An Architecture Supporting Proactive Robot Companion Behavior

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Abstract. An essential aspect of human robot interaction is proactive robot behavior particularly in situations where the robot is able to determine by itself if, how and when it can intervene and help. This is certainly valuable since it permits the user to be freed from the burden of permanently monitoring the robot and choosing the command that should be issued to the robot. In this work we present an architecture for proactive robot behavior. Its main features involve the ability to select high level goals based on scenario recognition. The goals are then refined by a specific planner that is able to determine if the robot can contribute to the goal achievement and finally a human aware supervision system that allows the robot to share the human activity thanks to its ability to achieve task cooperatively. The paper describes the overall system and its implementation on a realistic testbed.

1 INTRODUCTION

When we see an elderly person moving a table by itself, we take initiative and take the other side of the table and help him move that table. Similarly robot companions in human environment will need to take initiative and help their human partner without requiring an explicit command. This would lead to a fluent human robot interaction and ultimately enable robot to create strong bonds with the human (one of the important challenge in human robot interaction [33]).

For robot to take initiative it should be able to answer following questions: What to observe? When to take initiative? How to insert itself to the on-going activity? For the first question, robot needs to have an recognition mechanism to detect scenarios (situations) calling for robot action, like: to help the elderly person moving a table. Second one will require a robot to take decision whether to be proactive or not: Does it have the capacity to hold the table? Finally a mechanism to hold current robot goals (stop cleaning the room and redo it later, for instance) and execute and supervise the new course of decided actions: Grab the table and also keep pace with human (ability to do joint task).

The work presented here consists of a system that permits proactive robot behavior by addressing a number of above mentioned issues. It focuses on (1) the use of chronicle recognition mechanism that can efficiently detect activities to which to robot may potentially participate, (2) a human aware planner that is able to determine if, how and when the robot can contribute and (3) a supervision system which is responsible for monitoring and executing robot tasks in close cooperation with human partners.

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Section 2 discusses related work. Section 3 presents the system architecture and then, sections 3.1, 3.2, 3.3 and 3.4 give a short description of the components involved in the decisional layer. Section 4 deals with the implemented system and illustrates its use through several examples involving a mobile robot behaving proactively. Finally, section 5 concludes and discusses future work.

2 RELATED WORK

Work related to proactive robot behavior initially began with mixed initiative approaches. In mixed-initiative approach focus is on initiative shifts between human and robot, and is related to robot tasks. Mixed-initiative (also called facilitated initiative [20]) based on operator modalities [15][16] use a control architecture that allows robot to have different levels of autonomy. It can be in tele-operated, safe mode, shared control, collaborative task mode (CTM) and totally autonomous mode. Robot can take varying degree of “initiative” based on the mode chosen, the current context and even the difficulty of the task at hand. For example robot takes initiative and leads in navigation tasks in CTM mode.

A planner based mixed initiative approach is used in search and rescue scenario by[5]. Its architecture is based on model based execution monitoring (activities model defined) and a reactive planner monitors task execution using that model. If human operator changes execution order, planner responds by proposing a new execution order to him.

[3] uses an affect based mixed-initiative interaction approach using human robot interface. Robot responding to changes in human operators emotions (detecting drowsiness,inattentiveness etc) can take initiative from or may offer it back to human. Some approaches[2] also use emotion based planning for mixed initiative interaction.

Other methods like [29], use initiative for removing ambiguity in human intentions. Architecture consists of intention recognition using Dynamic Bayesian Networks and planner for task execution. Planner executes robot tasks for correctly inferred intentions and for ambiguous intentions planner selects an action from a table (defined by human) to induce human response and remove ambguity. In robot care [9][8], robots shows proactive behavior based on activity monitoring using activities defined as a schedule. And constraint violations of schedule trigger system initiative and perform some action in the form of a alarm or suggestions to the assisted person.

In our context, proactive behavior is not only based on constraint violations[9],or governed by operator modality[15][16] or planning based[5][29] but as our system aims at multi-layered proactive behavior it consists of a whole system from detection of robot goals (for itself and as well as for human goal), their management through task agenda, a planning mechanism that plans taking into account human and finally an execution and monitoring system takes into account human at every level of interaction. Affect based [3][2] approaches would be suited for initiative taking in close human robot contact situations.

3 SYSTEM ARCHITECTURE

We have devised a control architecture dedicated to robot decision and action in a human context (Figure 1). It enhances robot capacity to be proactive for robot related as well as human related tasks.It has been developed as an instance of the generic the LAAS Architecture for Autonomous Systems[4].

The decisional layer consists of four components:

- The **Task Agenda** A mechanism for robot higher level goal management.
- **CRS** An chronicle recognition system for modeling and recognizing scenarios.
- **HATP**: A task planning system that is able to synthesize socially acceptable robot plans that may involve human-robot collaborative action.
- **SHARY** which constitutes the decisional kernel. It is based on an incremental context-based task refinement in a human context.

We will now explain the different parts of this architecture.

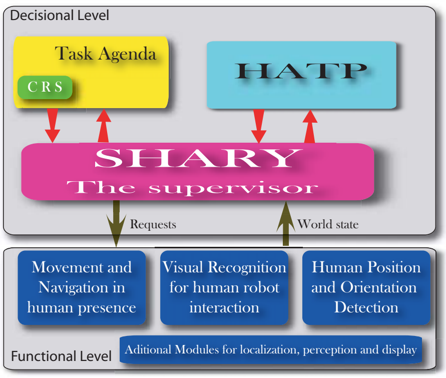


Figure 1. Architecture for proactive robots companions: The decisional layer consists of four components. SHARY, which is in charge of task supervision and execution. HATP the planner which provides other decisional abilities, and Task Agenda which manages high-level robot goals in a human and CRS is in charge of the interpretation activity of the persons in the robot vicinity.

3.1 Task Agenda

The role of the Task Agenda is to manage high-level robot goals and their associated tasks. It maintains an ordered list of high-level tasks and is embedded with basic mechanism to pre-empt and suspend current task if a higher priority task arrives and reschedule it when higher priority tasks end. New Agenda tasks are generated either by users requests (through multi-modal dialog) or on chronicles recognized by CRS. Currently task priorities are staticaly set according to human involvement in task initiation and execution. These priorities are not modified by plan modification and interaction history. Similarly task relevance is not tested when resuming execution. This should be improved soon.

3.2 CRS

A robot companion besides acting on human commands needs to actively monitor its environment and infer new goals for itself and human partners goals. It needs to incorporate a capacity to recognize an activity happening in its vicinity. Our approach is to model these events into temporally constrained networks called chronicles[23] (representing a situation or scenario)and using Chronicle Recognition System (CRS)[18] (developed by [17]) for monitoring these scenarios.

For example breakfast cooking scenario: First we can define events for this chronicle, human takes frying pan from kitchen-shelf, gets eggs from the fridge and turns on stove. Then we need to define temporal constraints on these events, these events can happen between 3 - 5 minutes and these events should occur in the morning. When recognized, robot can start setting the table for the breakfast while the human cooks.

We have defined many scenarios based on presence or absence of human activity around robot. These scenarios are so modeled to enable system to have different proactive behaviors. For example robot can look to find goals for itself (do housekeeping, be curious etc, like[30]) or find a human goal where it can help (like setting the breakfast table for human). When a chronicle model matches a defined scenario, CRS informs the supervisor. Supervisor acts according to behavior it represents, can add it as a new robot task in task agenda or if relevant to human goal, requests the planner for a plan.

The key aspects for CRS use are:

- It handles time explicitly.
- It can monitor modeled scenarios on the fly, by matching observations to model events and temporal constraints propagation.
- It can maintain several hypothesis (chronicles), that is, complete tree of instances of partial chronicles currently taking place.
- Can easily integrate several events in different scenarios and keep their window of relevance with respect to each scenario.

Human activity is essentially difficult to model, different humans will approach an activity differntly causing uncertainty around scenario recognition, for example, in a cooking scenario, there can be several different ways a human can start the activity, can take the eggs from fridge, can get frying pan from kitchen-shelf or can turn on stove first etc. One way to handle this uncertainty is by defining several chronicle for a same situation. Complexity does not increase significantly due to multiple chronicles as CRS is quite efficient in handling many chronicle insances[18].

3.3 Human Aware Task Planner - HATP

HATP is a planner designed for heterogeneous Agent interactions, in our case humans and robots. It is based on hierarchical task planning[24] and integration of behavior rules, which orient robot decision and produce social plans. HATP has also its own language[6], which allows us to model human preference, ability and capacity as we can see in the figure 2 we describe the fact that the human needs Glasses by a boolean attribute associate to the entity “Human” called "needGlasses" it has the true value if human needs the glasses and false otherwise. We complement the human model with the action description which takes into account the fact that the action is performed by the human or by the robot.

We take inspiration from human interaction to establish rules for a right social behaviors in human robot interaction. We define six types of rules[6]:

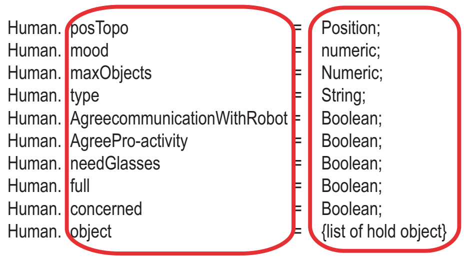


Figure 2. HATP Human model: In this example we can see HATP building the human model. The entity "HUMAN" is described by a set of attributes which represents respectively human topological position, degree of human desire to be involved in task, human ability, boolean attribute describing if human allow robot pro-active behaviour, boolean attribute describing if human needs glasses, boolean attribute describing if human is concerned about current task, list of objects that human takes.

- Undesirable states
- Undesirable sequences
- Bad decompositions
- Effort balancing
- Timeouts
- Crossed links

HATP planning process is composed of two threads. One thread is responsible for the plan refinement[28] and a second thread is responsible for plan evaluation. The second one is based on the Analytic Hierarchy Process (AHP)[21], it gives to the plan evaluation a total control on the plan quality because it combines the penalty added by the rules violations with the costs of actions. Both of them integrate human model. For example we can model the human desire to be involved in the task and the fact that he/she has physical handicap. In this situation HATP will produce plans involving the human in the task that respect his/her capability. Otherwise it produces plans with as least as possible human involvement.

In this paper, the main HATP performances is its ability to take into account human actions and to produce social plans, its capacity to handle contingencies, and also the possibility for HATP to start planning from a partial plans[6] (It gives the robot the possibility to analyse human plans and correct or complement them for proactive behaviour).

3.4 SHARY : The supervision and execution system

SHARY'S[11], [12]originality, as a supervision system, lies in its ability to take into account not only the task achievement but also communication and monitoring needed to support interactive task achievement in a flexible way. SHARY allows to define a task or a hierarchy of tasks linked to more or less elaborated "communication policies" that enable to execute tasks given the possibility to deal with contingencies that could occur during its execution (or even to stop the task in case of unexpected events).

A communication scheme, for a given joint task, represents all possible turn taking steps and synchronization between the robot and its human partner [13]. Each time a state is visited the corresponding task recipe or atomic task is launched.

From a practical point of view, a communication scheme is a finite state automaton. Its states are communication acts expressed by the robot through dialog or by an expressive motion. Its transitions are communication acts directly expressed by the human or inferred from her/his behavior by monitoring tasks.

We have some generic communication scheme with a defined set of communication acts that are mandatory in the framework of task achievement [1]. This set takes inspiration from Joint Intention Theory ([14]) that states that each partner should be informed of the beginning, realization and ending of a joint task.

While executing a specific task this generic communication acts will be instantiated as an act_X_task with a recipe, an execution state, etc. For example, when the robot is proposing to give the human an object, it is realizing the act_X_task defined by the `Give Object` task and the `ASK-TASK` act.

Task Recipe: Task recipes are methods that compute the partially ordered list of subtasks of an act_X_task. This sub-task tree contains both a set of tasks needed for the achievement of the act_X_task but also a list of tasks required for monitoring the execution. Recipes can be scripts, i.e. provided by the programmer, or can be synthesized by a planner such as HATP [28] presented previously.

Figure 3 describes SHARY execution at a given task level and exhibits the incremental context-based task refinement process which results in a dynamic hierarchical task tree.

Toward Proactivity: Using the system proposed so far we already managed to make the robot create proactively new robot only tasks (like cleaning a table) and also to ask human for help proactively if robot couldn't achieve one of its task alone (cannot pick up a bottle). We improve the system to make the robot act proactively for human goals recognized and instantiated by CRS.

If the new human goal recognized by CRS has a higher priority than ongoing task, the robot starts managing the human goal as if it has been directly asked by human until it receives the recipe from HATP. We then add a check step to make the robot monitor if the recipe given by HATP contains robot sub tasks and stop the task otherwise. Finally the robot asks human permission to realize the action described in the recipe and continues execution only if human agrees. The first step prevents the robot from bothering the human for nothing. The second steps ensure human agreement with robot initiative.

4 EXPERIMENTS

The system has been implemented and integrated on a fully equipped mobile manipulator called Jido and tested in the experimental environment, shown in figure4. It simulates a living-room with different objects of everyday human life (tables, chairs,. . .). The robot goal is to assists human in his daily life, for this the robot able to perform a number of tasks Serving, Cleaning and maintaining an updated knowledge of the state of the world (detecting and tracking persons in the room, detecting and recognizing new objects placed on tables by the persons. . . .).

Besides decisional capabilities that we have discussed, our robot has its functional level rich set of capabilities, as that involve motion[25], navigation[32], manipulation[31], perspective placement [27] in presence of humans as well as perception of human activities[7] and face tracking[22]. The challenge for the system is to perform these tasks showing proactive robot behavior and also interleaving it with social behavior when interacting with the human. We present, in the sequel, illustrative examples of Jido capabilities. A human living room furnished environment (Coffee Table,Cupboard Table chairs, Cupboard, Chairs) and objects (Glasses for reading, Books, Bottles, 2 Glasses for drink) is the setting for the examples.

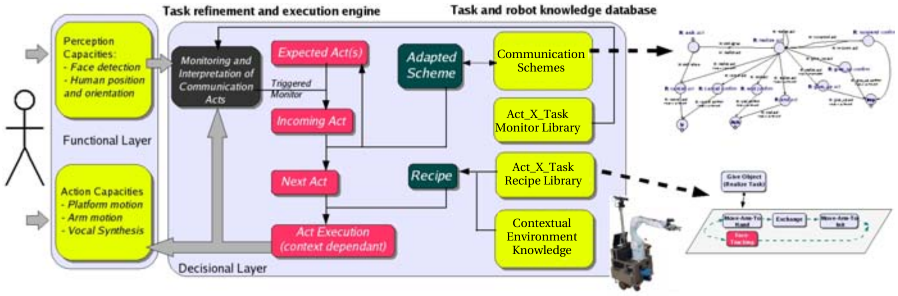
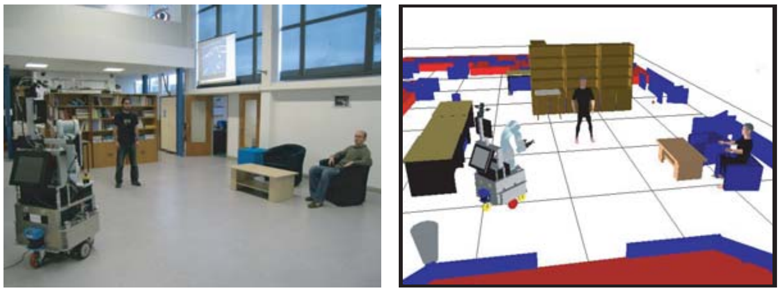


Figure 3. General Description of Shary (at a given task level inside a hierarchy of tasks): when the task is created, a communication scheme associated to the task is instantiated according to the task, the context and the concerned agent = *Adapted Scheme*. This scheme gives the first act to execute. The recipe corresponding to that act (precisely to this act_X_task) is instantiated by the help of a recipes library: *Recipe*. During *Act Execution*, communication and execution monitoring is done through wait on *Expected Acts*. When a monitor is triggered *Incoming Act*, i.e. when an expected act happens, the current act is stopped and the answer is instantiated given the communication scheme *Next Act*. And so on...



(a) A "living-room" (b) 3D model used by the robot

Figure 4. Robot working environment.

The examples will focus on three different kind of proactive robot behavior:

Example 1: proactively generate new tasks involving robot

As mentioned in section 3.1 the Task Agenda implements the ability for the robot to manage its high-level goals. New tasks can be obtained via dialog or can be generated via CRS based on the recognition of chronicles representing human activity[18]. In the task Agenda there are some modes dedicated to the achievement of a family of tasks. These modes are defined such as "clean", "serve" and also "Curiosity". While in this mode the robot will try to achieve tasks to keep an updated world model of objects on the table if the robot had inferred possible changes through CRS.

In this example human comes near the table and stays there for some time and leaves. When this chronicle is recognized, CRS sends an Update Knowledge request to the supervisor indicating uncertainty of the table state. And when robot is not doing a more prioritized task it goes and looks at the table to find current table state. This helps robot keep an up-to-date world model of objects on the table. Figure 8 illustrates the example described.

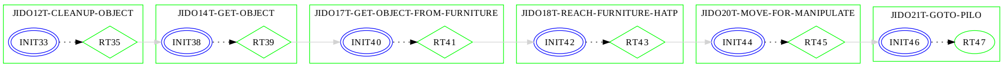
Example 2: proactively ask human help to achieve a robot task

Through this scenario, we would like to show the ability of the system to take initiative and ask human help to remove an ambiguity or to escape from a blocked situation. The task consists in Jido cleaning the living-room table by picking up the bottle and throwing it into the trash. Figure 6 illustrates the plan produced by HATP for normal execution as well as a snapshot of a current task refinement decomposition performed by SHARY. Initially HATP produces a plan where Jido can do the task itself. SHARY executes the plan. During the execution of the (move to table) task our human aware motion planner (MHP[31]) places our robot in front of the table for safe manipulation in human presence. Sometimes Jido cannot reach the bottle. SHARY would then ask HATP to replan. If there is a person present in the environment that can reach the bottle, HATP will provide a new plan where human will reach the bottle and give it to Jido. Executing this plan will consist in Jido asking the human to give it the bottle.

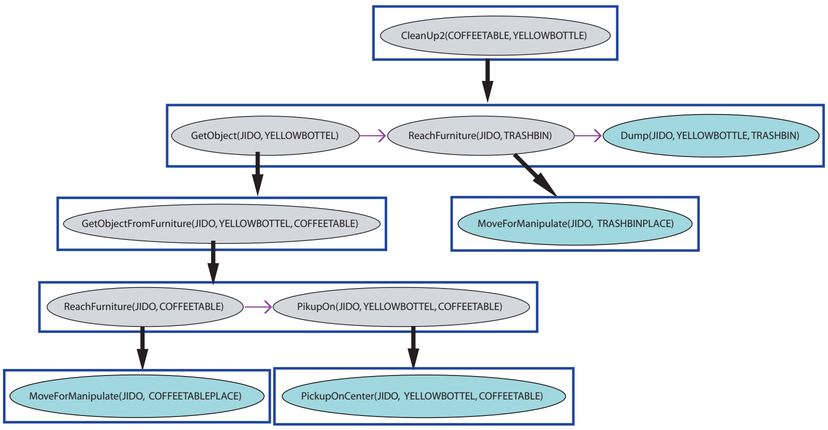
Figure 7 illustrates the different steps including request to the planner when robot can ask human help.

(a) (b) (c) (d) (e)

Figure 5. Example 3: proactively generate new tasks involving robot. a person approaches the table near the cupboard and stays still for a moment before leaving. This induces the fact that the person might have put or taken bottles. Jido takes the initiative to approach the table and to update its knowledge using its perception functions.



(a) Current execution task stack in SHARY: Boxes are tasks, circles and diamonds shapes are act_X_tasks (`RT` is the abbreviation of `REALIZE-TASK`), gray arrows represent decomposition links and dotted arrows are transitions between act_X_tasks inside a communication scheme. Blue color corresponds to *achieved* tasks and acts while green color means that they are being executed.



(b) Hierarchical plan from HATP for the `clean-up` task

(c) Snapshot from the experiment

Figure 6. Example 2: proactively ask human help to achieve a robot tasks Achieving `clear-up(yellow-bottle)` consists mainly in achieving its act_X_task `RT` or its plan HATP as well. The HATP plan stops at a given abstract level in task decomposition (6(b)). Consequently, SHARY needs to further refine these tasks corresponding to the leaves in the HATP plan tree. This is illustrated in 6(a) for `MoveForManipulate` task.

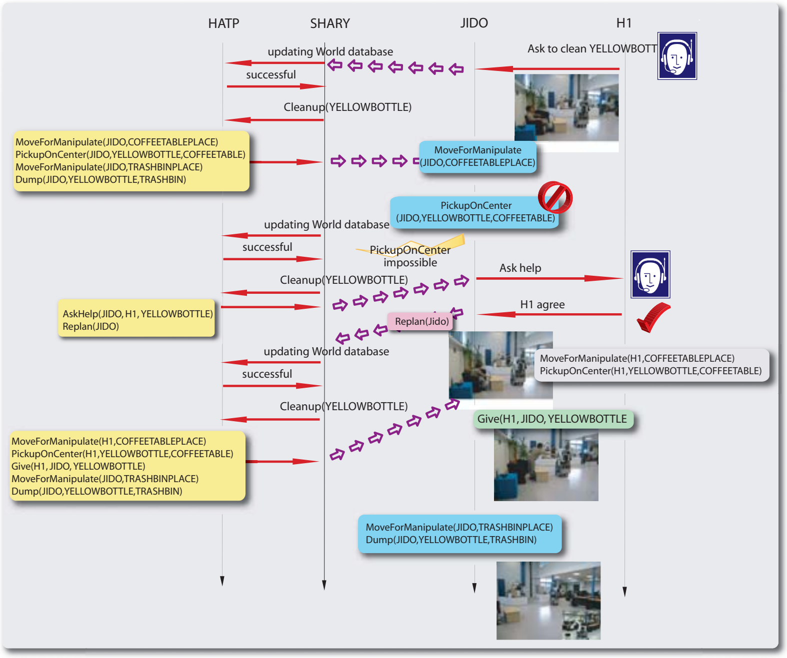


Figure 7. **Example 2(In difficulty ask Help):** `clean-up` task execution: At the top left of the figure, we see a simple version of the first HATP plan computed to achieve the `clean-up`. In the middle and at the right side of the figure, we see the execution stream corresponding to this plan execution. This first plan failed due to robot inability to take the bottle (even when it has perceived it). SHARY asks a new feasible plan. HATP finds a plan with a higher cost and two streams and where the person is requested to participate by giving the bottle to Jido. The robot can then proceed and move to throw the bottle in the trash bin.

Example 3 : act proactively to help human achieve his goal

In this scenario we will see the capacity of the system to generate a pro-active behavior to help human achieve his/her goal. Robot observes the environment via CRS and if it recognizes a scenario that corresponds to human goal, it transmits this human goal to SHARY. SHARY adds this probable new goal in the task Agenda which analyzes its priority in comparison to the other present in the TODO list. If the new goal has the priority SHARY requests HATP for a plan, HATP searches for plans that minimize human effort. If it exists at least one, it supplies the best one to the SHARY. If the plan contains some task for the robot, Shary starts the execution otherwise there is no thing to do for the robot and it carries on its current activity.

In this example, Jido observes human going near the bookshelf, taking the book and sitting on the sofa. CRS recognizes this scenario as human wants to read and informs SHARY. Which adds this task to the Agenda which puts it on the top of the list after analysis. Shary sends a planning request to HATP. HATP starts planning, taking into account human preference, ability and capacity (like John wears glasses where as Jack does not) finds a plan where human should have his reading glasses (Assuming an ambient camera system through which jido knows that human is not wearing glasses) because one of the precondition of the **to read** task is to have reading glasses. SHARY checks if there is some thing to do and executes HATP plan if there is. Figure 8(a) shows the system activities flow for this example. Figure 8(b) shows, the HATP plan with two streams, one for human, showing his course of action and other strean showing robot course of action to intervene and help human achieve his goal of reading by bringing the reading glasses for him.

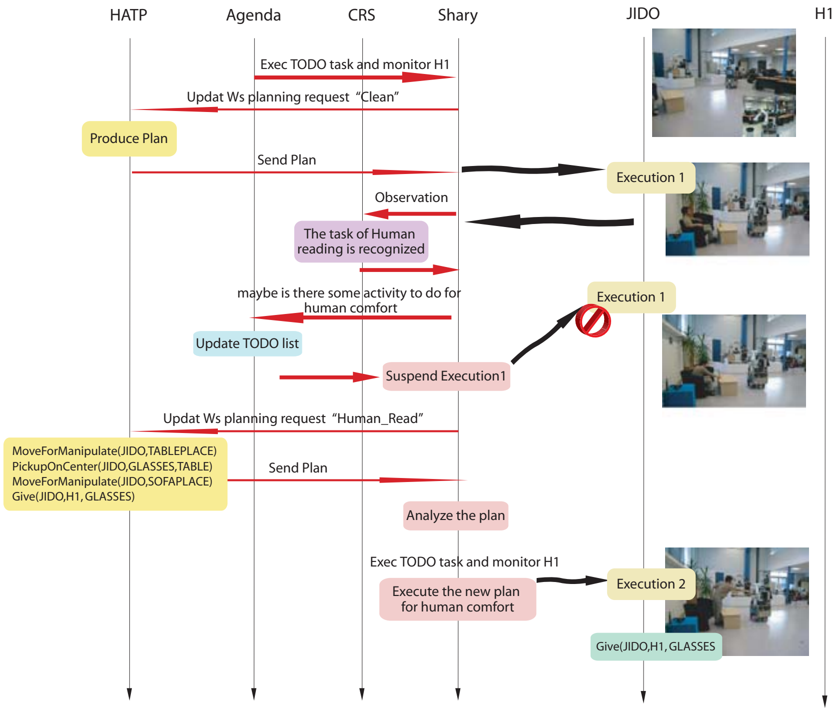
CONCLUSION AND FUTURE WORK

In this paper, we have presented a system architecture for proactive robot initiative taking, adding to its already rich set of human robot interaction (hri) capabilities. We have discussed main components involved in initiative taking and describe how they are working in our system. We have demonstrated through implemented examples various aspects of the system, scenario recogniton, planning based initiative taking and execution through hri dedicated supervisor.

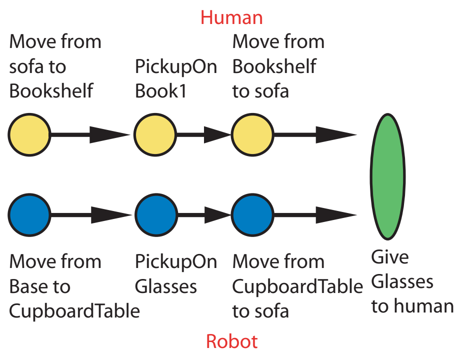
Deciding on whether to take initiative and whether to ask permission or inform about initiative taking is not easy. These issues were simplified here. The robot always took initiative if there are some plan involving robot and always asked for permission before execution.

Human preferences regarding robot initiative taking were not taken into account to produce plan. Some people could be reluctant to initiative taking robots whereas some other would be very enthusiastic and possibly bothered that the robot asks permission each time it wants to take initiative. We could also imagine that the individual preference of a particular person evolves both in a very short term (Emergency situations, Human emotional state, recent dialogues and actions) and in a longer term (people gradually becoming more confident or conversely more suspicious or annoyed). HATP is able to model human preferences so we could very easily introduce parameters stating individual preferences toward robot productivity to adapt the resulting plans to each individuals. The new challenge would then be to make this preference evolves according to context and interaction memory.

Concerning scenario recognition, we can use chronicle learning[26] for obtaining new chronicles or focus on proba-



(a) While the robot is doing some task, CRS detects a human reading chronicle. It informs SHARY that create a task in the task Agenda. SHARY sends a planning request to HATP, HATP produces a plan. SHARY analyses the plan and if there is a robot task for helping human executes it.



(b) HATP produced plan, with two streams: one for human course of action, and another for robot actions where it can proactively intervene to help human

Figure 8. Example 3: act proactively to achieve human goal The general flow of activities in the system

bilistic approaches for better handling of uncertainty. Or can look to probabilistic approaches for interpreting human activity, like[10, 19].

Task agenda being based on fixed task priority prohibits natural and rational behavior. It needs to be more dynamic, should take into many factors, for instance, task progress. For that plan monitoring will be important, CRS can be useful if plans can be synthesized into chronicles.

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