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Information-Theoretic Measures as a Generic Approach to Human-Robot Interaction: Application in CORBYS Project

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ABSTRACT
The objective of the CORBYS project is to design and implement a robot control architecture that allows the integration of high-level cognitive control modules, such as a semantically-driven self-awareness module and a cognitive framework for anticipation of, and synergy with, human behaviour based on biologically-inspired information-theoretic principles. CORBYS aims to provide a generic control architecture to benefit a wide range of applications where robots work in synergy with humans, ranging from mobile robots such as robotic followers to gait rehabilitation robots. The behaviour of the two demonstrators, used for validating this architecture, will each be driven by a combination of task specific algorithms and generic cognitive algorithms. In this paper we focus on the generic algorithms based on information theory.

Categories and Subject Descriptors
I.2.9 [**Artificial Intelligence**]: Robotics – *Miscellaneous*

Keywords
Information Theory; Empowerment; Intrinsic Motivation

1. ROBOTIC DEMONSTRATORS
As the first practical application of the CORBYS control architecture, a novel cognitive mobile gait rehabilitation system is being developed during the project's lifetime. The system comprises a mobile platform and a powered orthosis attached to the platform.

The mobile platform will provide mobility for the patient while the powered orthosis will assist in completing his/her leg movements. CORBYS cognitive modules create appropriate commands for low-level robot control derived from the patient's intentions. The cognitive modules are supported by an advanced multi-sensor system consisting of physiological wearable sensors and EEG sensors for perception of the physical and psychological state of the patient. Through cognitive robot control, the CORBYS gait rehabilitation system will be a situationally-aware system capable of learning and reasoning to optimally match the requirements of the patient at different stages of rehabilitation in a range of gait disorders.

The second CORBYS demonstrator is an existing mobile robot that follows a human co-worker during investigation of the environment. The robot is equipped with sensors to perceive and reconstruct the dynamic environment, including the location of the human co-worker. Supported by sensor measurements, the cognitive modules provide a trajectory to the low-level control which realizes a following behavior, whilst maintaining controllability and mobility of the robot.

2. GENERIC COGNITIVE ABILITIES
One question being addressed in the CORBYS project is: Which generic cognitive abilities could benefit both demonstrators, and possibly, an even wider range of robots? Interacting with humans, as both demonstrators do, increases the need for generality, because human behavior is highly unpredictable, and therefore hard to account for in advance. In summary, we are looking for algorithms that can both deal with generic robot architectures and generic situations.

One approach being realized in the CORBYS project is to use information-theoretic measurements to define and work towards certain desirable system properties, which can then be combined with task-dependent robot behavior. Information theory has the advantage that it operates only on random variables, so the perception-action loop of the robot, i.e. its sensors and actuators, can be analyzed as discrete or continuous variables, without the need for labeling. In the following sections we focus on *information flow* and *empowerment* as two information-theoretic measurements; briefly introduce them, and argue that they correspond to desired generic properties.

2.1 Empowerment
Empowerment [1] is an information-theoretic quantity that measures how much an agent is in control of the world it perceives. It can be formalized as the Shannon channel capacity from an agent's actions to an agent's sensors. High empowerment corresponds to having several options to choose from, which all lead to perceivably different and predictable

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outcomes. Low empowerment corresponds to either having no actuator choices, or to a situation in which all actions lead to either the same, or a random outcome.

In the context of a generic robot this means that maximizing the robot's empowerment provides an intrinsic motivation to avoid getting stuck, entering highly unstable situations, or interacting with unpredictable other agents.

After developing a fast, continuous approximation of empowerment [2] we tested how the second CORBYS demonstrator would follow a human, if it was optimizing its trajectory using empowerment [3]. The result was that, even if the robot was currently at an optimal distance to the human, it would still improve its positioning so as to maximize empowerment and to locate itself at a position of high maneuverability. This was particularly beneficial when the human moved through a space that the robot could not, because the robot would start to circumnavigate the obstacle earlier than a robot without empowerment. Also, the robot would avoid positioning itself too close to walls, or in corners or dead ends; all positions where the robot would have low empowerment.

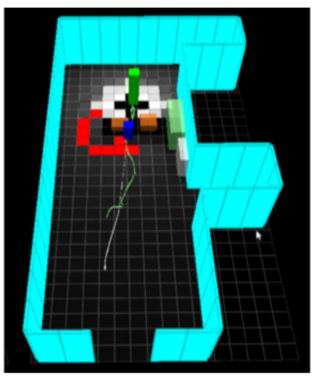

Fig. 2. Visualization of the empowerment-based trajectory planning [3]. The blue cuboid represents the robot, the green cuboid is the human and, the other cuboids are obstacles. The red, high empowered path, shows how the robot, even if the desired distance is already achieved, circumnavigates the obstacles to be in a better position to continue following the human.

Our recent theoretical work on empowerment and unpredictable agents [4] suggests that the same algorithm would also avoid humans if their behavior was unpredictable, but would allow for closer interaction once the robot has a clear grasp of what the humans wants to do.

In the future, we plan to evaluate and optimize the empowerment of the human partner in the interaction. Being empowered means being in overall control of the situation one is in, and this, in general, seems desirable for the human partner in the interaction. This would then result in a motivation for the robot to react predictably to the human's cues, to not interfere with what the human is doing, and to follow the humans lead. All these are desirable properties for both demonstrators. For example, for the robotic gait rehabilitation system, this would mean that the robot would provide the level of support the patient needs only when the patient needs it.

Furthermore, as we hypothesized that humans try to maximize their empowerment in specific situations [5], the ability to evaluate the human's future empowerment could aid a robot in predicting the human's actions.

2.2 Information Flow

Information flow [6] quantifies the amount of causal influence one variable has on another. Incidentally, empowerment can also be expressed as the maximal potential information flow from actuators to sensors. In our human-robot interaction scenarios we aim to quantify how much causal influence the robot and the human have on the outcome of the overall situation, or on a relevant subset thereof.

This is particularly relevant for the first CORBYS demonstrator, because the powered orthosis should influence the outcome, since it is designed to correct the human's gait patterns, but it should not be the sole originator of movement. By measuring the information flow from EMG sensors corresponding to the human muscle commands to the resulting joint angles the robot should be able to evaluate if the human is still initiating the resulting movements. On the other hand, the information flow from the robot's actuators to the resulting joint angles could help to identify the amount of correction that is still required.

The desired values for both flows can be adjusted to generically reflect the causal dominance relation between the human and the robot. For the second demonstrator the desired flow is purely from the human to the robot. A causal flow from the robot to the human would indicate that the robot is interfering with the human's state, which is not desirable in this robotic follower scenario. In conclusion, theoretical evaluation and preliminary testing on actual robots indicate that both formalisms are capable of providing some desired robot's behavior.

3. ACKNOWLEDGEMENTS

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