THE SURFACE AVATAR EXPERIMENT:

A GLIMPSE INTO THE FUTURE OF ASTRONAUT-ROBOT COLLABORATION FOR PLANETARY INFRASTRUCTURE MAINTENANCE

Dr.-Ing. Daniel Leidner

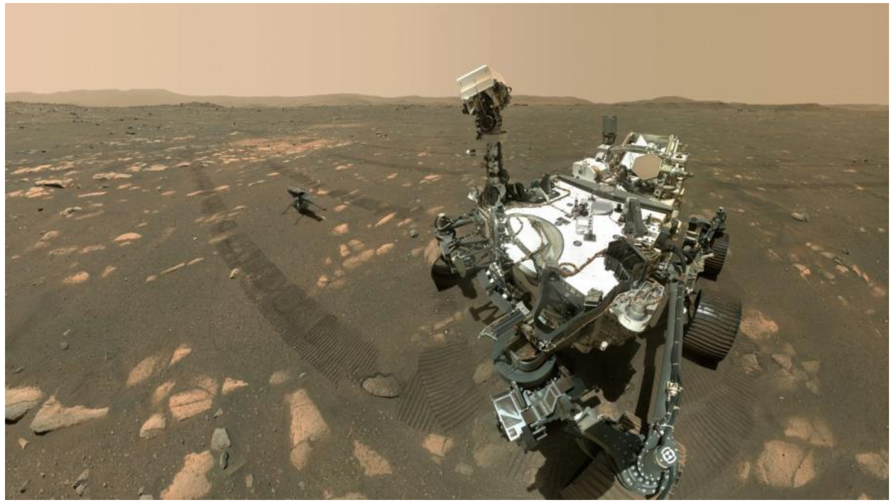
Where Are we with Teleoperation and Autonomy in Space Robotics with the State of the Art?

Teleoperation

- Activity plans dictate the mission of Mars rovers step by step [1]
- Cameras provide information from different views, also in 3D [2]
- Hazard maps inform operators about terrain for safe traversal [3]

Autonomy

- Recent updates in the software architecture allow for autonomous execution of longer sequences [4]
- Autonomy infused navigation enabled a distance record drive of 245.76 meters [5]
- **However, there is no fallback through either human intervention or robotic intelligence available**



Credit: NASA

The Next Step in Crewed Exploration of Moon and Mars

On-ground Assistance Robots

On-orbit Astronaut Crew

Dr.-Ing. Daniel Leidner, 02.06.2023

Credit: NASA - First Humans on Mars (Artist's Concept)

From Direct Teleoperation to Supervised Autonomy

DLR

Low Latency (< 1s)

High Latency (> 5s)

Direct Teleoperation
(2020 - 2021)

Sliding Autonomy
(2022 - 2024)

Supervised Autonomy
(2017 - 2018)

ANALOG 1

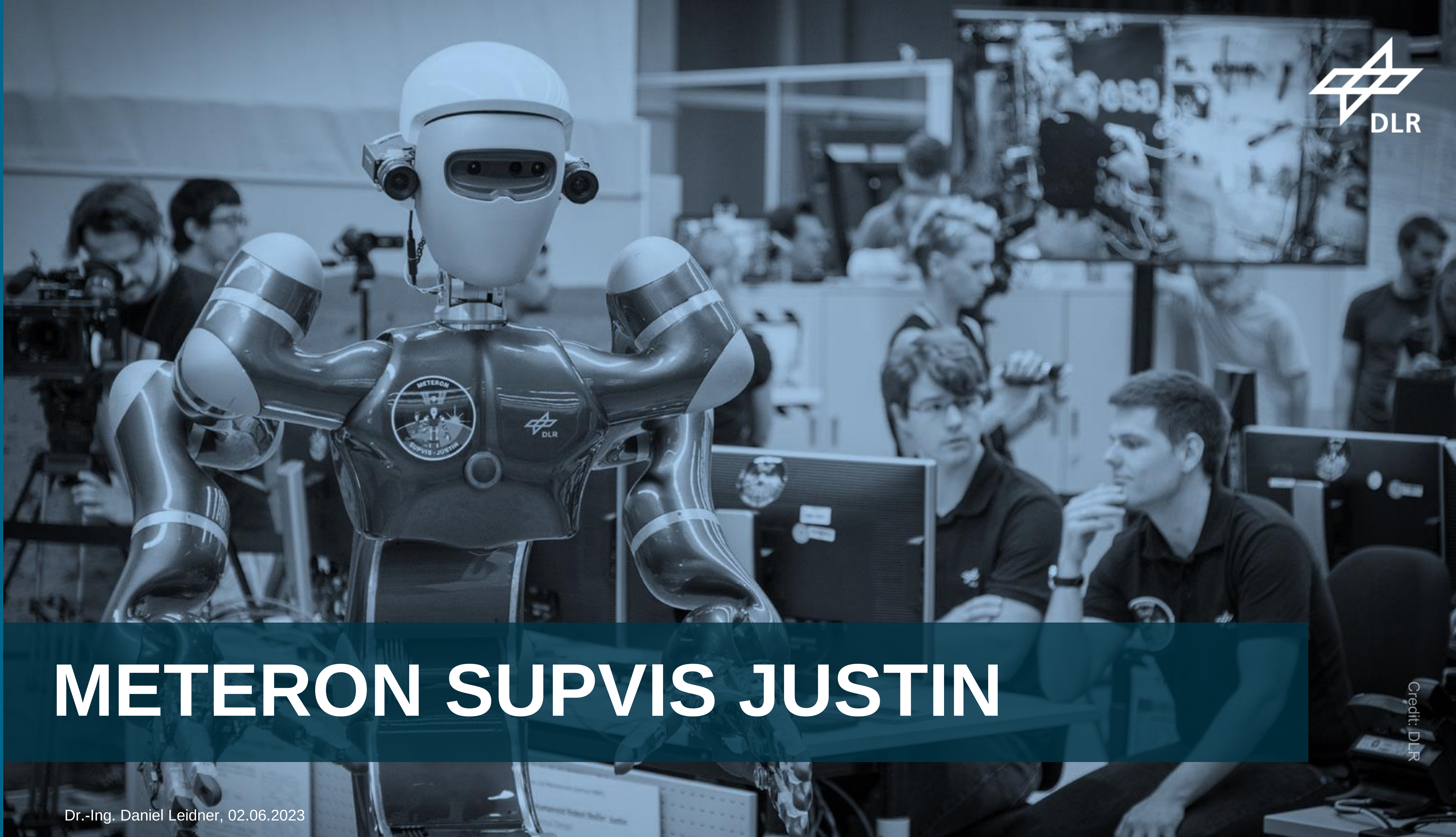
Force-feedback Telemanipulation from Orbit

High delays (here 3s) make direct teleoperation difficult

Passivity needs to be preserved to avoid instabilities

However, high delays create high cognitive load

Panzirsch, M., Pereira, A., Singh, H., ... **Leidner, D.**, Albu-Schäffer, A., Lii, N., & Krüger, T. (2022). Exploring planet geology through force-feedback telemanipulation from orbit. *Science Robotics*, *7*(65).

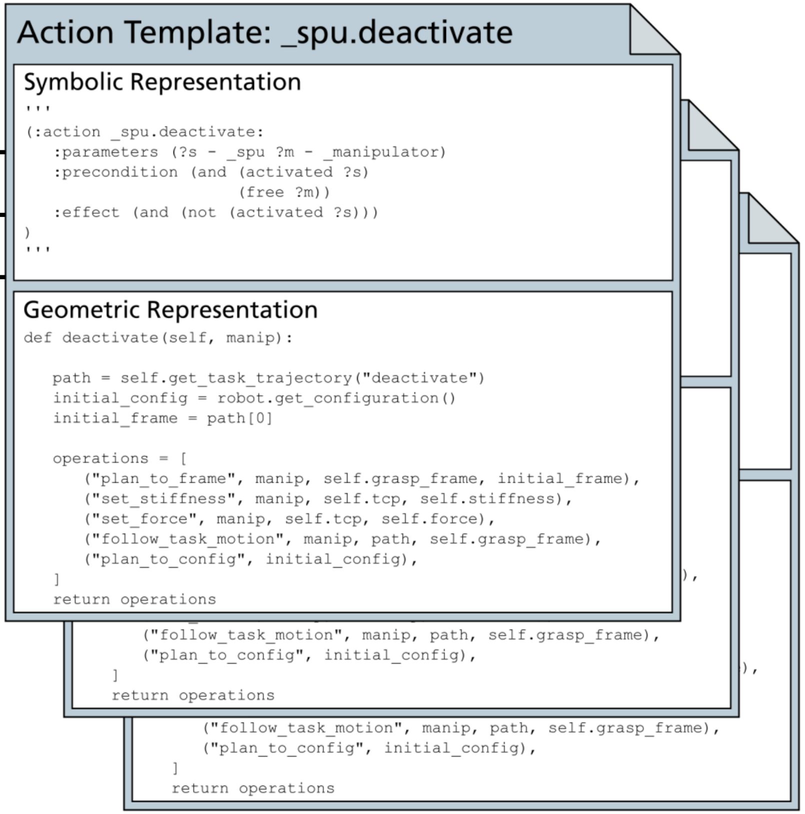


METERON SUPVIS JUSTIN

Knowledge-enabled Teleoperation Interface

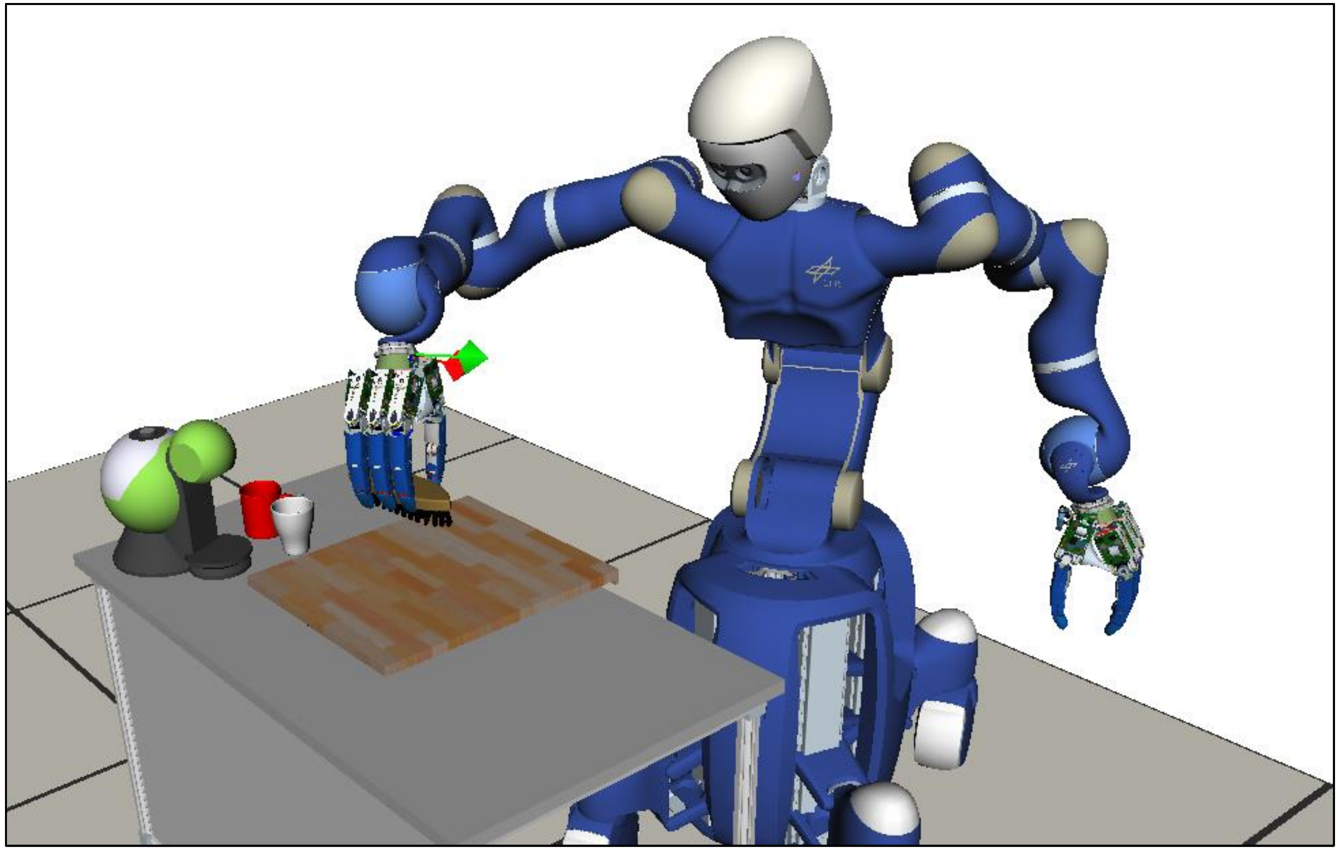
METERON application at the **International** Space Station (ISS)

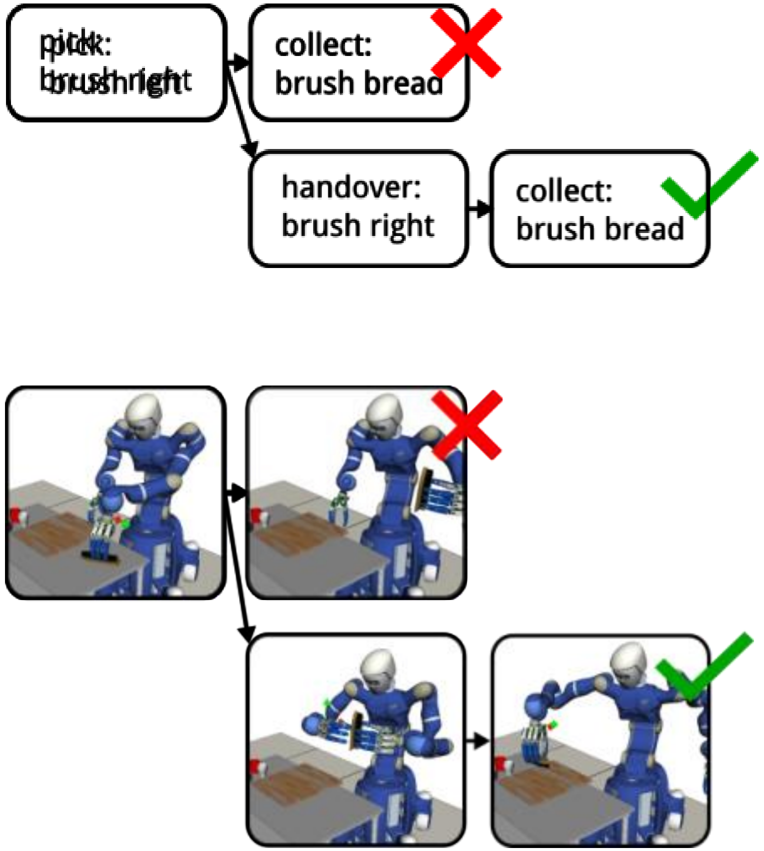
Catalog of robot skills



Birkenkampf, P., Leidner, D., & Borst, C. (2014). A knowledge-driven shared autonomy human-robot interface for tablet computers. In *IEEE-RAS International Conference on Humanoid Robots,* pp. 152-159

Planning with Action Templates, Hybrid Reasoning





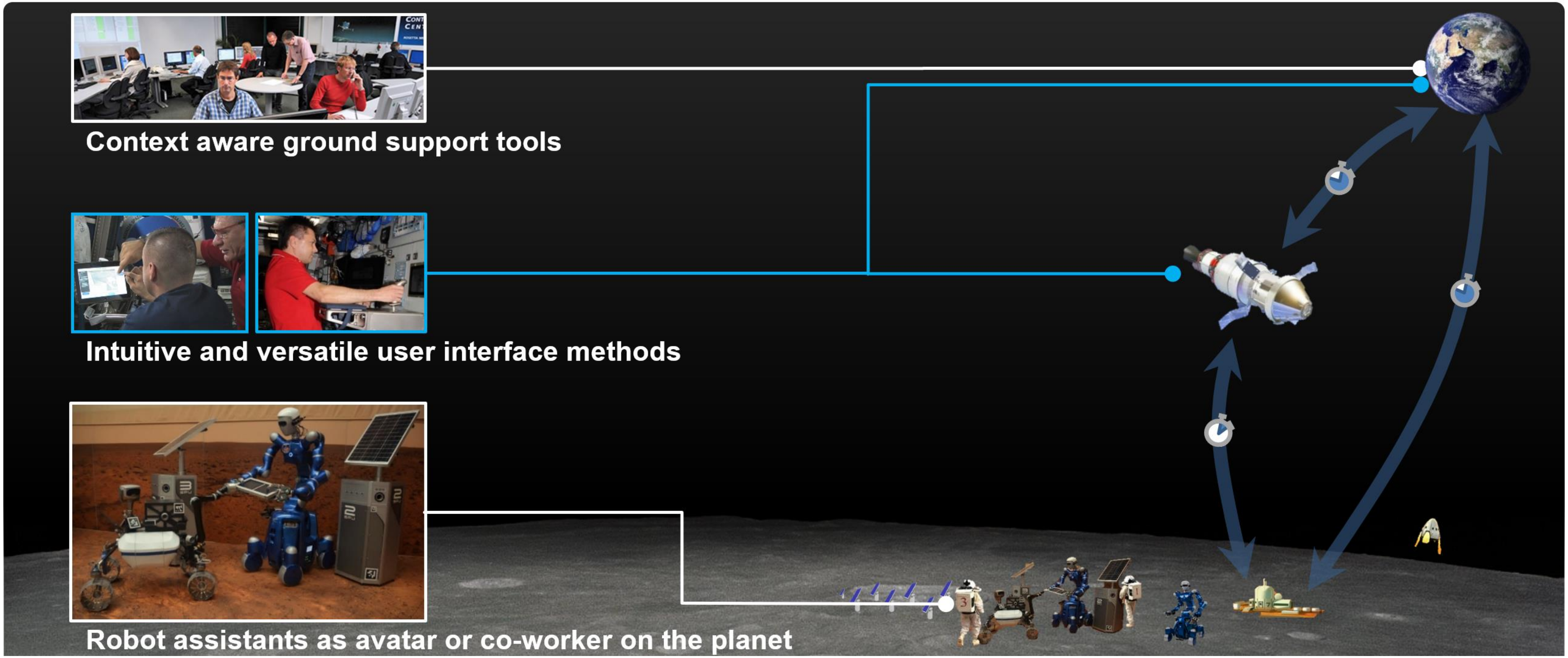
Leidner, D., Borst, C., & Hirzinger, G. (2012). Things are made for what they are: Solving manipulation tasks by using functional object classes. In *IEEE-RAS International Conference on Humanoid Robots.* pp. 429-435

SURFACE AVATAR

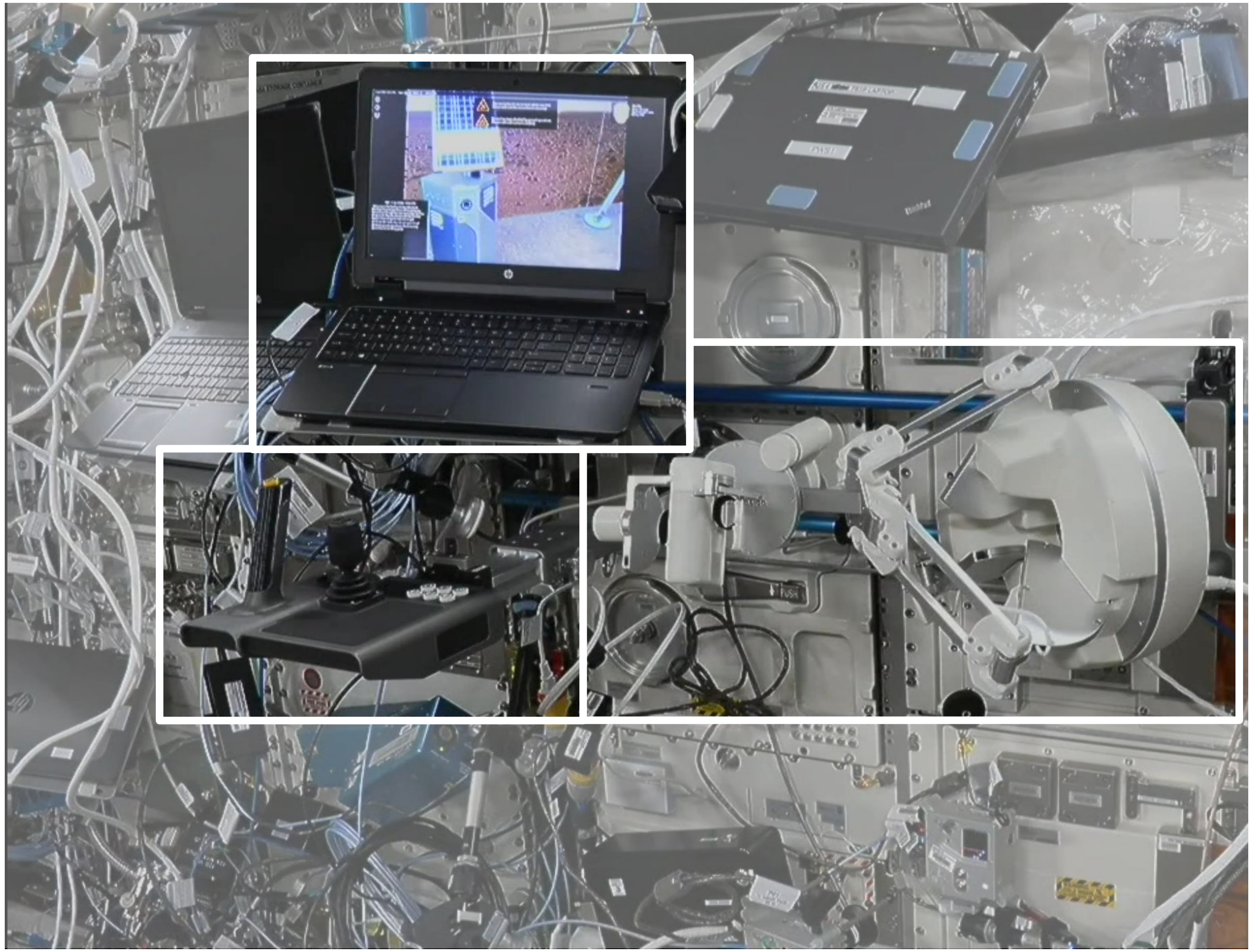
Credit: DLR

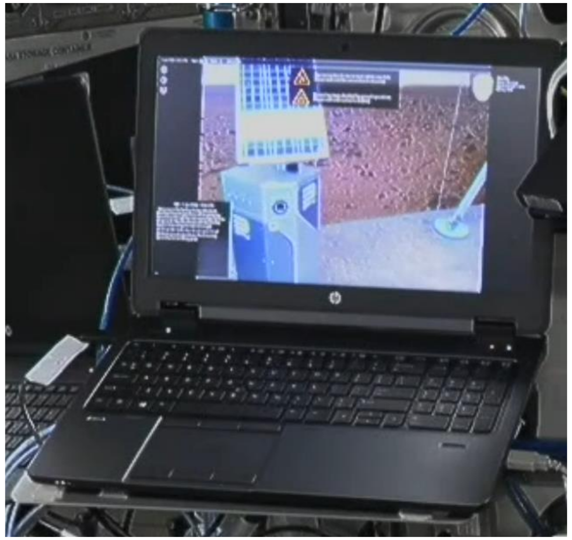
Multi-robot, Multi-modal, Multi-operator Operations

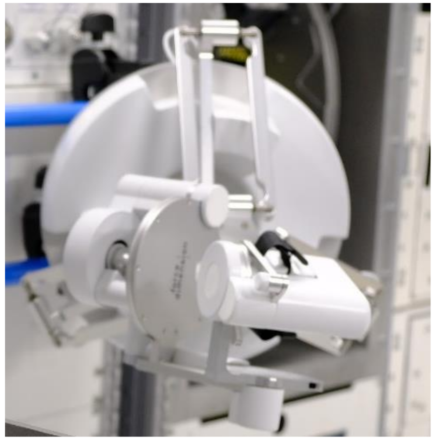
DLR



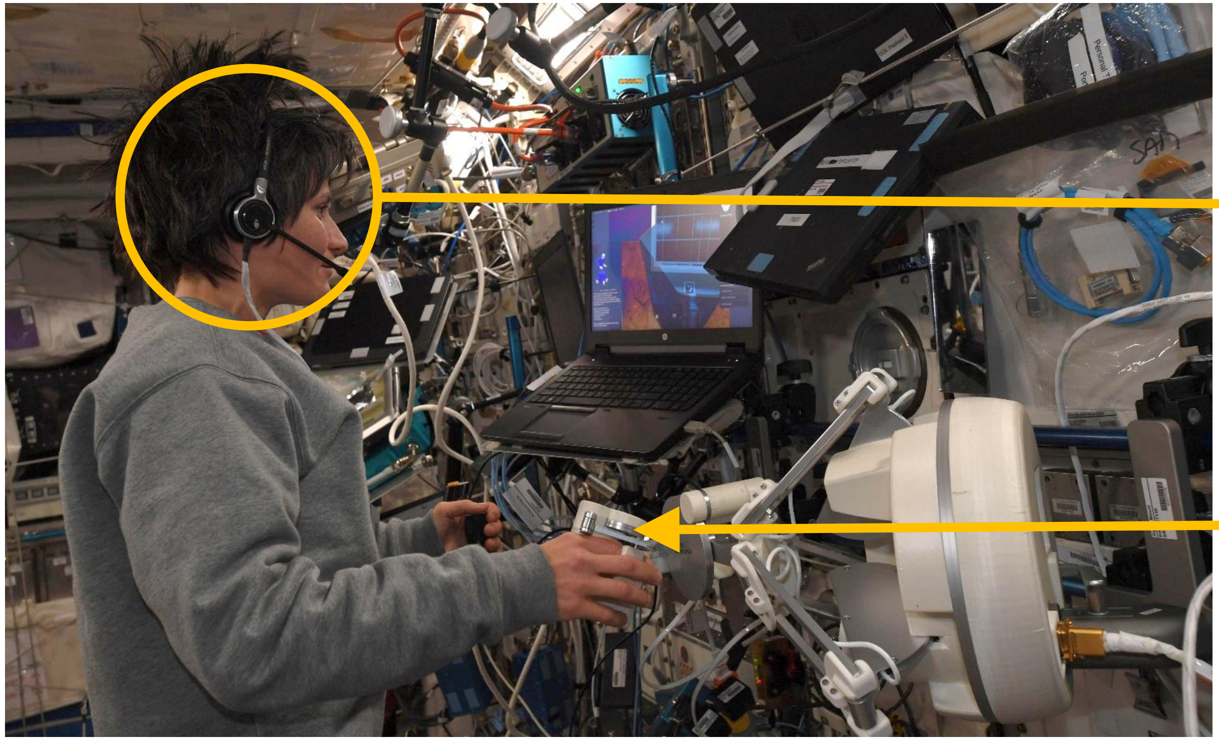
On-orbit robot command terminal
Telepresence to supervised autonomy in one console

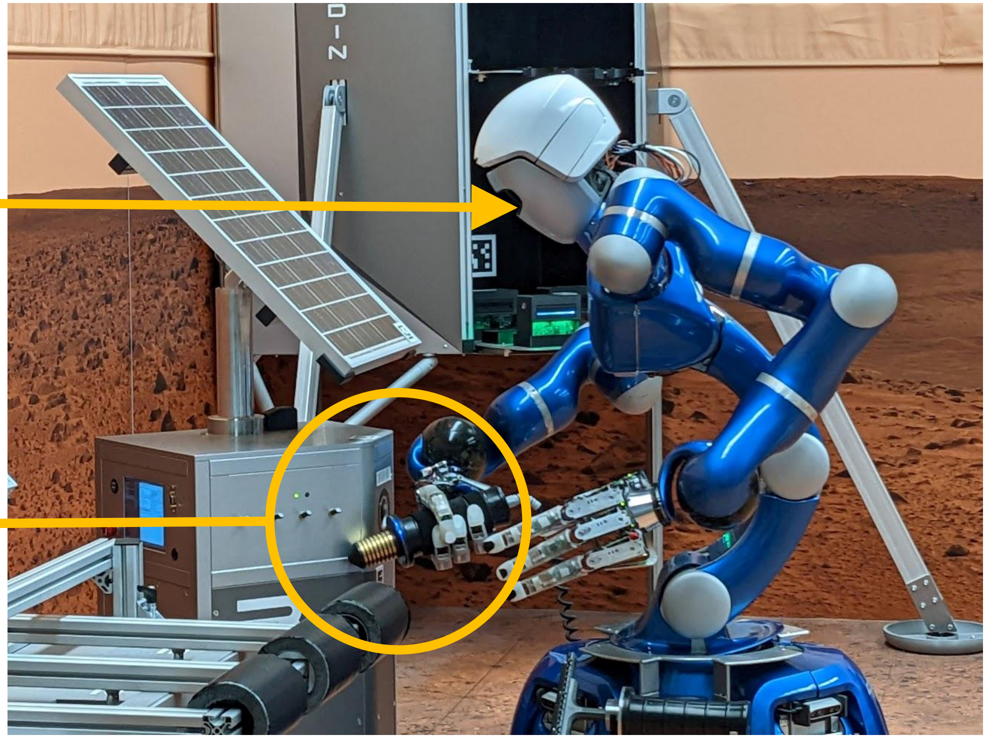






Final Goal: Seamless Switching of Teleoperation Modalities

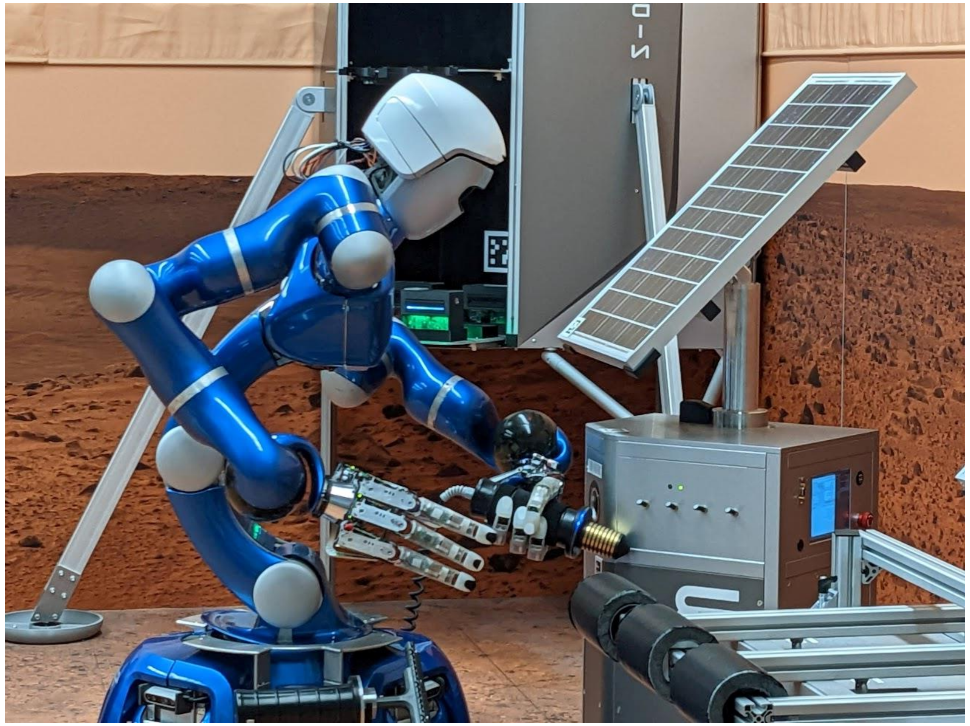




During **supervised autonomy** operations, semantic state inference is used to inform the crew about errors such that they can take over control using **direct teleoperation**!

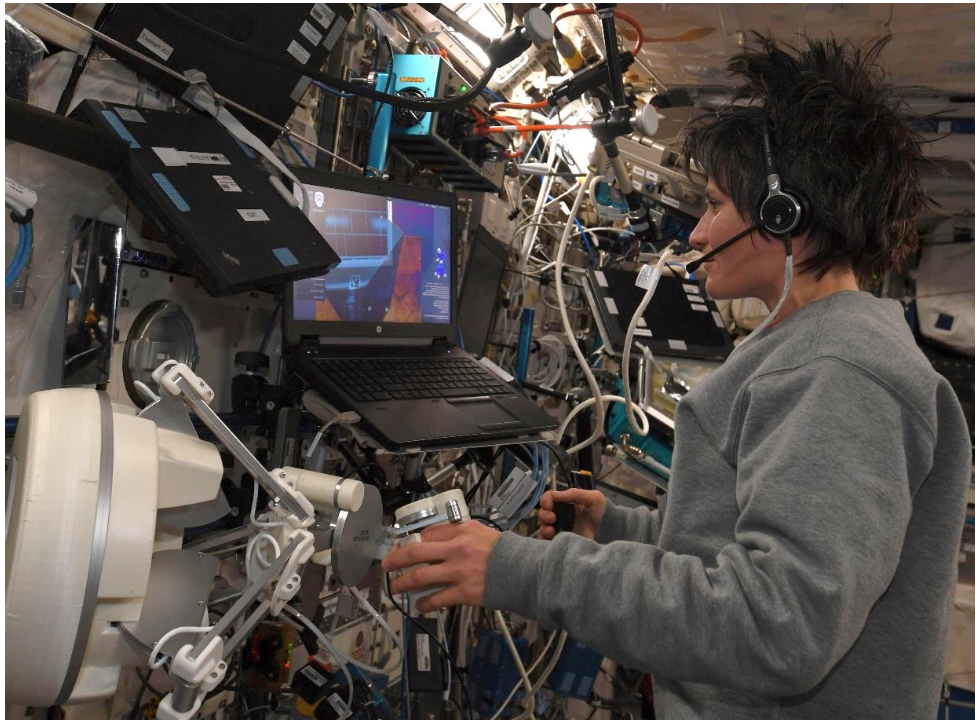
The Issue with Sliding Autonomy

During supervised autonomy operations…



…the robot is <u>unaware</u> of error situations!

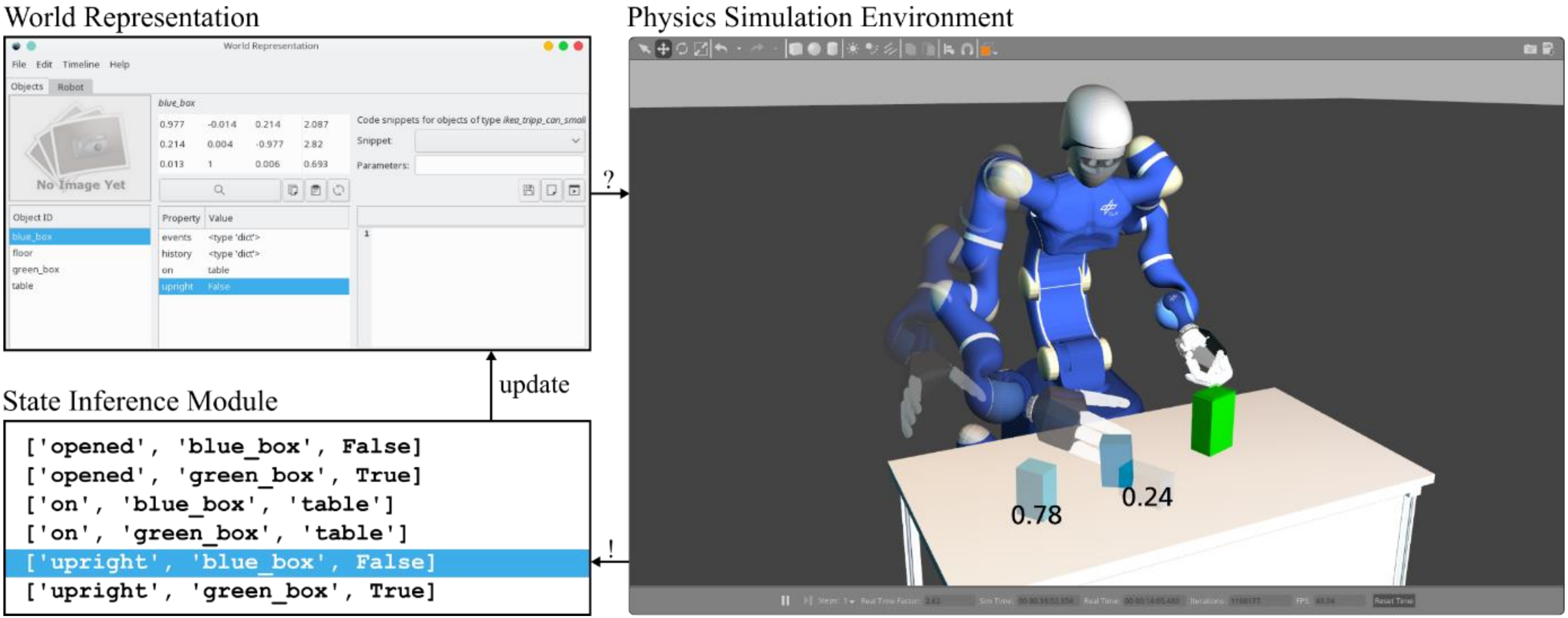
During direct teloperation…



…the robot is <u>unaware</u> any effects it creates!

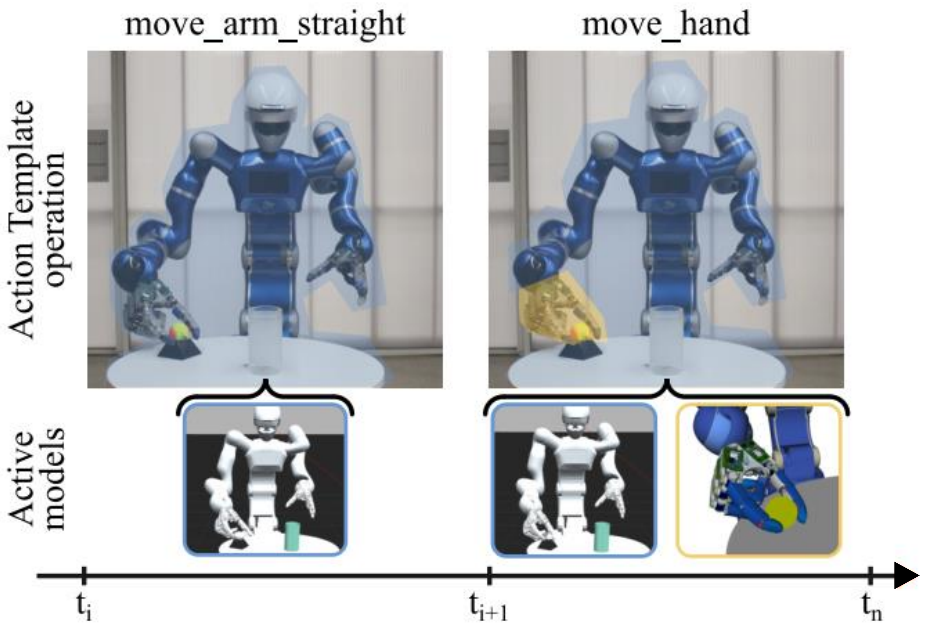
How can the robot infer arbitrary state changes?

Semantic State Estimation using Digital Twin Knowledge

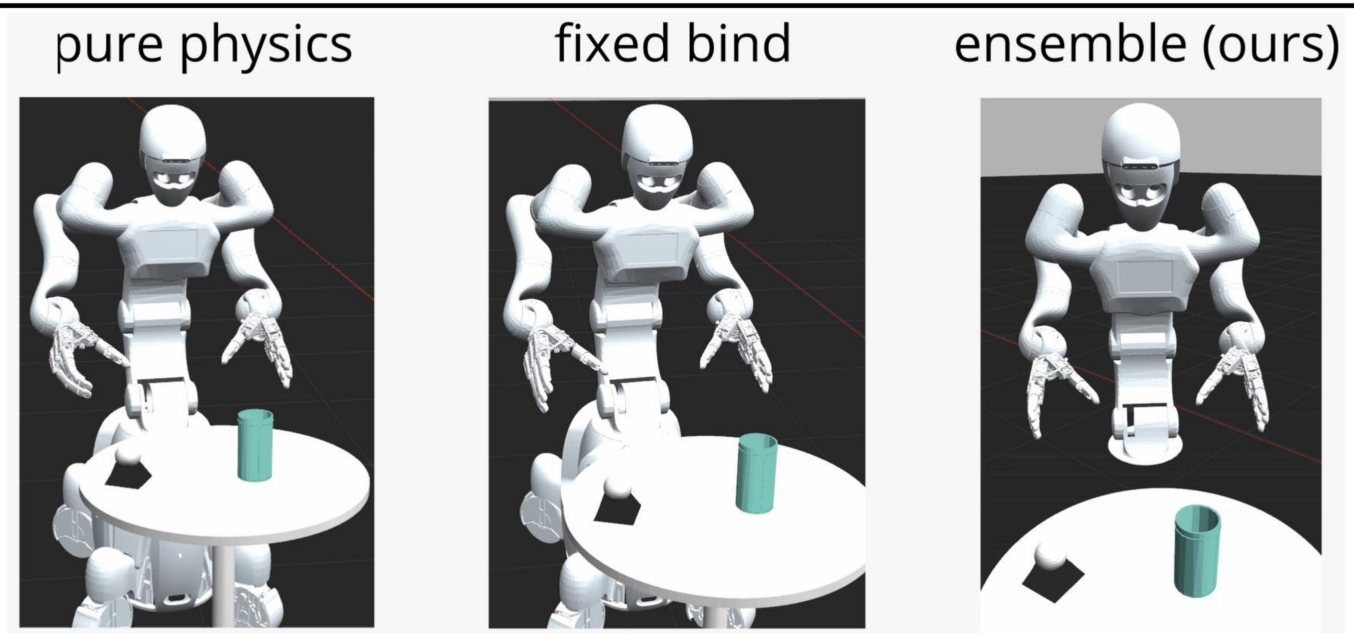


Bauer, A. S., Schmaus, P., Albu-Schäffer, A., & **Leidner, D**. (2018, October). Inferring semantic state transitions during telerobotic manipulation. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).* pp. 1-9.

Context-specific Simulation Ensembles



Depending on the action, different ensembles of state estimators may result in higher estimation accuracy



Experiment	Baseline 1 (pure simulation)	Baseline 2 (rigid binding)	Baseline 3 (force binding)	Our approach (model ensemble)
Ball drop (success)	0/5	2/5	0/5	4/5
Ball drop (fail)	0/5	5/5	0/5	5/5
Peg-in-hole	0/5	0/5	0/5	3/5

Bauer, A. S., Köpken, A., and **Leidner D.** "Multi-Agent Heterogeneous Digital Twin Framework with Dynamic Responsibility Allocation for Complex Task Simulation." *Conference on Autonomous Agents and Multiagent Systems*. 2022.

Summary and Conclusions

Low Latency (< 1s)

High Latency (> 5s)

Direct Teleoperation
(2020 - 2021)

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(2022 - 2024)

Supervised Autonomy
(2017 - 2018)

Where Are we with Teleoperation and Autonomy in Space Robotics with the State of the Art?

(1) I. Deliz, A. Connell, C. Joswig, J. J. Marquez and B. Kanefsky, “COCPIT: Collaborative Activity Planning Software for Mars Perseverance Rover,” *2022 IEEE Aerospace Conference (AERO)*, Big Sky, MT, USA, 2022, pp. 01-13

(2) Bell, J. F., Maki, J. N., Mehall, G. L., Ravine, M. A., Caplinger, M. A., Bailey, Z. J., ... & Wolff, M. J. “The Mars 2020 perseverance rover mast camera zoom (Mastcam-Z) multispectral, stereoscopic imaging investigation” *Space science reviews*, *217*, 2021. pp. 1-40.

(3) R.E. Arvidson, P. DeGrosse, J.P. Grotzinger, M.C. Heverly, J. Shechet, S.J. Moreland, M.A. Newby, N. Stein, A.C. Steffy, F. Zhou, A.M. Zastrow, A.R. Vasavada, A.A. Fraeman, E.K. Stilly, “Relating geologic units and mobility system kinematics contributing to Curiosity wheel damage at Gale Crater, Mars”, Journal of Terramechanics, Volume 73, 2017, pp. 73-93.

(4) G. Pyrzak, R. Puncel, M. A. Vona and R. Lopez-Roig, “The Mars 2020 Ground Data System Architecture,” *2022 IEEE Aerospace Conference (AERO)*, Big Sky, MT, USA, 2022, pp. 1-20

(5) https://www.space.com/perseverance-distance-record-mars