Implicit Communication in Human-Robot Collaborative Transport

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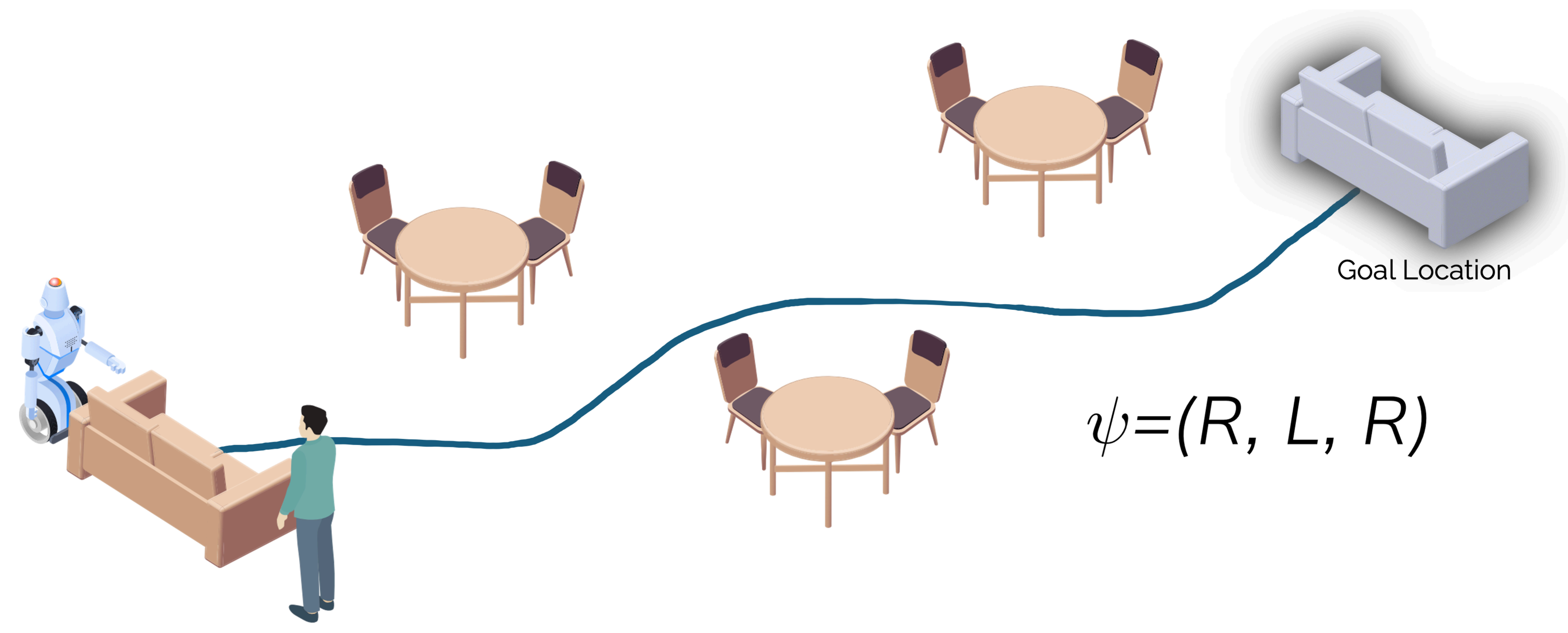
Summary

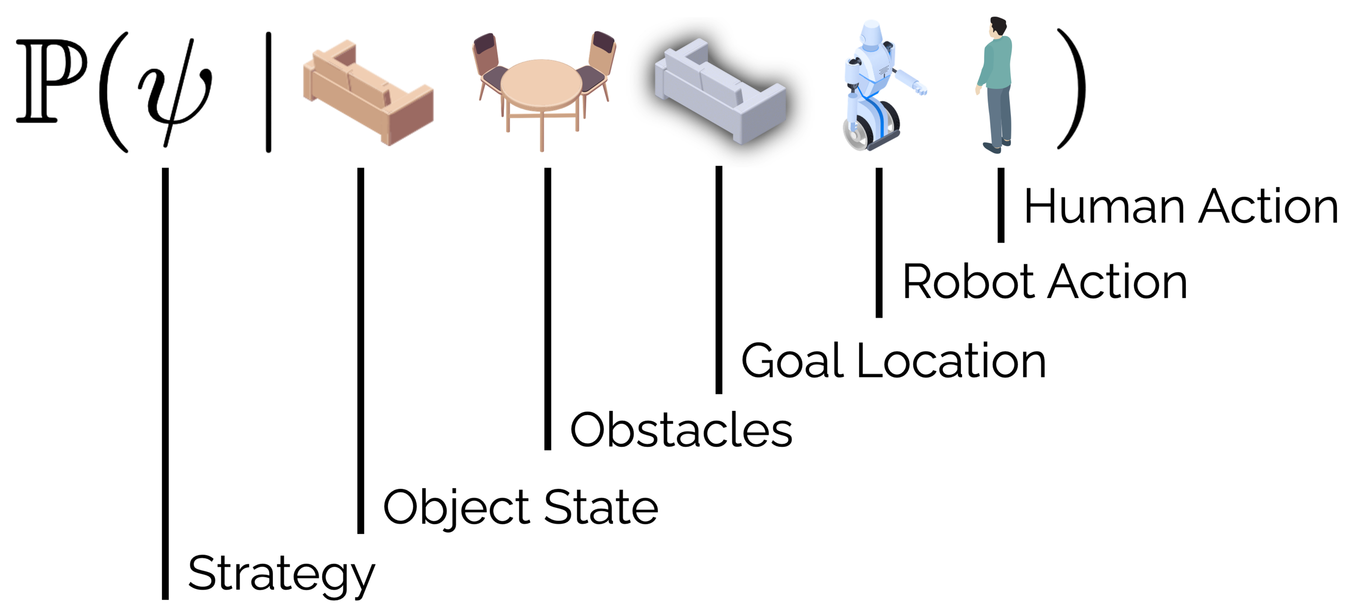
- Human-robot collaborative transport, in which a robot and a user collaboratively move an object to a goal pose, demands tight **implicit coordination** between two heterogeneous agents in the absence of explicit communication.
- Our **key insight** is that the two agents can coordinate fluently by **encoding communicative signals** into actions that affect the state of the transported object.
- We design an inference mechanism that probabilistically maps observations of joint actions executed by the two agents to a set of workspace traversal strategies.
- We deploy our framework on a mobile manipulator and perform evaluation in a within-subjects lab study.
- We find that our framework enables **better team performance** and empowers the robot to be perceived as a significantly **more fluent and competent partner** compared to baselines lacking a communicative mechanism.

Framework

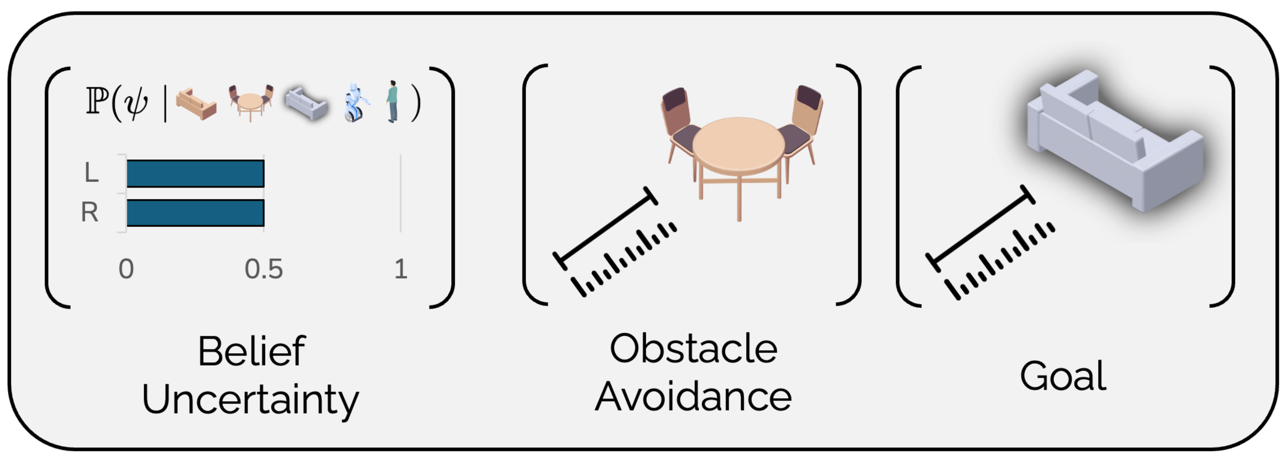
We identify strategies of **workspace traversal** based on the underlying topology of the workspace.

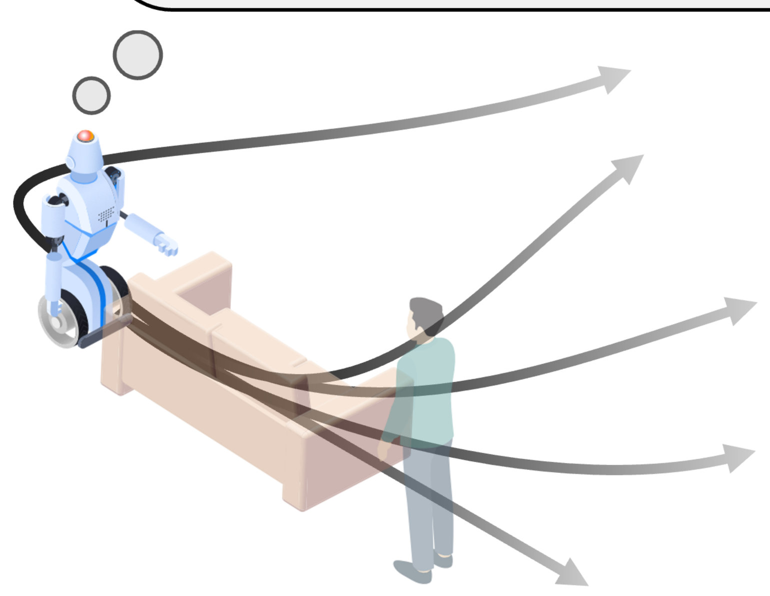


We design an inference mechanism to estimate the **human's belief of the unfolding strategy**.

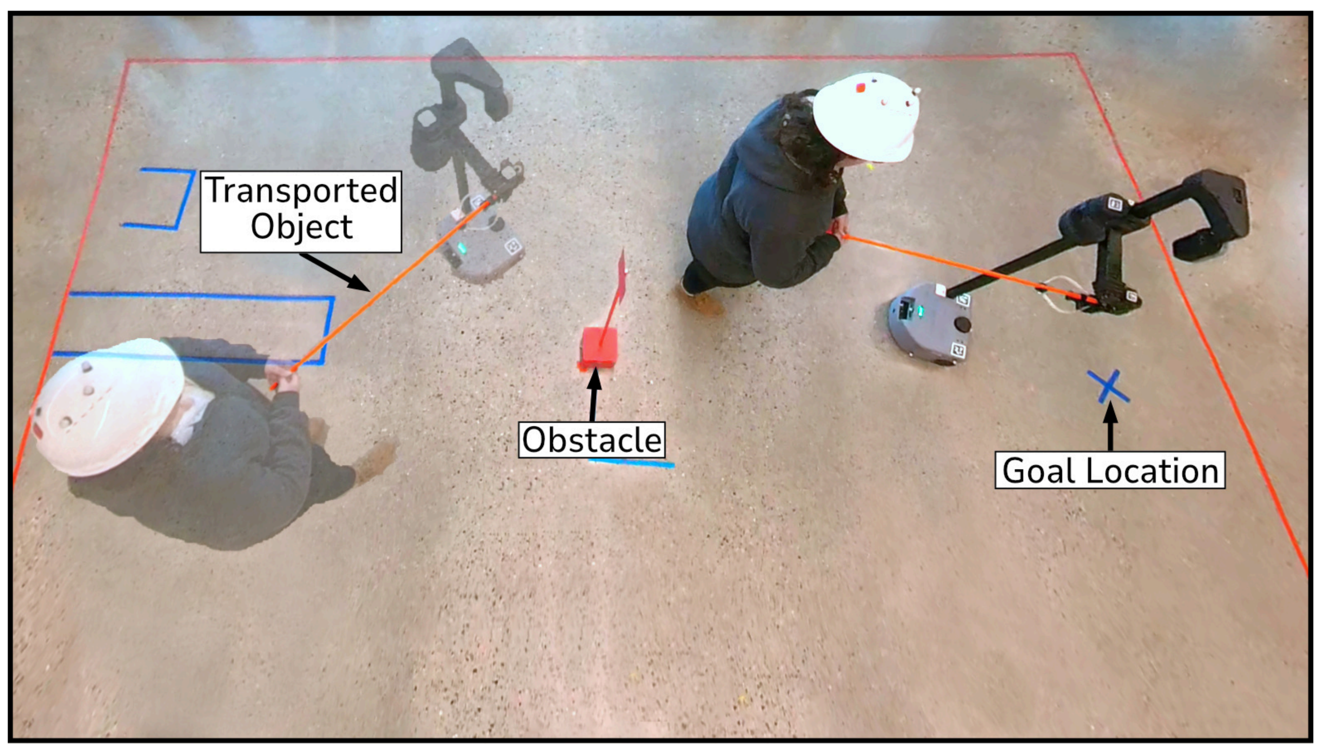


Finally, we calculate the **entropy of the belief** as a natural measurement of uncertainty and introduce it as a cost term in a model predictive controller.





User Study



Setup from our user study (N=24) involving the collaborative transport of an object by a user and a mobile manipulator in a workspace (2.8 x 5.6 m²) with an obstacle (0.15 x 0.15 m²).

We compare the performance of our framework (**IC-MPC**) against two baselines in an IRB-approved user study (U-M HUM00254044).

- **Vanilla-MPC**: A purely functional ablation of IC-MPC without communicative mechanisms (the **belief uncertainty** cost term).
- **VRNN**: A learning-based path planner that predicts future object paths based on the object's state history alone.

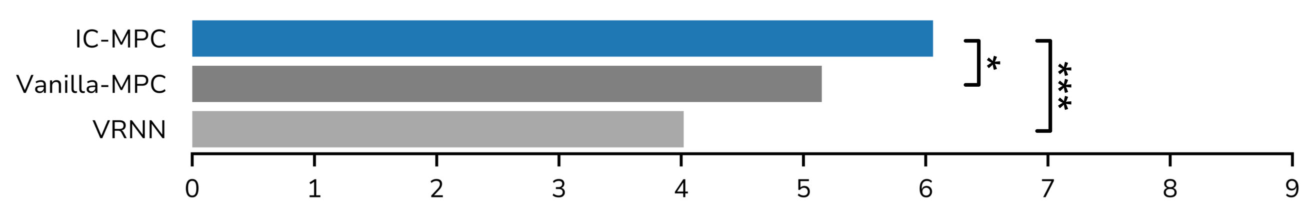
Hypotheses

- **H1**: IC-MPC is more effective at completing the task in collaboration with a user compared to Vanilla-MPC and VRNN as measured by *success rate, completion time, and acceleration*.
- **H2**: IC-MPC is viewed more favorably as a collaborator compared Vanilla-MPC and VRNN as measured by users' responses to the *RoSAS (warmth, competence, discomfort)* and *Fluency in HRI* questionnaires.

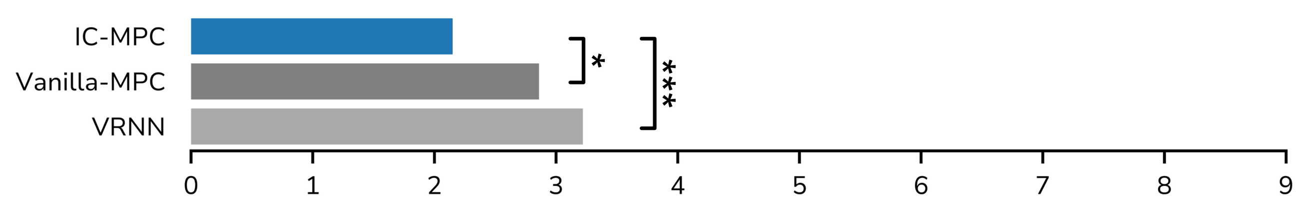
Results

We find partial support for both **H1** and **H2**. Compared to baselines, IC-MPC was viewed as

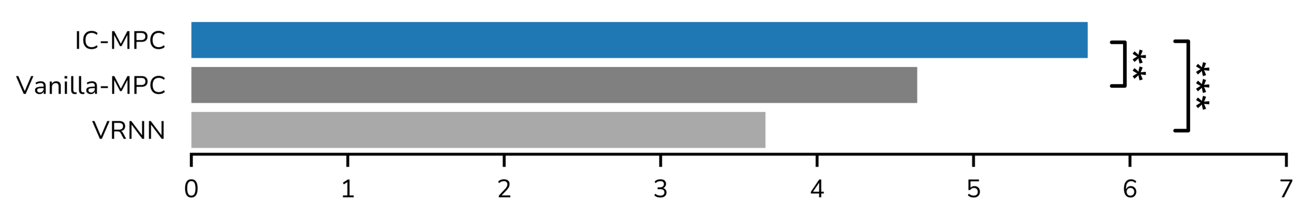
- *more competent*



- *less discomforting*

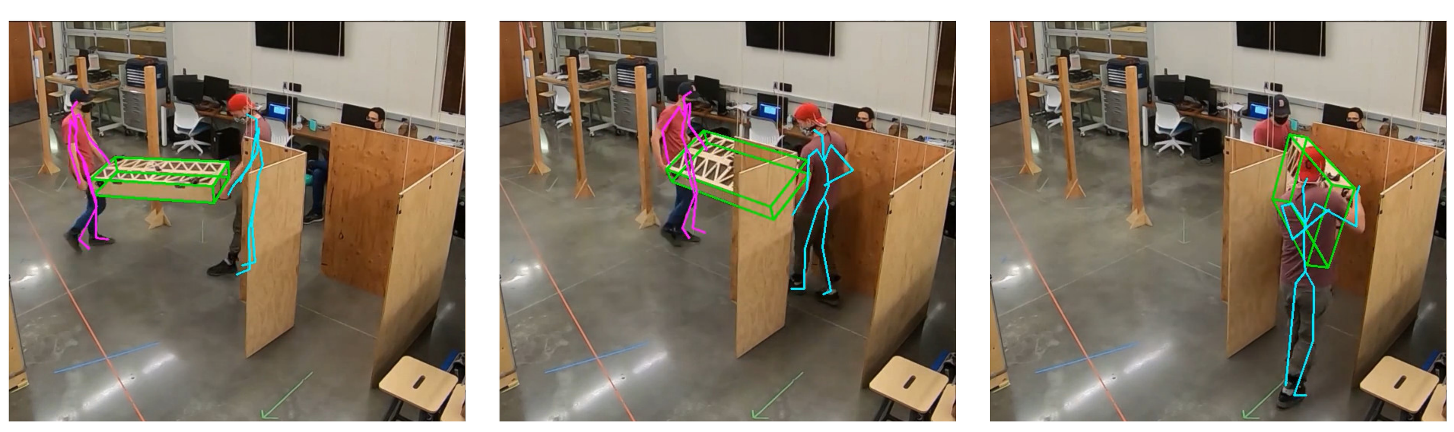


- a *more fluent* collaborator



No statistically significant improvements were found for *completion time*, *acceleration*, or *warmth*.

In this work, **analytical probabilistic models** for belief estimation and **constant-velocity human motion prediction** were effective in enabling greater team performance and more positive user impressions compared to baseline methods. In an ongoing continuation of this work, we build upon a dataset of human-human collaborative transport to learn human models supporting more complex environments and movements, e.g., **pivoting through a narrow passageway** (below).



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