Safe and Efficient Reinforcement Learning for Environmental Monitoring

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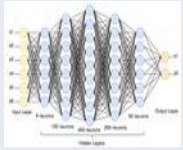
Ital-IA 2023, 30/05/2023
Workshop AI per la Sostenibilità

Our Research: areas and goals

Research areas

Reinforcement Learning



Machine Learning

Planning and High Level Control

Time Series Forecasting

Logic Programming

Anomaly Detection

Formal Verification

Goals

Efficiency

Safety
Trustability
Explainability

Applications and Projects Related to Sustainability

Water Monitoring with ASV

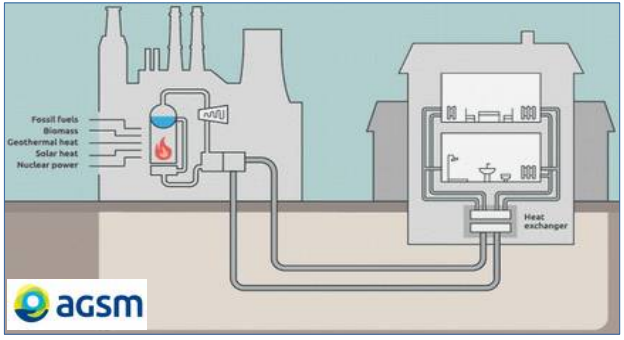
INTCATCH 2020

- ≈8.7 M€ funding from EU
- 20 partners across EU
- Tight collaboration with companies

Italiadomani I-NEST

- **Interconnected Nord-Est Innovation (PNRR)**
- ≈110 M€ funding from MUR
- 27 partners across EU
- Tight collaboration with companies

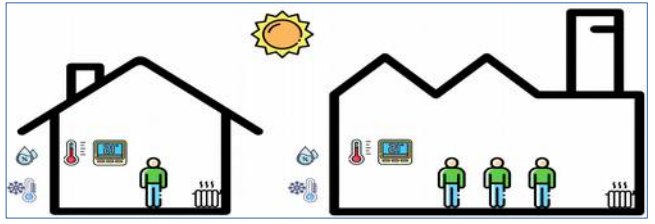
Efficiency Improvement of District Heating Networks



GHOTEM Veneto Clima Energia POR

- **Global HOuse Thermal & Electrical energy Management**
- ≈5.7 M€ funding from EU
- 14 partners across Veneto
- Tight collaboration with companies

Sustainable Living in Smart Buildings



SAFE PLACE Veneto Clima Energia POR

- **Sistemi IoT per ambienti di vita salubri e sicuri**
- ≈8.7 M€ funding from EU
- 20 partners across EU
- Tight collaboration with companies

CORE-WOOD FORESTAOROVENETO POR

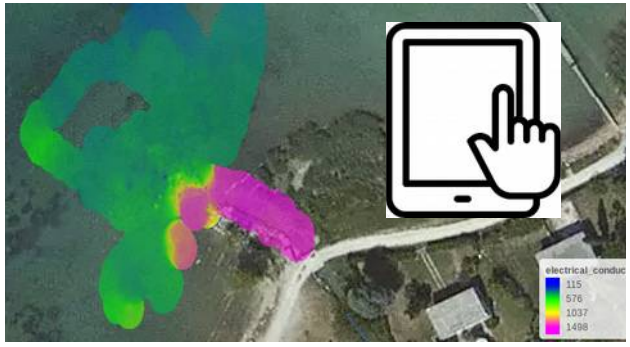
- **Riposizionamento competitivo della filiera del legno**
- ≈4.8 M€ funding from EU
- 17 partners across EU
- Tight collaboration with companies

1. Autonomy for ASV Involved in Water Monitoring (INTCATCH)

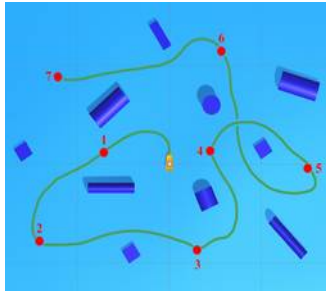
Operate beyond line of sight

Repeatable measurements

Citizen science

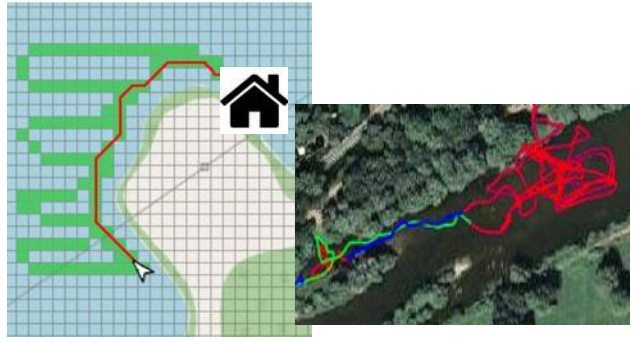


Safe DRL for Navigation in Aquatic Scenarios (shielding based on ANN Verification)



INTCATCH 2020

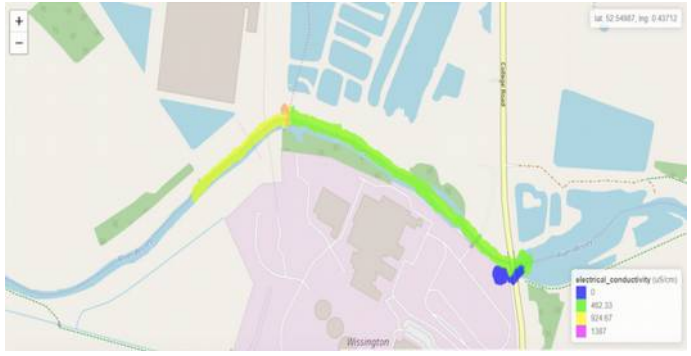
Planning under Uncertainty for High Level Control



Use of INTCATCH Drones

- 10 Drones (3 IT, 3 UK, 2 ESP, 2 GRE)
- **More than 250 data collecting missions** (about 50 UNIVR)
- NGO engagement: 190 individuals (Thames21)
- Engagement of key stakeholders (e.g. ARPAV Italy)
- Data easily available http://waquin.intcatch.eu/

Fimon Lake, IT (DO)
Together with ARPAV



Wissey River, UK (EC)

Recent publications

- D. Corsi, E. Marchesini, A. Farinelli, **Formal Verification of Neural Networks for Safety-Critical Tasks in Deep Reinforcement Learning**, in: Proc. 37th Conf. on Uncertainty in Artificial Intelligence (**UAI**), 2021.
- E. Marchesini, D. Corsi, A. Farinelli, **Benchmarking safe deep reinforcement learning in aquatic navigation**, in: 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (**IROS**), 2021.

Formal Verification of RL

- L. Steccanella, D. D. Bloisi, A. Castellini, A. Farinelli, **Waterline and obstacle detection in images from low-cost autonomous boats for environmental monitoring**, Robotics and Autonomous Systems (**RAS**) 124 (2020) 103346.

Obstacle Detection (Images)

- D. Azzalini, A. Castellini, M. Luperto, A. Farinelli, F. Amigoni, **Hmms for anomaly detection in autonomous robots**, in: Proceedings of the 19th International Conference on Autonomous Agents and MultiAgent Systems (**AAMAS**), IFAAMAS, 2020, pp. 105–113.

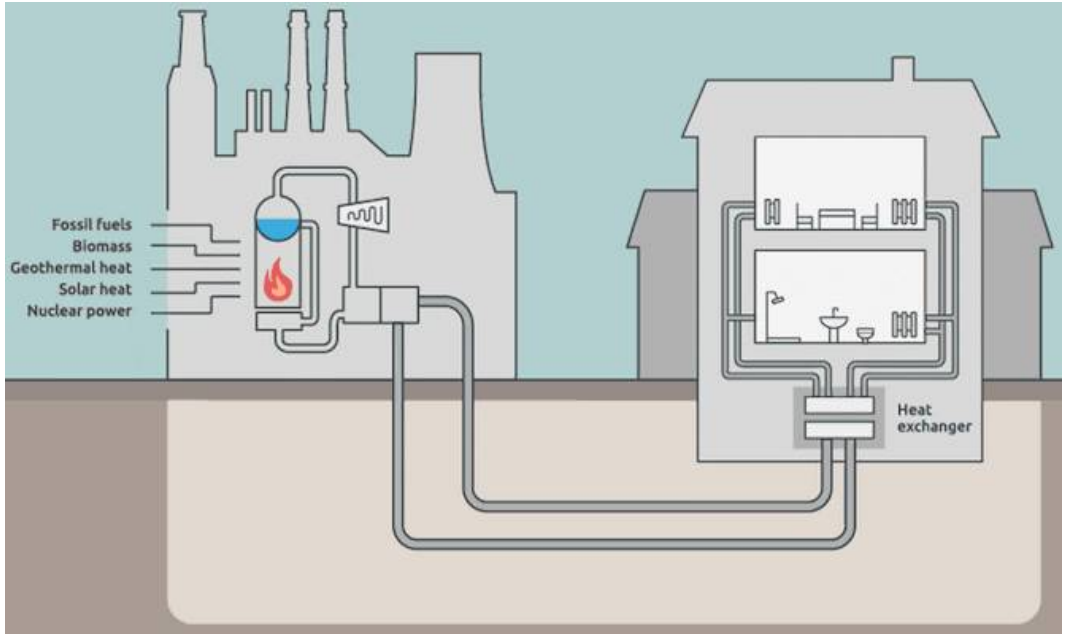
Obstacle Detection (Time Series)

- G. Mazzi, A. Castellini, A. Farinelli, **Identification of unexpected decisions in partially observable monte-carlo planning: A rule-based approach**, in: Proceedings of the 20th International Conference on Autonomous Agents and MultiAgent Systems (**AAMAS**), IFAAMAS, 2021, p. 889–897.
- G. Mazzi, D. Meli, A. Castellini, A. Farinelli, **Learning logic specifications for soft policy guidance in POMCP**, in: Proceedings of the 22nd Conference on Autonomous Agents and MultiAgent Systems (**AAMAS**), IFAAMAS, 2023. Accepted.

Anomaly Detection and Explainability (POMDPs)

2. Demand Forecasting in District Heating Networks (GHOTEM)

District Heating Network

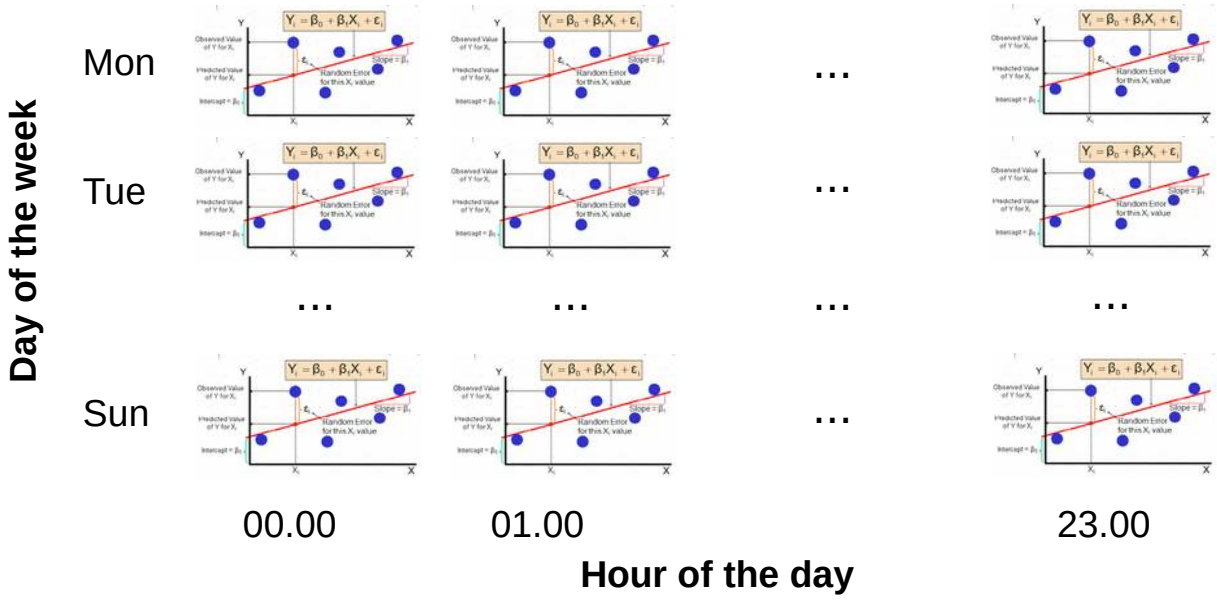


Goal: to **predict** the heating load in the next 48 hours

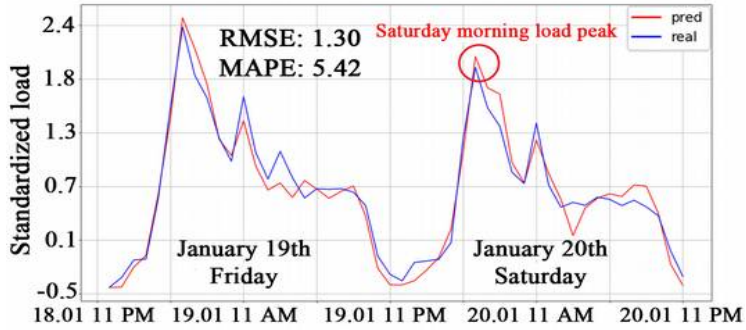
- **Heating** and **cooling** demand: 40% of the overall energy usage in Europe
- Pollution control
- Sustainable development
- Improved power station maintenance
- Predictive model **interpretability**

Our Solution: a Multi-Equation Linear Regression Model

To preserve both **interpretability** and **predictive ability** we used a **multi-equation multivariate linear regression model**



Results using (interpretable) regression models



Other solutions to forcasting using different methods

Recent publications

- A. Castellini, F. Bianchi and A. Farinelli. **Generation and interpretation of parsimonious predictive models for load forecasting in smart heating networks**. **Applied Intelligence**, Springer Nature, 2022
- A. Castellini, F. Bianchi, A. Farinelli. **Predictive model generation for load forecasting in district heating networks**. **IEEE Intelligent Systems**, 36(4):86-95, 2021
- F. Bianchi, A. Castellini, P. Tarocco, A. Farinelli. **Load Forecasting in District Heating Networks: Model Comparison on a Real-World Case Study**. In Proceedings of the Fourth International Conference on Machine Learning, Optimization, and Data Science (**LOD**), 2019, **LNCS** 11943, pages 553-565, Springer-Verlag, 2020

Multivariate Regression

- F. Bianchi, P. Tarocco, A. Castellini, A. Farinelli. **Convolutional Neural Network and Stochastic Variational Gaussian Process for Heating Load Forecasting**. In Proceedings of the Fifth International Conference on Machine Learning, Optimization, and Data Science (**LOD**), 2020, **LNCS** 12514, pages 244-256, Springer-Verlag, 2020

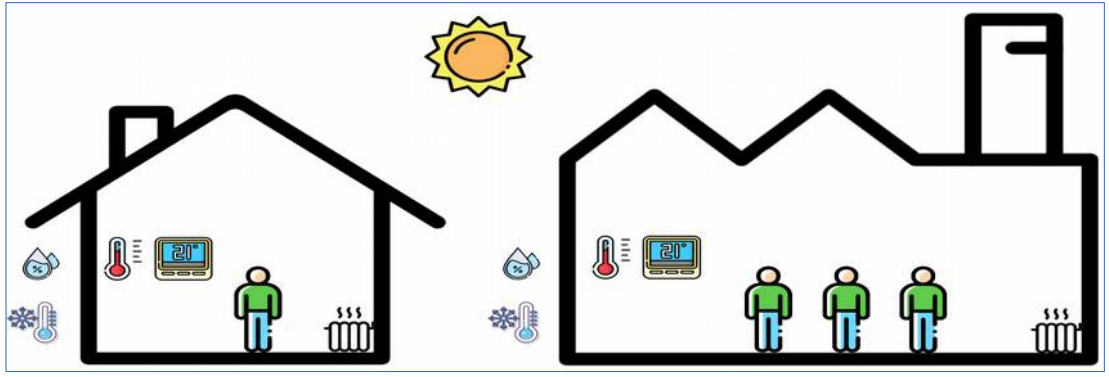
CNN and GP

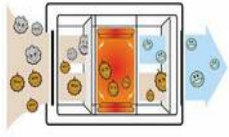
- F. Bianchi, F. Masillo, A. Castellini, A. Farinelli. **XM HeatForecast: Heating Load Forecasting in Smart District Heating Networks**. In Proceedings of the Fifth International Conference on Machine Learning, Optimization, and Data Science (**LOD**), 2020, **LNCS** 12514, pages 601-612, Springer-Verlag, 2020

Software

3. Air Quality Control in Smart Buildings (SAFE PLACE)

Smart Buildings



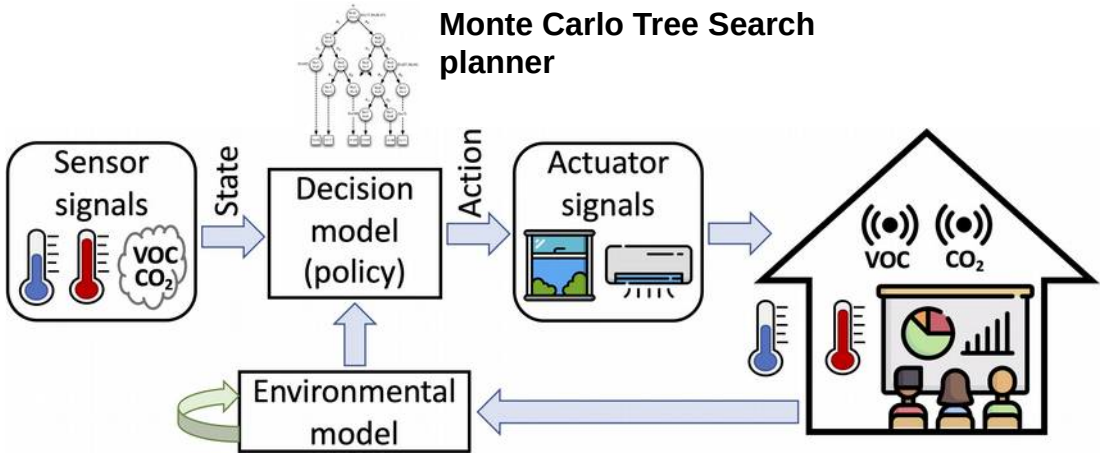


Goal: to optimally **control** air quality and thermal comfort in smart buildings

- Measures to counter the SARS-Cov-19 pandemic
- **Sustainable living**
- Improved **indood air quality**
- Reduced environmental impact of **HVAC** systems
- **Sequential decision making** with **uncertainty**

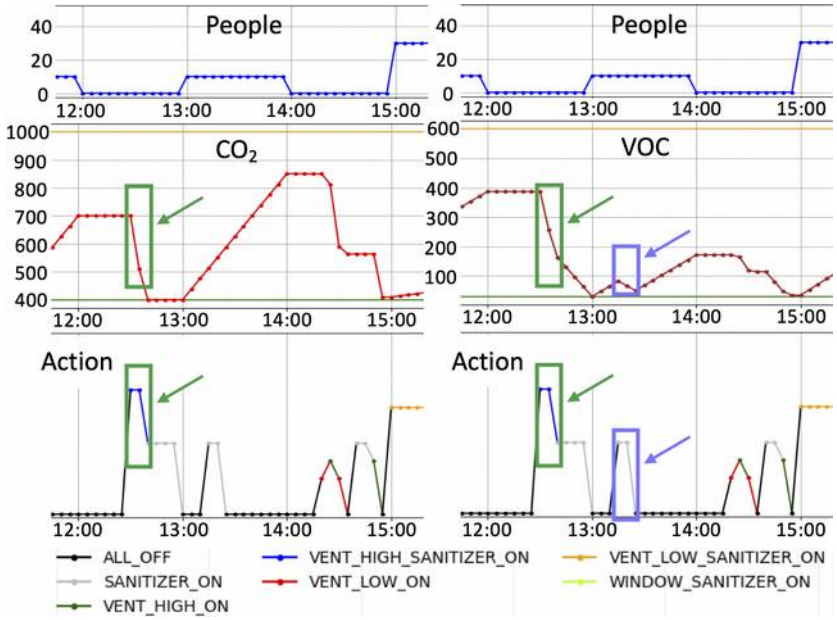
Our Solution: Adaptive Model-Based RL with MCTS

Framework

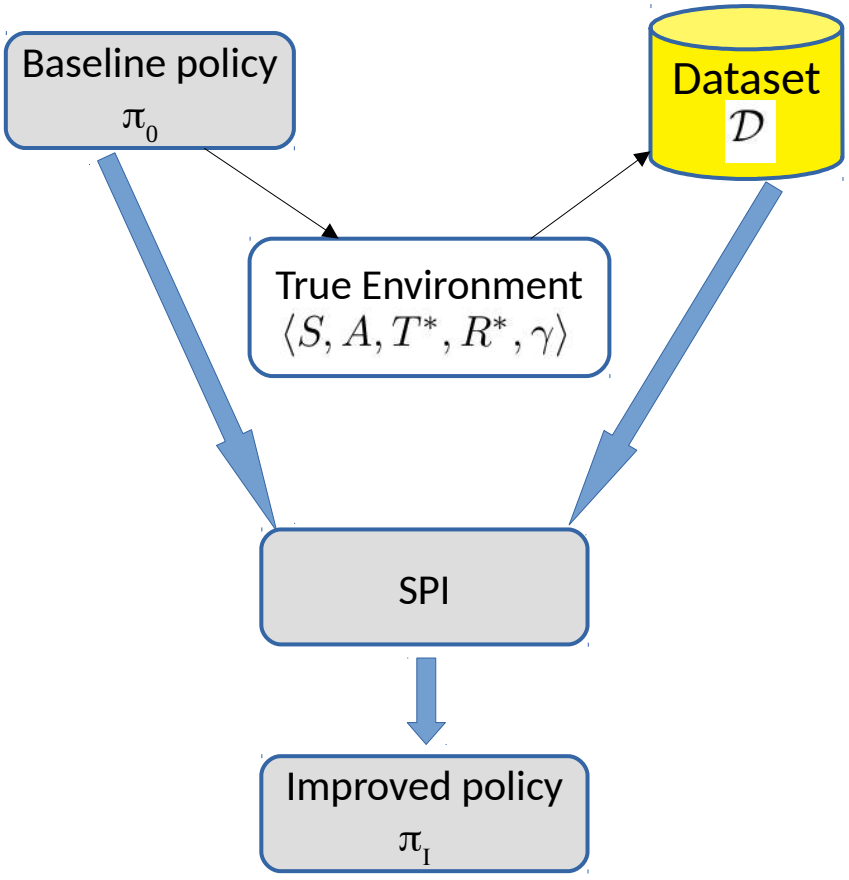


Adaptive RL for Air Quality Control

Results using our MCTS-based planner



Safe Policy Improvement

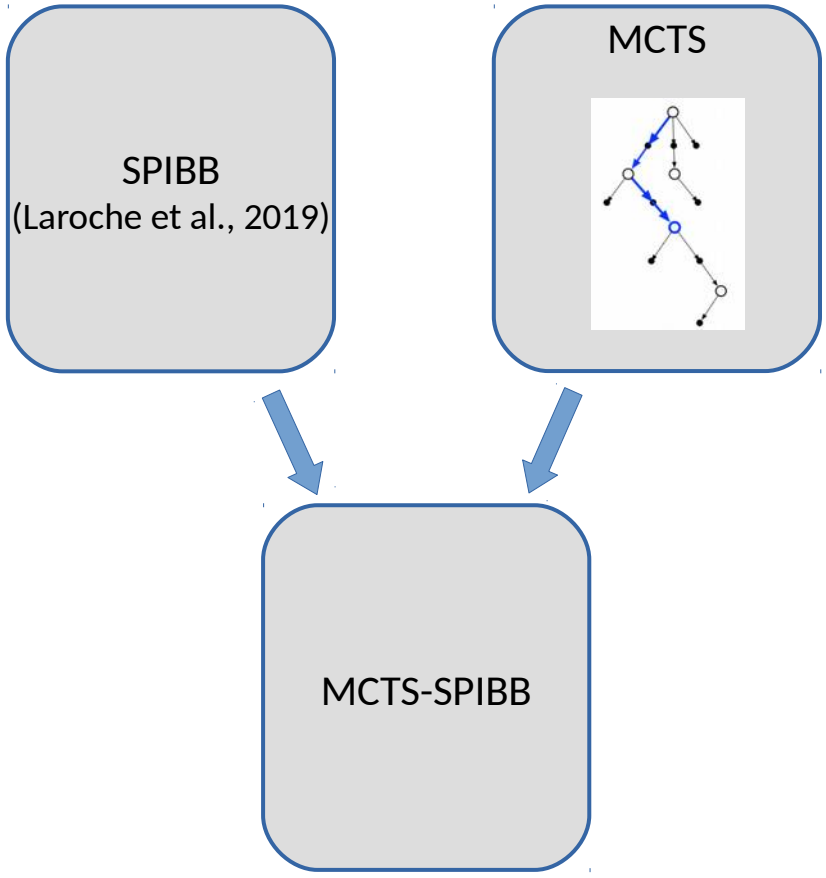


Notation:

- **True environment** $\langle S, A, T^*, R^*, \gamma \rangle$
- Unknown **transition model** T^*
- Known **reward function** R^*
- Known **baseline policy** π_0
- Known **dataset of trajectories** $\mathcal{D} = \langle s_j, a_j, r_j, s'_j \rangle_{j \in [1,N]}$ generated by the **baseline policy** in the **true environment**
- **Performance** of policy π on environment M: $\rho(\pi, M) = V_M^{\pi}(s_0)$

- **Problem: Can we generate a policy π_I that "safely" improves the performance of π_0?**

Our Solution: MCTS-SPIBB



Recent publications

- M. Capuzzo, A. Zanella, M. Zuccotto, F. Cunico, M. Cristani, A. Castellini, A. Farinelli, L. Gamberini, **IoT systems for healthy and safe life environments**, in: 7th IEEE Forum on Research and Technologies for Society and Industry Innovation (**RTSI**), 2022.

Safe Place RL/Planning

- A. Castellini, G. Chalkiadakis, A. Farinelli, **Influence of State-Variable Constraints on Partially Observable Monte Carlo Planning**, in International Joint Conference on Artificial Intelligence (**IJCAI**), ijcai.org, 2019, pp. 5540–5546.

- M. Zuccotto, A. Castellini, A. Farinelli, **Learning state-variable relationships for improving POMCP performance**, in: Proceedings of the 37th ACM/SIGAPP Symposium on Applied Computing (**SAC**), Association for Computing Machinery, 2022, p. 739–747.

Prior Knowledge In POMCP

- A. Castellini, F. Bianchi, E. Zorzi, T. Simao, A. Farinelli, M. Spaan. **Scalable Safe Policy Improvement via Monte Carlo Tree Search**, International Conference on Machine Learning (**ICML**), 2023, accepted.

MCTS-SPIBB

Infrastructures

Intcatch drones

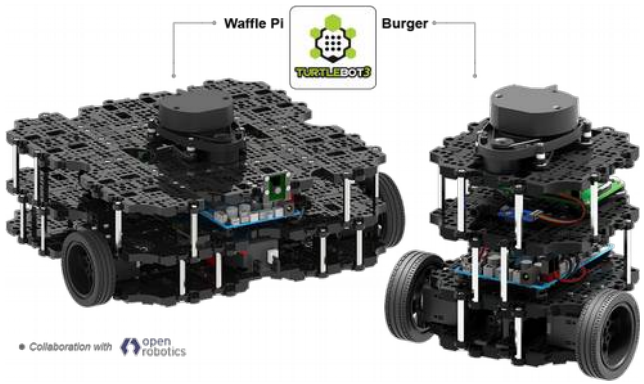
3 ASV

ICE-Lab: Research infrastructure, realistic production line for validation (https://www.icelab.di.univr.it/)

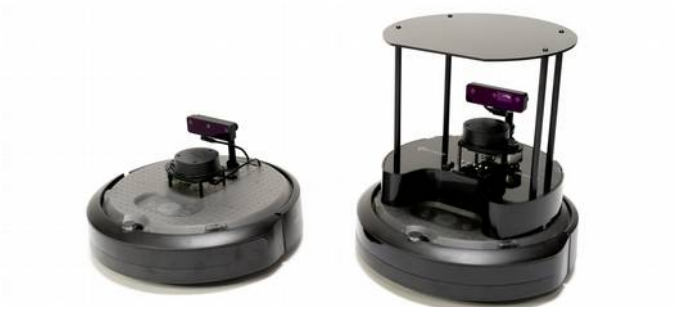
2 RB Kairos

? Kuka?

Turtlebots



5 Turtlebot3



2 Turtlebot5

Links with the new LM in Artificial Intelligence @Univr

Machine Learning & Deep Learning (12 CFU)

Statistical learning (6 CFU)

Planning & Automated Reasoning (12 CFU)

Knowledge Representation (6 CFU)

Reinforcement Learning & Advanced Programming for AI (12 CFU)

AI in Robotics (6 CFU)

Explainable AI (6 CFU)

~ ISLa People ~

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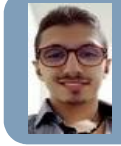

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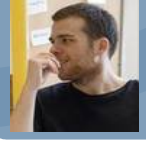

D. Corsi
AdR

Thank you!

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