

Figure 2: Architecture of the robot control system

production) and inference based on geometric and temporal reasoning. SPARK maintains all geometric positions and configurations of agents, objects and furniture coming from perception and previous or *a priori* knowledge. Reasoning about human perspective allows to compute facts such as: GREY_TAPE ISBEHIND HUMAN1, GREY_TAPE ISVISIBLEBY HUMAN1.

Monitoring human activity is crucial to maintain a coherent state of the world. Full human action and activity monitoring is a difficult task that requires knowledge and reasoning both on high level facts like goals, intentions and plans, as well as bottom-up data from agent and object motions. Simple temporal and geometric reasoning on human hand trajectories and potential objects placements can provide some useful clues for high level human monitoring processes.

The facts produced by the geometric and temporal reasoning component are stored in a central symbolic knowledge base, called ORO. Besides acting as a facts database, the ORO platform [3] exposes several functions: operations on knowledge statements relying on inference (through a continuous first-order logic classification process), management of *per-agent* symbolic models, and also higher cognitive and human-robot interaction related functionalities like categorization of sets of concepts and natural language grounding [4].

2.2 Goal and Plan Management

In order to devise how a given goal can be accomplished, the robot has to elaborate a plan, *i.e.* a set of actions to be achieved by itself and its human partners. This is the role of HATP [2] (for Human Aware Task Planner). HATP is based on a Hierarchical Task Network (HTN) refinement which

performs an iterative task decomposition into sub-tasks until reaching atomic actions [7]. One key feature is that HATP is able to produce plans for the robot actions as well as for the other participants (humans or robots). The resulting plan, called “shared plan” is a set of actions that form a stream for each agent involved in the goal achievement. Depending on the context, some “shared plans” contain causal relations between agents. It can be tuned by setting up different costs depending on the actions to apply and by taking into account a set of constraints called social rules. This tuning aims at adapting the robot behavior according to the desired level of cooperation of the robot [2]. Depending on the context and on the shared plan elaborated by HATP for a given goal, the robot controller decides to execute an action or to ask its human partner to do it. Actions feasibility by the human or the robot could be regularly reconsidered based on reachability/visibility constraints.

2.3 Action refinement, Execution and Monitoring

Let us take a simple example to illustrate a full run of the system. We assume here that the robot (and the human) has been given the joint goal “CLEAN TABLE”. For HATP, this means putting all tapes that are currently on the table in the trashbin. Depending on the state of the world and agent preferences, different plans are produced.

There is only one tape on the table and it is reachable only by the robot while the trashbin is reachable only by the human.

Figure 2.3 illustrates the main processes occurring during a multi-step human-robot collaborative goal achievement. The plan produced is quite straightforward and is shown in

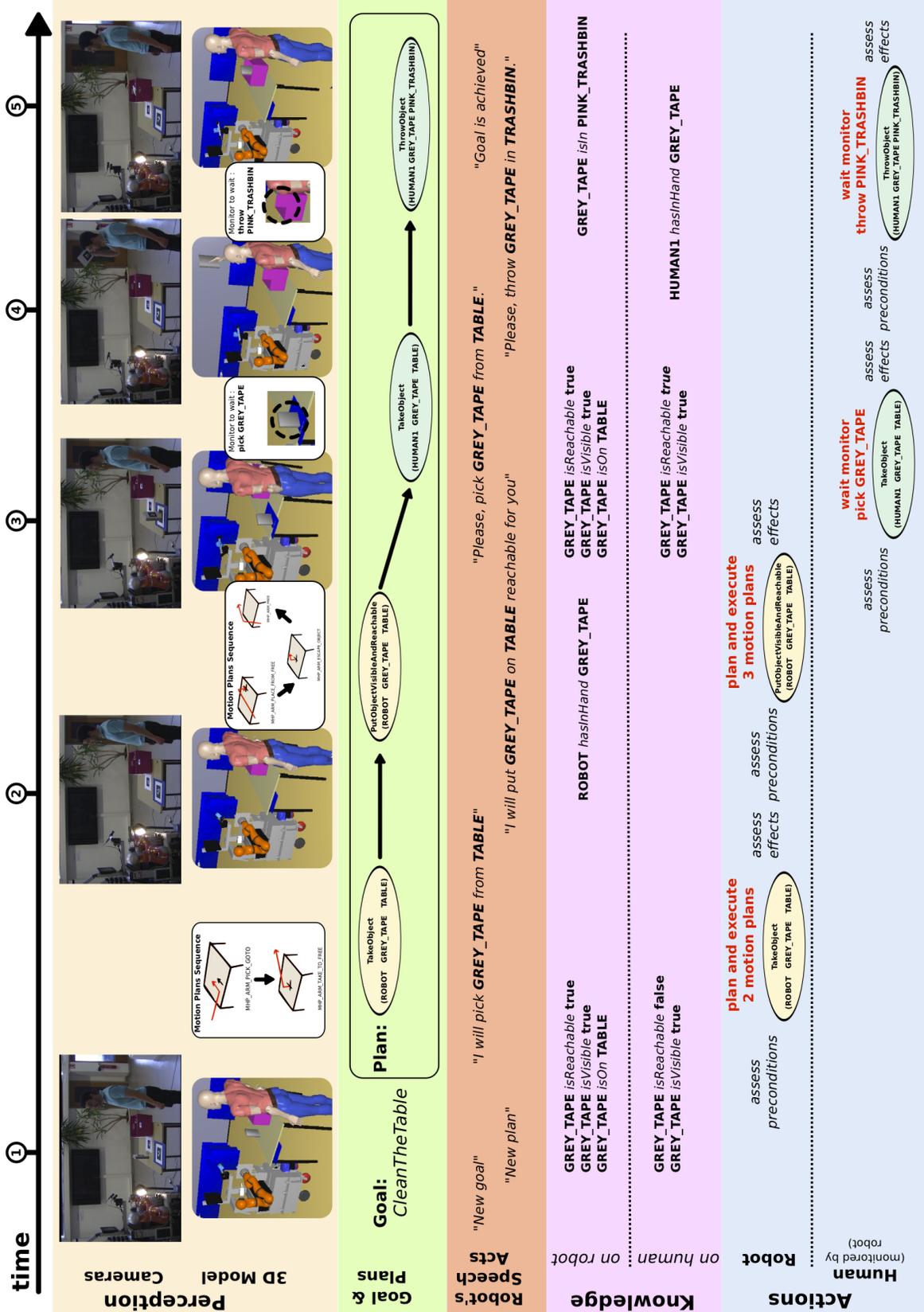


Figure 3: The main processes occurring during a multi-step human-robot collaborative goal achievement

the third row called “Goal and Plan”. It consists in 4 successive actions involving the robot and the human. Robot grasps the tape and then places it on the table at a position where it is visible and reachable for the human. Human then is asked to pick the tape and to throw it in the trashbin. The first row, named “Cameras”, shows several snapshots corresponding to various execution steps. Snapshot 1 corresponds to the initial situation. Snapshots 2, 3, 4 and 5 give the state after the successive achievement of the four actions in the plan. The second row, named “3D Model”, shows the display of SPARK at the same instants. The fourth row, called “Robot Speech Acts”, illustrates robot speech acts produced along the execution to inform the human partner about goal and plan creation and status and to verbalize the actions that the human is asked to execute. The fifth row illustrates robot knowledge on itself and on the objects. The sixth row illustrates the robot knowledge about the human state. The seventh row gives ongoing robot action with action preconditions and effects assessment as well as motion execution tasks. The eighth row gives ongoing human action with action preconditions and effects assessment and monitoring activity.

3. ACKNOWLEDGMENTS

This work has been conducted within the ANR-CONTINT ROBOERGOSUM (DECISION ANR-12- CORD-0030-02).

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