Keynote abstract.
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Towards Conscious Service Robots

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Abstract

Deep learning has achieved remarkable success in areas such as visual perception, speech recognition, natural language processing, and multimodal models, inspiring hope for revolutionary advances in autonomous robotics. However, real-world robotic applications present unique challenges, including many sources of variability, high-dimensional state and action spaces, non-linear dependencies, and partial observability. A key challenge is the non-stationarity of robots and their environments, which leads to performance issues when trained models encounter out-of-distribution data. Unlike current machine learning models, humans adapt efficiently to changes and quickly learn new tasks—a capability attributed to the cognitive architecture of the human mind. This includes systematic generalization exploiting compositionality, allowing humans to understand and manipulate new objects and tasks by recombining known components.

The human brain employs both habitual and controlled processing, with fast, routine actions handled unconsciously by System 1 and more complex, deliberate tasks managed in a conscious way by System 2 [1], [2] (Fig. 1). Despite its limited capacity, System 2 enables flexible problem-solving and self-monitoring. To achieve human-like learning and reasoning, robots must integrate causal models, a working memory, planning, and meta-cognitive processing.

I advocate for a bottom-up approach to integrating consciousness-inspired cognitive functions into service robots by extending highly successful System 1 processing without changing tools. I envision to develop methods for learning perception and planning that enable robots to handle novel situations and self-monitor. This can be achieved through three specific research objectives: (i) Developing unconscious perception and control via fast, habitual processing, creating structured representations of robot workspaces from raw sensory data, and learning predictive models for these representations to manage routine skills. (ii) Establishing conscious prediction and planning by selecting few elements for a working memory, learning abstract predictions, and planning actions based on rollouts and search. (iii) Implementing conscious self-monitoring to assess confidence in perceptions and predictions and learning policies that gather information when needed and avoid dangers.

Intuitive immersive telepresence systems enable transporting human presence to remote locations in real time. My team NimbRo developed the winning entry for the ANA Avatar XPRIZE competition [3] (Fig. 2a). Telepresence also provides a rich source of environment interaction data for learning structured perception and autonomous behavior.

By incorporating insights from human cognition, the next generation of service robots will systematically generalize their knowledge to cope with novelty. This new generation of robots will also monitor themselves to obtain more information when needed, to avoid risks, and to detect and mitigate errors. Conscious service robots have much potential for numerous open-ended application domains, including assistance in everyday environments.

My team NimbRo develops perception, planning, and learning for anthropomorphic mobile manipulation robots providing personal assistance [4] and benchmarks them in the RoboCup@Home league, where we recently won the German Open and RoboCup 2024 OPL competitions (Fig. 2b).

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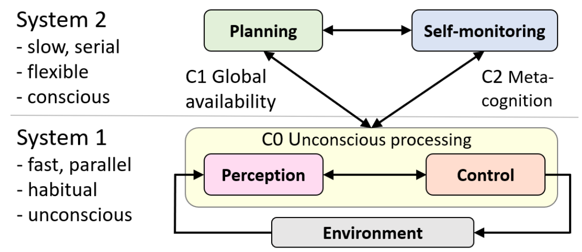

Fig. 1: Human cognitive functions according to Kahneman [1] (System 1, System 2) and Dehaene et al. [2] (C0, C1, C2).

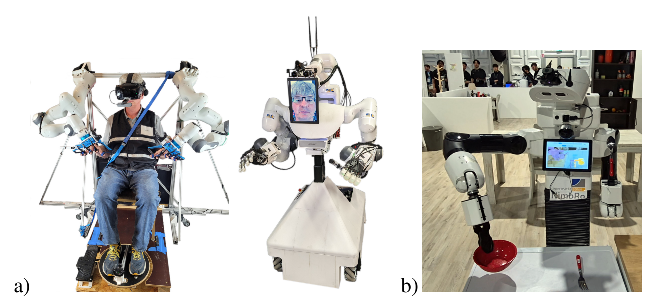

Fig. 2: a) NimbRo Avatar system [3]; b) NimbRo@Home robot.

References

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