ROBOPROX

RA7
Human-machine collaboration

Robert Babuska & team

Department of Artificial Intelligence, CIIRC

14. 3. 2024

Co-funded by the European Union

MINISTRY OF EDUCATION, YOUTH AND SPORTS

Robotics and Advanced Industrial Production
CZ.02.01.01/00/22_008/0004590

RA7 Team - Staff

Prof. Robert Babuska (lead)

Dr. Karla Stepanova (co-lead)

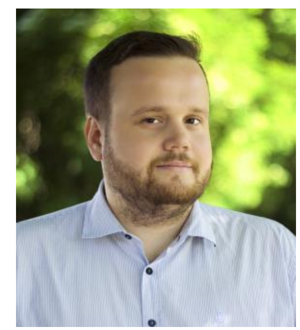
Dr. Jan Behrens

Prof. Vaclav Hlavac

Dr. Jiri Kubalik

Dr. Radoslav Skoviera

Dr. Karel Smolek



Dr. Jan Zahalka

+1 PD and 2 PhD vacancies

RA7 Team – PhD students and Postdocs

Petr Vanc (PhD student)

+1 PD and 2 PhD vacancies

RA7 Research Topics

- Modular knowledge-enabled architecture for HRC (**Stepanova**, **Skoviera**)
- Interactive skill and task specification, learning (Babuska, Zahalka, **Kubalik**)
- Planning, scheduling and execution of tasks in the HRC workspace (**Behrens**)
- Interactive perception (Hlavac, **Skoviera**)
- Application to a robotic system for radiation detection (**Smolek**)

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Collaborations

Existing:

TU Delft, Bosch (Renningen), University of Bremen, University of Amsterdam, Reykjavík University, University of Birmingham, Factorio Solutions, ...

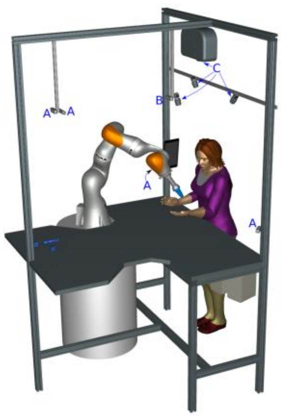
Planned withing ROBOPROX:

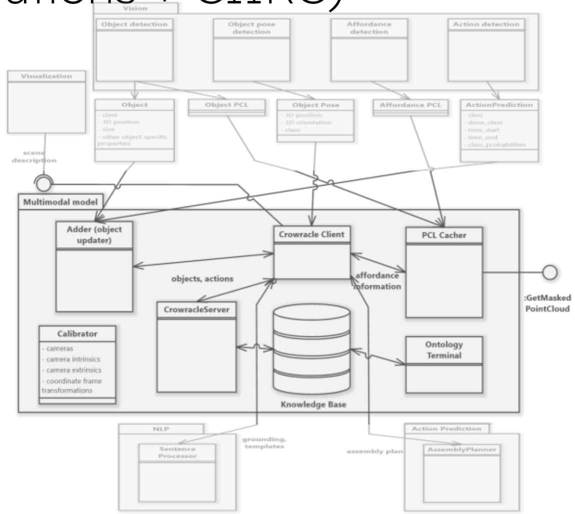
RA13 (Kadera), RA9 (Svoboda), RA8 (Saska), RA10 (Faigl), RA14 (Janota), RA6 (Preucil), RA9 (Hoffman), DFKI (Korbayova)

Modular knowledge-enabled architecture for HRC

Collaborative robotic workspace - functional sample

(Factorio Solutions + CIIRC)

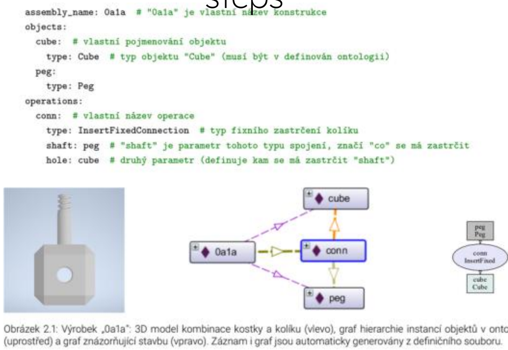




Testbed workplace

Experimental setup A404

Representation of assembly products for detection and prediction of assembly steps



Project description:
http://imitrob.ciirc.cvut.cz/projects/crow/

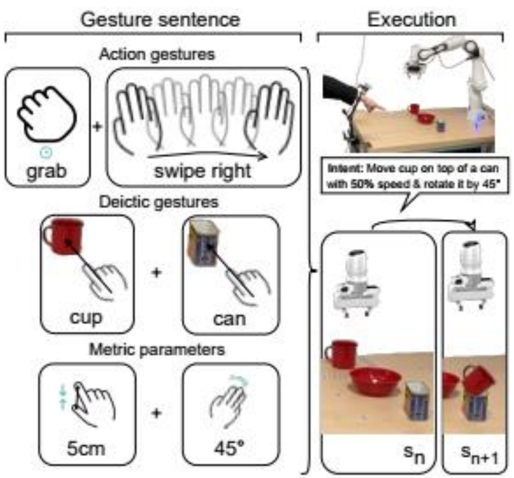
Modular knowledge-enabled architecture for HRC – Interactive perception

What we will aim for:

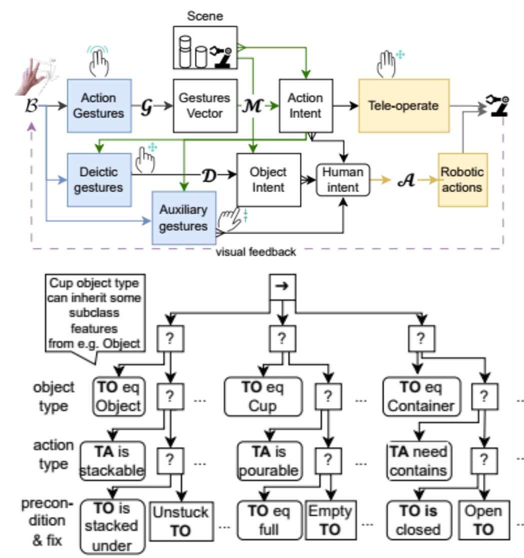
- Specifying use-cases and evaluation metrics
- Learning unknown properties via interactive perception
- Improving effectiveness of the communication and robustness of knowledge representation
- **Cooperation**: P. Kadera (G13), Daniel Bessler, University of Bremen

Modular knowledge-enabled architecture for HRC – Skill and task representation

Instructing robot via gestures



- Proposed gesture pseudolanguage, multiple types of gestures can be combined to express human intent to a robot (i.e., expressing both the desired action and its parameters)
- Real-time processing of task instruction
- Context-awarness
- Reactive robot behavior via behavior trees



Vanc, P., Behrens, J. K., Stepanova, K., & Hlavac, V. (2023). Communicating human intent to a robotic companion by multi-type gesture sentences. IROS, 2023. http://imitrob.ciirc.cvut.cz/publications/chi23/index.html

Vanc, P., Behrens, J. K., & Stepanova, K. (2023). Context-aware robot control using gesture episodes. ICRA, 2023 https://github.com/imitrob/context_based_gesture_operation

Teleoperation gesture toolbox: https://github.com/imitrob/teleop_gesture_toolbox

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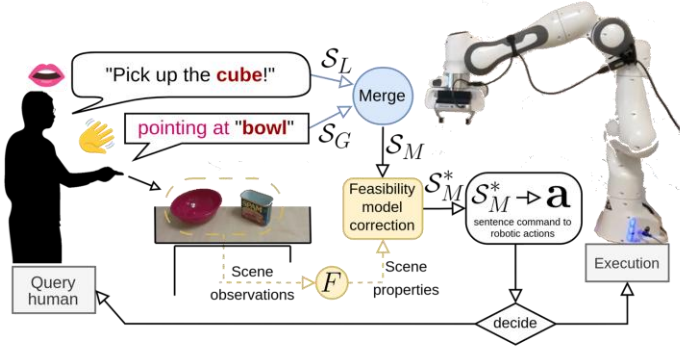
Modular knowledge-enabled architecture for HRC – Skill and task representation

What we will aim for:

- Learning skills and tasks (including preconditions, goals and parameters) from multimodal demonstration
- Incorporating planning and scheduling modules
- Reusable task representation, (e.g., individual skills represented by reusable subtrees)
- Probabilistic model on top of the actual task description to decide about next actions (i.e., acting, querying a user, etc.)
- Multimodal dialogue-based communication
- **Cooperations**: LfD: K. Zimmermann (G9), Jens Kober (TU Delft), Testing on other setups (M.Hoffmann (G9), M.Beetz, University of Bremen)

Multi-modal human-robot dialogue



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RO 7.2: Interactive skill and task specification, learning

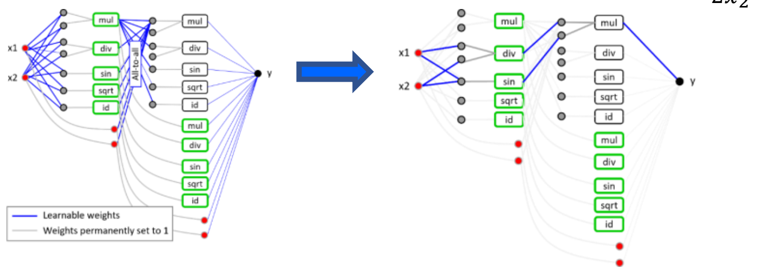
Symbolic regression (SR) automatically generates models as analytic free-form formulas from data.

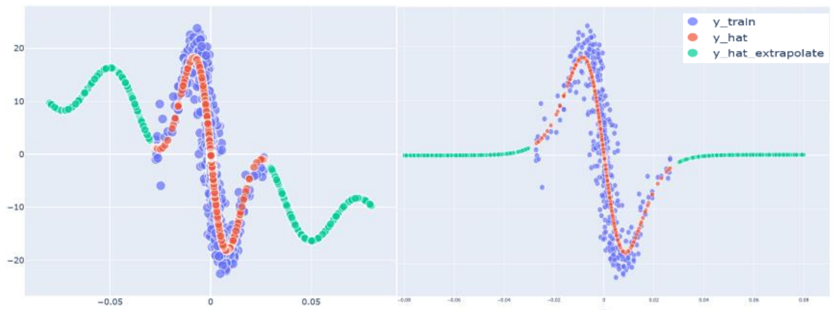
- Genetic programming – gradient-free evolutionary optimization approach that evolves a population of formulas.
- Neural network – gradient-based learning process
  - Ordinary NN learned towards a sparse topology representing a compact analytic formula.
  - Transformer learned to generate formula for given data.
- SR can incorporate prior knowledge about the desired properties of the modeled system, thus allowing the construction of precise and physically plausible models.

Master NN

Model:

$$y = \sin(0.3x_1 - 1.2x_2)\,\frac{x_1}{2x_2}$$





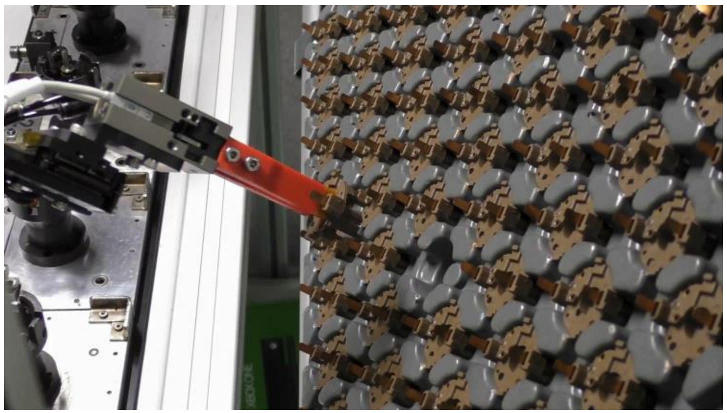
Jiří Kubalík, Erik Derner, Robert Babuška: *Toward Physically Plausible Data-Driven Models: A Novel Neural Network Approach to Symbolic Regression*. IEEE Access 11: 61481-61501 (2023)

RO 7.2: Interactive skill and task specification, learning

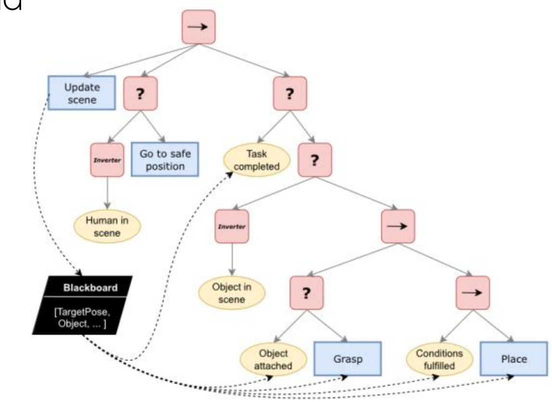
- What we will aim for:
  - Develop hybrid GP/NN-based SR approaches.
  - Investigate new mechanisms to incorporate prior knowledge into SR.
  - Investigate the possibilities to use large language models to assist with defining the underlying physics constraints for the studied system.
  - Develop SR methods to solve problems that lead to implicit equations, e.g., partial differential equations.
- International collaboration:
  - Miguel Fernandez Cortizas (Universidad Politécnica de Madrid)
  - Sunny Katyara (Irish Manufacturing Research)
- Cooperation with other RAs:
  - M. Macaš – RO 13.3: Quality Control in Flexible Manufacturing Systems

Planning, scheduling, and execution of tasks in the HRC workspace

Coordinating cooperating agents on shared tasks



- Schedule and dispatch heterogenous agents in time and space.
- Reduction to discrete optimization (Constraint Programming) problems allows flexible combination of diverse constraints (e.g., temporospatial coordination and task precedences)
- Connect safe and efficient robot control with online decision making (skill representation, reactive control via Behavior Trees)



Behrens, JK, Stepanova, K., & Babuska, R. (2020, May). Simultaneous task allocation and motion scheduling for complex tasks executed by multiple robots. In *2020 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 11443-11449). IEEE.

Planning, scheduling, and execution of tasks in the HRC workspace

What we aim for:

- To make robots smart, attentive, and proactive coworkers.
- Apply online and uncertainty-aware planning and scheduling to Human-Robot Collaboration scenarios.
- Explore sliding autonomy and reactive control to achieve higher performance and efficiency.

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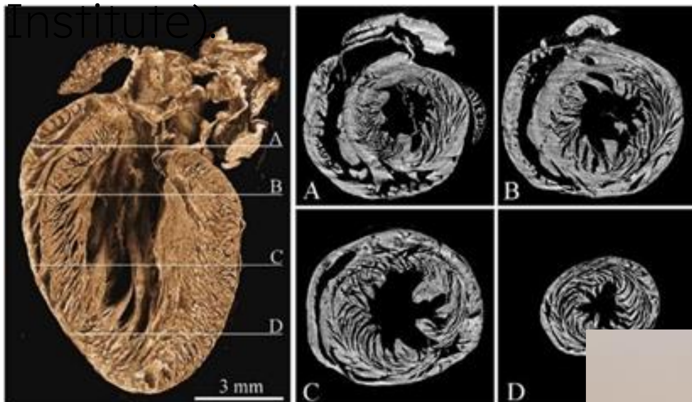
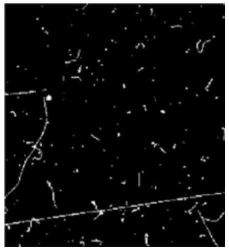
Uncertainty-Aware Human-Robot Collaboration Using Scheduling and Reactive Control

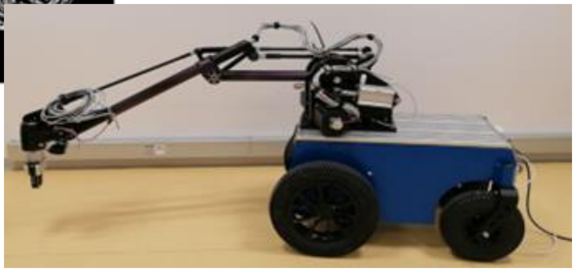
Author: Marina Ionova
Supervisor: Dr. Jan Kristof Behrens, MSc.

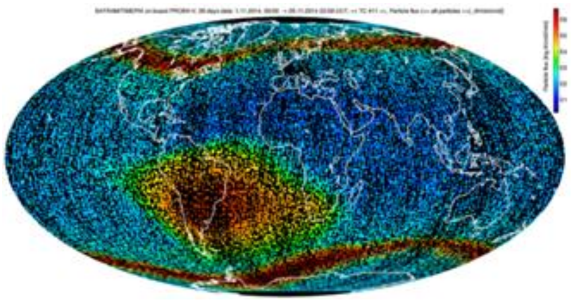
Application to a robotic system for radiation detection

- Institute of Experimental and Applied Physics – member of the Medipix collaboration (CERN) for the development of semiconductor pixel detectors of ionizing particles.
- Developed algorithms for particle identification (pattern recognition, neural networks…) and applications in fundamental physics experiments, high resolution CT, space applications, robotic system for radiation safety – for manipulation with radioactive objects, for 2D scanning of contaminated wounds (collaboration with CIIRC and National Radiation Protection Institute).









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Application to a robotic system for radiation detection

Plans for the ROBOPROX project:

- Development of the robotic arm able to scan 3D surface for a radioactive contamination
- Recognition of alpha, beta, gamma contamination using advanced Medipix/Timepix semiconductor pixel detectors.
- Development of radiation resistant pixel detectors useful for the mentioned applications.

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Thank you for your attention!

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BRNO UNIVERSITY OF TECHNOLOGY

VSB TECHNICAL UNIVERSITY OF OSTRAVA

UNIVERSITY OF WEST BOHEMIA

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