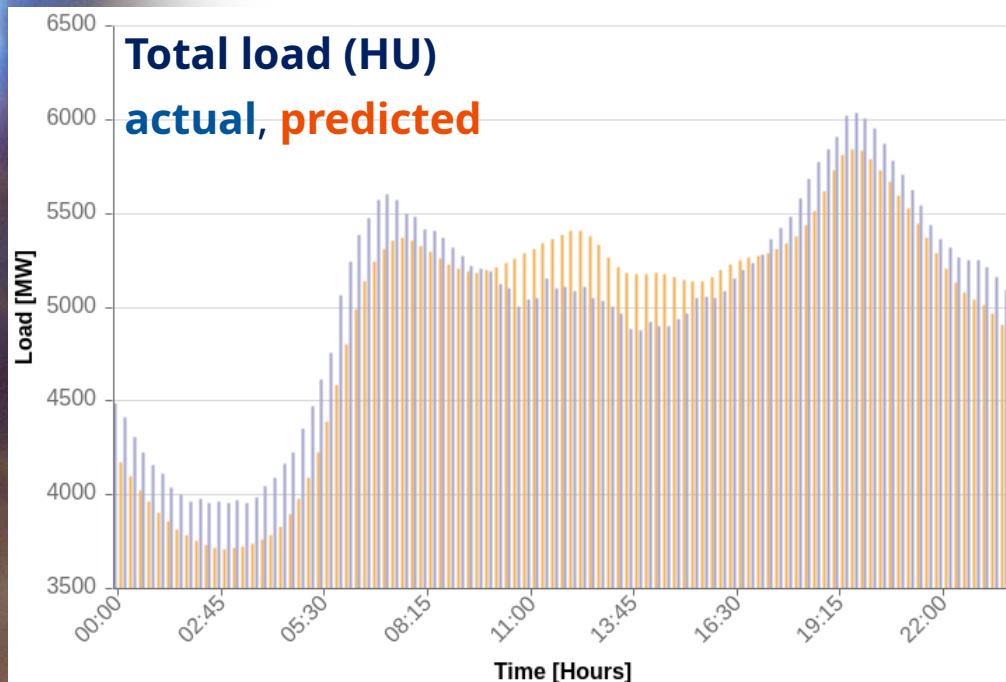
In this task, the best predictive supervised learning method was XGBoost

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:

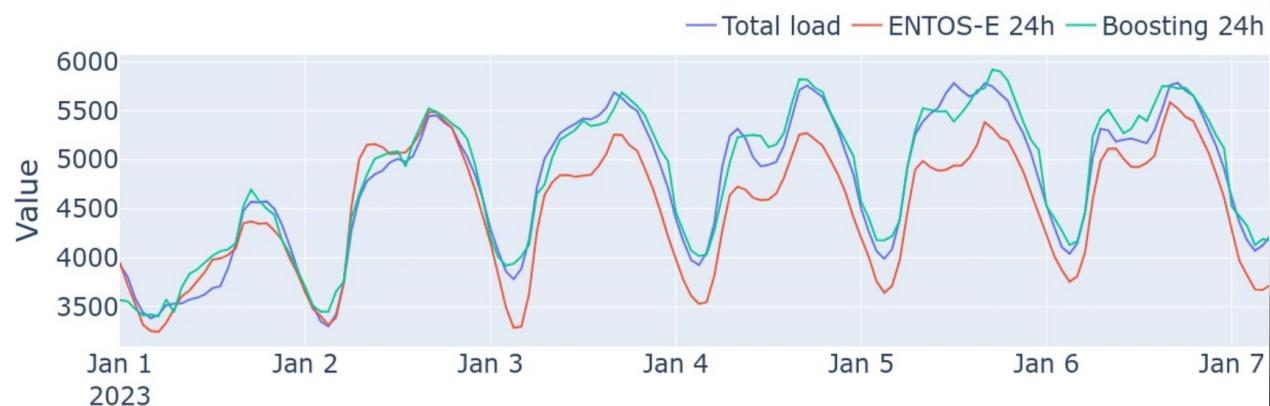
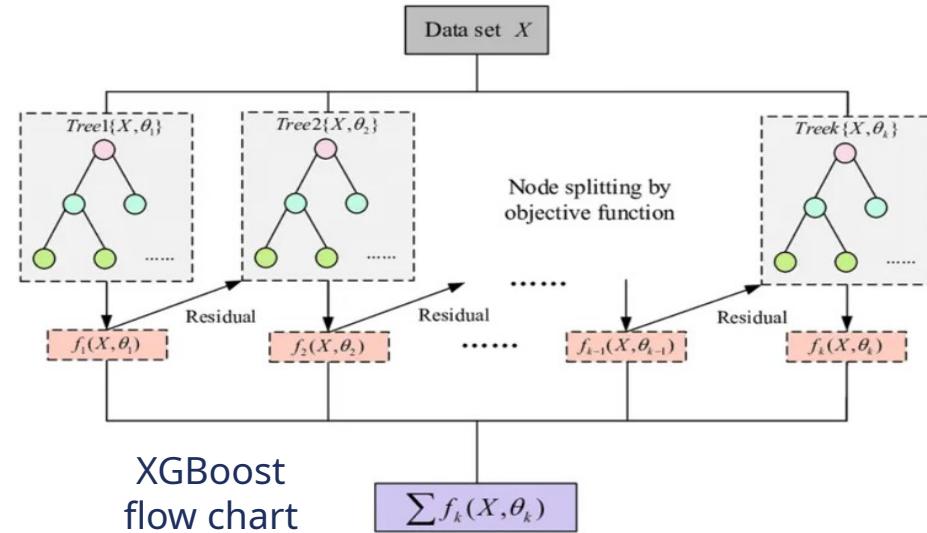
- **XGBoost**, decision tree-based hybrid method

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")

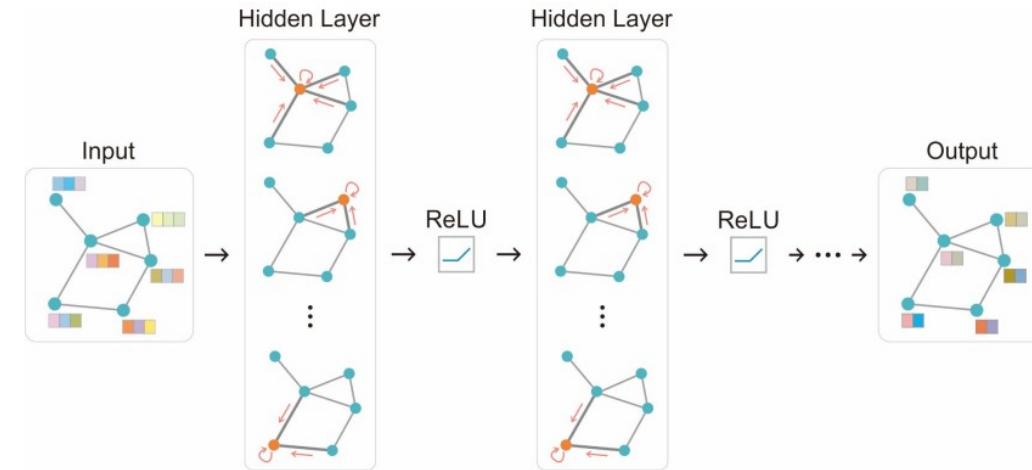
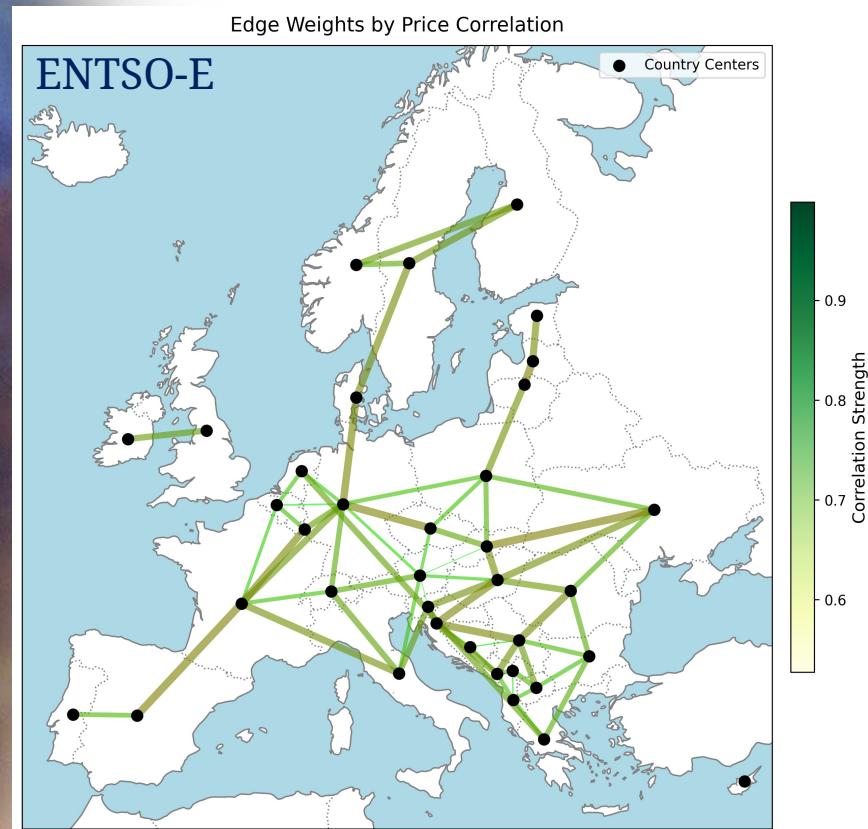


Electricity price forecasting with graphs (MSc)

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

Task:

Forecasting day-ahead electricity prices with hourly resolution.

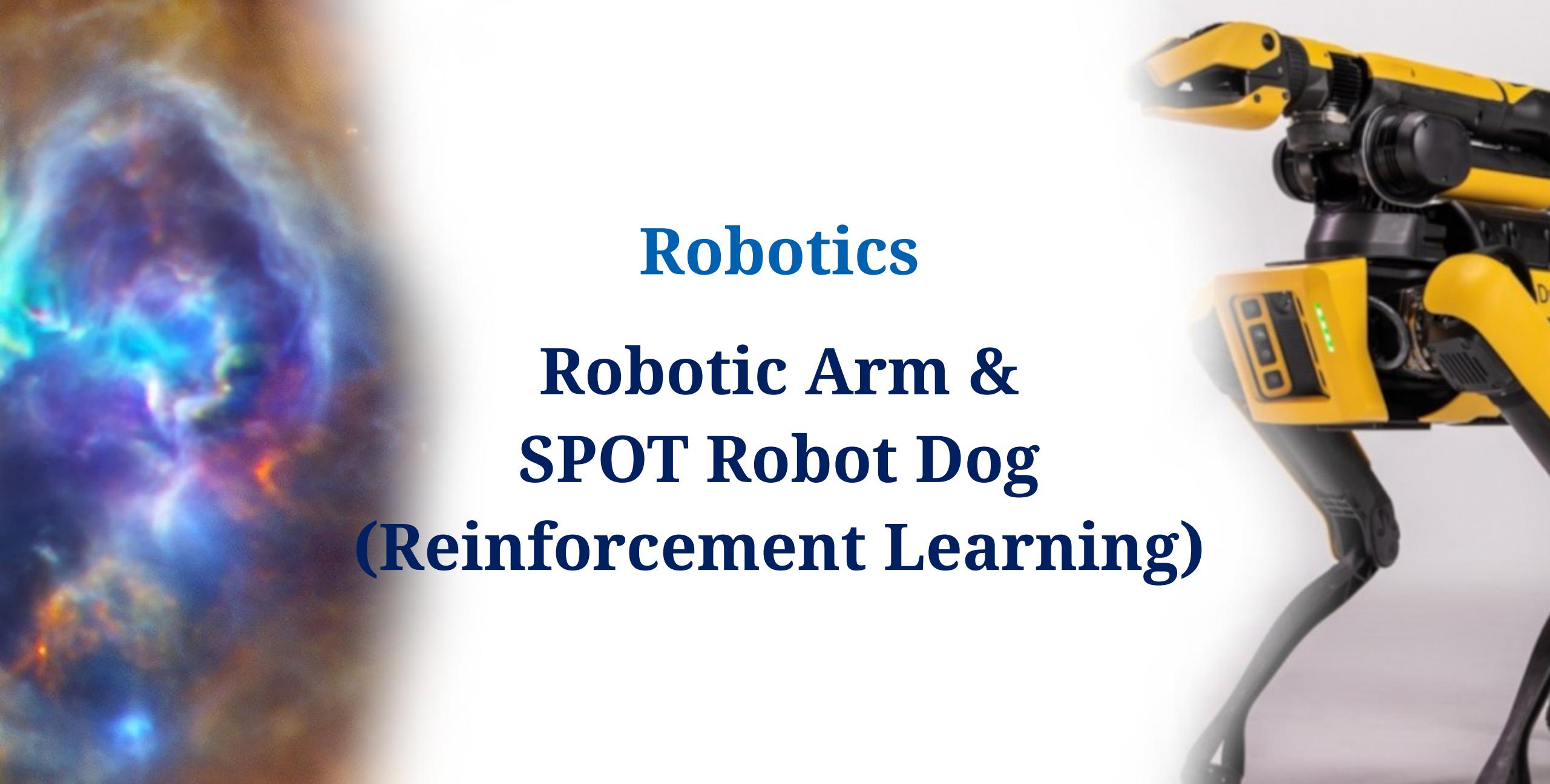


Architecture of the
Graph Convolutional Network (GCN) model

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

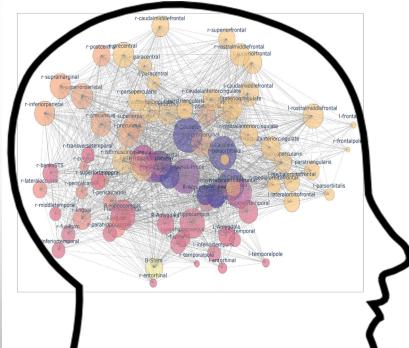
(Reinforcement Learning)

QUANSER QArm Robotic Arm

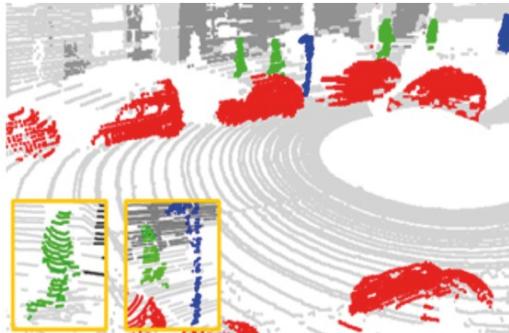


Robotic Arm in the Ligeti Kindergarten
in Pilisvörösvár (4–6 year olds, Oct. 2024)

AI National Lab. (MILAB) – Research Areas



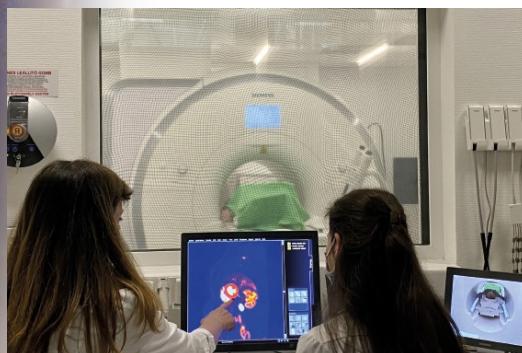
WP1: Foundations of AI



WP2: Machine Perception

gyártás logisztika döntési Vezetőség döntések
Mesterséges Intelligencia erőfeszítéseket Stratégiajával igények
fejlesztési agrár kiegészítő MILAB modellek projektek
kiemelt mélytanulás Nemzetközi
irányok kapcsolatok alkalmazások kritikus
alkalmazott MI technológia magyar
kijelölt közlekedés gyártás alkalmazási
személyes adatok piaci alkalmazási
amatőrök matematikai Vezető nemzeti
innováció kutatási egészségügyi
kutatás Koordináció adat Szakmai
Pillér társadalmi gépi kutatások ipar
adatok hazai valósítja művelt alap
helyszínen művek távközlés

WP3: Human Lang. Proc.



WP4: Medical, Health,
and Bio Applications

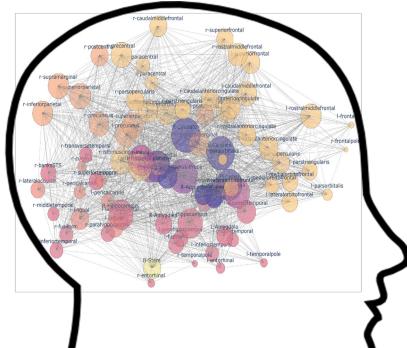


WP5: Sensors, IoT, and
Telecomm.

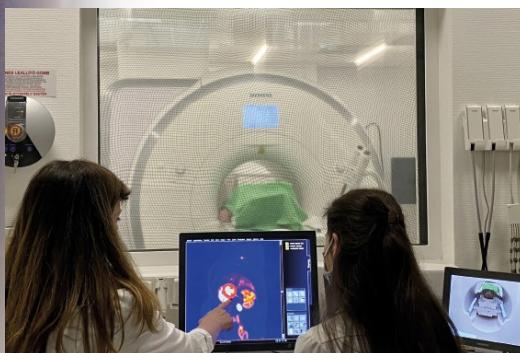


WP6: Security and Privacy

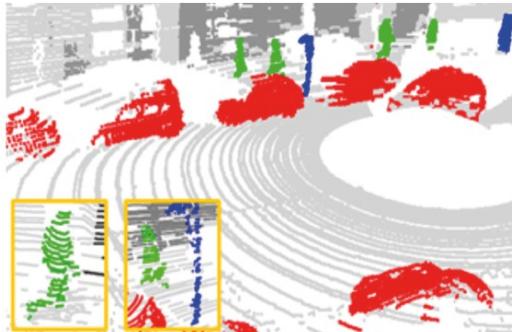
AI National Lab. (MILAB) – Research Areas



WP1: Foundations of AI



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szolgáltatások közelében
szükséges témá Magyarország
szükséges témá Pillér
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szükséges témá Pillér

WP3: Human Lang. Proc.

our
robotic
tasks



WP6: Security and Privacy

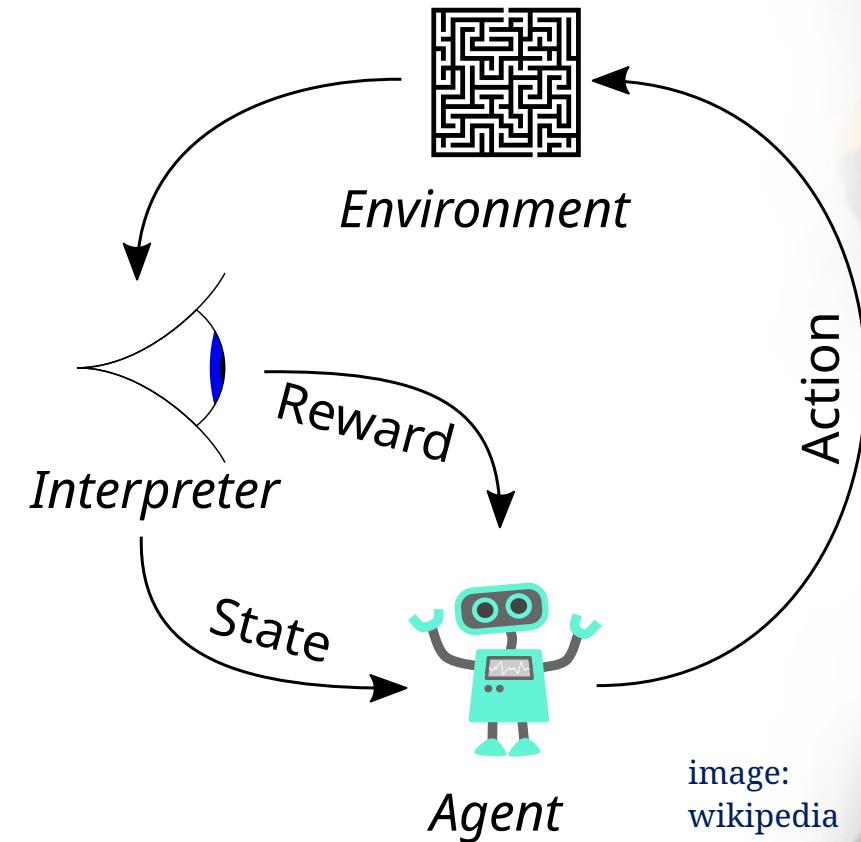
QArm – Block tower building with RL

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.



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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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...

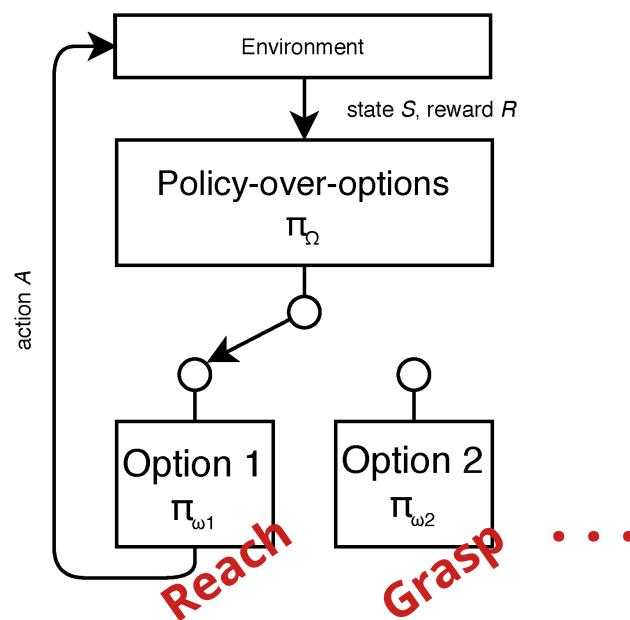
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Block tower building with –Hierarchical– RL

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



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)



HUN
REN | SZTAKI



fotó: Telex

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)

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



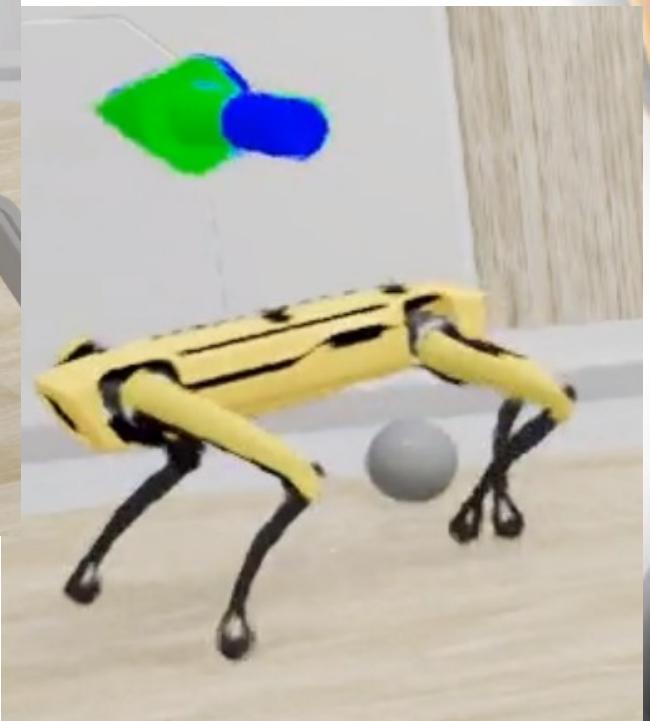
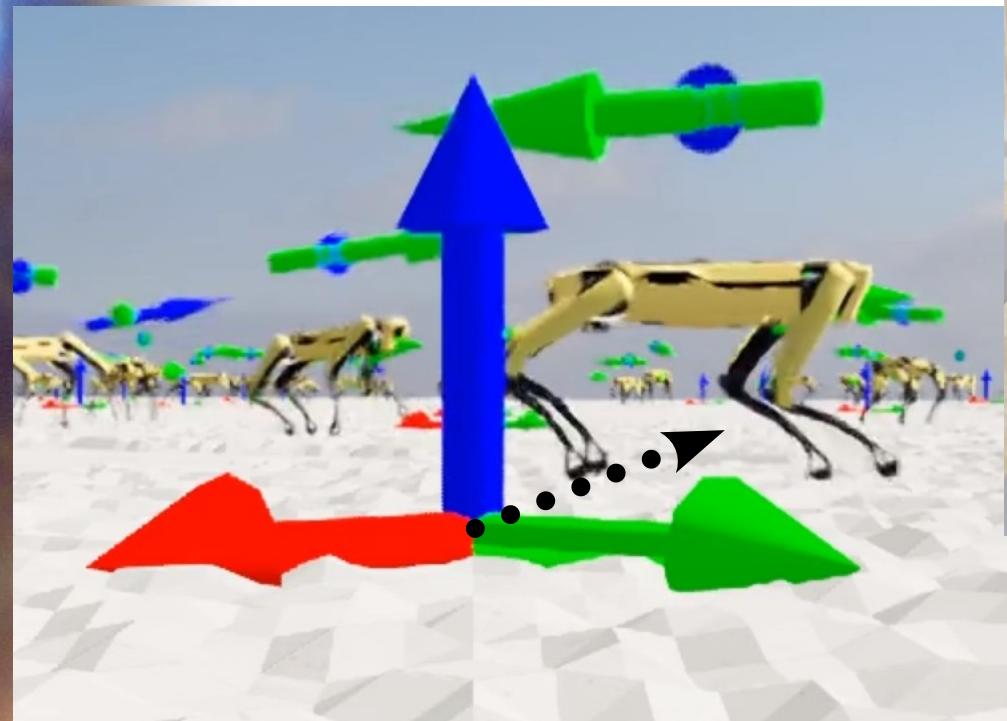
Simulation environment: NVIDIA Isaac Lab / Isaac Sim (PhysX, RTX)

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

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)

Simulated elementary tasks moments



Thanks for the Attention!

