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Resource-Adaptive Action Planning in a Dialogue System for Repair Support ⋆

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Abstract. For reasonable application in critical domains dialogue systems not only have to pay attention to user knowledge and dialogue goals but they also have to adapt their dialogue behaviour to current limitations of the user's cognitive processing capabilities. In case of a help system the point of concern is on the one hand the aspect as to what kind of help is appropriate for the user $\mathcal{P}$ (*What* to do?). This action planning has to take into account $\mathcal{P}$'s resource limitations like time pressure and working memory load. On the other hand the system's utterances should also be adapted to $\mathcal{P}$'s language processing capabilities (*What* to say – and *how*?). This work presents primarily approaches to adaptive action planning. Its interaction with dialogue planning is outlined.

1 Introduction

1.1 Issues

In the field of human-computer-communication considerable progress has been made since the first approaches to user modelling in adapting system behaviour to individual user knowledge and current dialogue goals. However up to now such systems barely take into account the resource limitations restricting the dialogue partner's cognitive processing.

In the field of planning for example, current systems almost exclusively take into account the resource limitations of the planning process ignoring those of other agents. In addition, such planners have hardly been applied to the modelling of dialogue situations.[1]

This work is concerned with the question of how a dialogue system can adapt its dialogue behaviour to the individual cognitive resource limitations of its dialogue partner $\mathcal{P}$. As a domain for such a system we have chosen the setting of a help system. The $\mathcal{S}$ystem $\mathcal{S}$ is faced with a diagnosis task and a repair task. The diagnosis—to find the cause of $\mathcal{P}$'s problem—has to be found interactively in a dialogue with $\mathcal{P}$. The repair task comprises of instructing $\mathcal{P}$ to take actions to solve the problem. For $\mathcal{S}$ both

⋆ This work has been founded by the Deutsche Forschungsgemeinschaft in its Special Research Program SFB 378, “Ressourcenadaptive kognitive Prozesse”, Project B2: `READY: Ressourcenadaptive Dialogführung'.

[1] An overview of such planning approaches is given by Wahlster, Jameson, Ndiaye, Schäfer, and Weis (1995).

tasks require information gathering (by questioning $\mathcal{P}$) and $\mathcal{P}$'s instructing. This paper mainly focuses on the selection and verbalization of actions in such a way that suits $\mathcal{P}$ to probably understand and execute them under his current constitution and the given constraints (e.g., time pressure).

Although actions are rather related to the repair task they are also important to the diagnosis part, e.g., when $\mathcal{S}$ instructs $\mathcal{P}$ to check a failure hypothesis.[2] When instructing $\mathcal{P}$ resource-adaptive dialogue behaviour is relevant in two fields: (a) action selection (action planning), because these actions have to be executed by $\mathcal{P}$; and (b) formulation of system utterances (dialogue planning), since $\mathcal{P}$'s understanding constitutes a prerequisite for his successful acting.

Resource-adaptive action and dialogue planning takes place considering estimations about $\mathcal{P}$'s *cognitive resource limitations*. Such information is maintained in the partner model of the dialogue system—besides classical aspects as, e.g., $\mathcal{P}$'s knowledge. Here the use of this information for adapting the system behaviour is investigated, not however issues of the partner model itself.[3] The following cognitive resource limitations of $\mathcal{P}$ are considered:

– **available working memory capacity (AWMC):** The partner model provides an estimate of the cognitive load presently acceptable for $\mathcal{P}$.[4]
– **time pressure:** The user has more or less time to solve his problem, e.g., depending on whether and when he has to meet a deadline.[5] As a simplifying starting point, time pressure is used as an analogue measure. Nevertheless, fixed deadlines can affect the dialogue behaviour of the system due to the fact that the estimation of $\mathcal{P}$'s time pressure will be updated during the discourse.

1.2 System Context of READY and Example Scenario

The project READY aims at laying the foundations for a **Re**source-**A**daptive **D**ialog S**y**stem. This system will estimate and explicitly model its user's cognitive resource limitations, which vary individually and from situation to situation, in order to adapt its dialogue behaviour to this limitations.[6] The system READY will exemplarily conduct spontaneous dialogues in a domain in which the dialogue partner's resource limitations play an important role:[7] READY provides repair support by phone to a dialogue partner $\mathcal{P}$, who has to repair the failure on the road; because he cannot make a note of the information offered by READY, and because of time restrictions, distractions and stress he is

[2] Many of the aspects depicted here with reference to instructions are also relevant to questions (besides others); but space restrictions do not allow for a detailed description.

[3] Details of acquisition, representation und maintenance of the partner model by means of dynamic Bayesian networks are given by Schäfer and Weyrath (1997). Based on perceived symptoms and causes of resource limitations estimations are build up by diagnostic respectively predictive inference, e.g., about $\mathcal{P}$'s working memory load and time pressure.

[4] This estimation is inferred among other things from $\mathcal{P}$'s age (cf., e.g., Kemper, Jackson, Cheung, & Anagnopoulos, 1993), emotional strain and distracting factors.

[5] The partner model is able to estimate $\mathcal{P}$'s time pressure not only by explicit utterances by $\mathcal{P}$ but also based on symptoms as extraordinarily high speech rate.

[6] An overview of the READY project is given by Wahlster et al. (1995).

[7] A first system prototype is planned for autumn 1997.

not always able to make complex inferences. The modelling is based on the assumption that all the communication in the scenario is realized exclusively by speech. Up to now the investigations have been concentrated on the core functionality of the system such as partner modeling, action and dialogue planning. In a later project phase modules for speech recognition, analysis and generation will be integrated.[8]

The following **example situation** serves to illustrate the different aspects of resource-adaptive system behaviour throughout the paper: A car driver $\mathcal{P}$ has a failure in the electrically movable sliding roof of his car: It stands open and refuses to close. After heavy (and persistent) rain falls have started $\mathcal{P}$ stops under a bridge. Before he has not solved this problem—with the help of the dialogue system $\mathcal{S}$—he cannot continue his ride. The explanation of alternative dialogue behaviours for $\mathcal{S}$ in the discourse with $\mathcal{P}$ relates to this initial situation.

2 Resource-Adaptive Action Planning

2.1 Discussed Issues

- According to which pragmatic criteria should $\mathcal{S}$ select the actions suggested to $\mathcal{P}$?
- How can domain knowledge about appropriate actions to achieve $\mathcal{P}$'s goal(s)—here to resolve the breakdown—be modeled? Domain knowledge here means the knowledge about nature and organization of actions, e.g., about how to replace a blown fuse.
- What aspects of actions are relevant to their execution by $\mathcal{P}$ with regard to the cognitive load?

2.2 Evaluation Criteria for Action Plans

To optimize its behaviour a dialogue system needs criteria according to which it can evaluate the alternatives at its disposal and select the appropriate ones. In accordance with the global goal of offering a successful breakdown service we use as *pragmatic evaluation criteria* for action plans the (expected) *success* of $\mathcal{P}$'s execution of the suggested actions and the (expected) *duration* of this execution. When aggregating the two separated evaluations to an overall one, current preferences about these two dimensions, e.g., based on time pressure and/or the importance of an action, can be taken into account. The estimations influencing the separate evaluations about actions can depend on $\mathcal{P}$'s cognitive abilities (modeled by AWMC in the partner model) as well as $\mathcal{P}$'s time pressure and knowledge level.

For example, a stressed driver not familiar with car technique will have more difficulties to control and replace a fuse than an expert; he will also need more time than a focused and concentrated driver with background knowledge about electrical connections. The two main criteria are now described in more detail:

[8] As a starting point we use semantic representations for user utterances which also reflect some performance-oriented aspects as, e.g., speech rate, hesitations and self corrections. Similar representations are used for system utterance.

Time consumption comprises the total time required until an instruction is executed. On the one hand there is the time the system requires for planning and verbalization (including articulating) of utterances. This aspect is mentioned here, because it is initially a decision on the action planning level with which degree of specificity (with respect to single steps) the suggested actions are described.[9] Thus, for example, instead of the instruction "Please, control the electric fuse of the sliding roof!" a sequence of single step instructions might be more suitable for a technically untalented person, beginning with "Open the fuse box on the top left of the driver's floor space! . . . ". On the other hand the total time consumption also comprises the expected time for $\mathcal{P}$ executing the suggested actions. Here differences arise when alternative action plans differ elementarily, i.e. by different single steps. But also in principle equal action plans can individually differ in the time they demand from $\mathcal{P}$: In order to execute an abstract instruction $\mathcal{P}$ has to plan the single steps, i.e. the elementary actions (as with the first variant of the example in the last section).

Our consideration of the criterion time consumption simplifying assumes a linear cost measure: The longer the resolving of $\mathcal{P}$'s problem lasts, the more unfavourable the evaluation. How "expensive" a certain time unit is depends on the evaluation preferences, and thus among other things on the time pressure.

The **success** of $\mathcal{P}$'s action plan execution is determined by the probability of success and the expected quality of the problem solution. The probability of success is affected by $\mathcal{P}$'s error rate when planning and executing the actions, but also by the inherent uncertainty of an action plan regarding its applicability (correctness). E.g., this uncertainty can originate from the uncertainty or incompleteness of ($\mathcal{S}$'s) knowledge about context conditions, so that a plan can possibly prove as not or badly applicable afterwards (qualification problem). The quality of an action plan can be measured by the quality and reliability of the results of a successful execution. In the field of diagnosis alternative proceedings can supply results of different reliability, e.g., the quick reading of the oil *pressure* lamp as an uncertain indication in relation to controlling the oil *level* by using the dip stick in the engine compartment. An aspect that can affect both quality and success is the robustness of a plan in the sense of *anytime execution* (e.g., see Dean & Boddy, 1988): A plan with a continuous success improvement over the time permits a premature breaking off with a partial success; e.g., the manual closing of an electric sliding roof (a crank procedure) is robuster than the changing the safety device in order to try it again using the motor. Under time pressure or strong uncertainty about its existence robust plans should be preferred.

The described pragmatic evaluation criteria and the factors influencing them form the starting point to situation-adapted handling of conflicting goals by taking trade-offs into account.

[9] In principle it would also be possible to assign this system time to the dialogue planning task; but this approach complicates the modeling of goal conflicts and trade-offs within action planning.

2.3 Planning Approach

For the planning of its assistance for $\mathcal{P}$ the dialogue system $\mathcal{S}$ needs knowledge about domain actions—in our scenario about proceedings for diagnosis and repair of breakdowns. It is assumed that the dialogue partner's knowledge forms a subset of $\mathcal{S}$'s knowledge, on which $\mathcal{S}$ can base itself if necessary.[10] The representation chosen for action knowledge is based on formalisms for hierarchical organization of such knowledge as developed so far (for an overview of such approaches see, e.g., Tate, Hendler, & Drummond, 1990). The special requirements imposed by resource-adaptive planning were considered; further details on this are described in Section 2.4, while the general approach is first sketched now.

Hierarchical Planning Approach: The organization of action knowledge relates the possible actions to domain goals for whose achievement they are suitable. This is realized by means of *plan operators* whose postconditions specify what is valid after their (successful) execution, i.e., which goals they can in principle be used for to reach. The general structure of plan operators is depicted in Figure 1, and an example is given in Figure 2. Abstract actions—meaning complexly composed actions— can be decomposed into sub-actions by means of *subgoals* in plan operators. By iterating this process over the subgoals one can finally arrive at the level of elementary actions, which are regarded as being directly executable. The tree-like structures built up this way according to goal-action relations describe structured proceedings for achieving goals.[11] The domain context necessary for a successful application of an plan operator can be restricted by specifying *applicability conditions* for the operator. The approach of building up action plans using plan operators for achieving subgoals ensures flexibility of modelling concerning the application by means of adding and modification of operators.

Relevant Characteristics of the Approach: The decomposition of goals into subgoals by means of plan operators opens a way of describing alternative proceedings on different levels of an action plan by specifying alternative plan operators. This hierarchical organization of actions by abstraction permits the variation of the *specificity of action descriptions*: This specificity relates to the choice of an abstraction level up to which an action plan gets expanded (i.e., gets decomposed into subgoals).

Conditioned subgoals, which are only relevant under certain contextual conditions, allow for dynamic and retarded adjustments of plans to different domain situations during plan execution (incremental planning / plan executing). E.g., in the current example it is only necessary to open a cover if the mechanical emergency crank of the sliding roof is covered by one.

[10] Incorrect knowledge of $\mathcal{P}$ is not explicitly modelled, however the probability that $\mathcal{P}$ can independently implement an abstractly described action correctly.

[11] Although the plan structures are built up dynamically they more compare to planning schemes than to HTN (hierarchical task network) planning approaches in respect to expression power and handling of subgoal interactions. The project READY is particularly concerned with appropriate applying of planning knowledge; therefore these restrictions can be accepted—and they simplify investigating our main research area.

Plan operator: <name>
Postconditions: <domain conditions>*;; effects of executing the operator*
Applicability conditions: <contextual conditions>
;; specify necessary domain conditions for the operator to be applicable
Action description:
- resource-related characteristics: <resource specifications>
;; serve to evaluate the action and their decomposition (if any)
- linguistic information: <semantic action representation>
;; specification of the abstract action of the operator as basis for dialogue planning
Subgoals: <subgoal specifications>*;; only relevant for operators for abstract actions*
;; decomposition of an abstract action into subgoals

Fig. 1. Schematic description of the syntax of plan operators.

Optional subgoals permit adjustments for example to time limits—with consideration of the importance of the pursued goal. Thus, in the example closing the crank cover can be omitted if necessary since it isn't absolutely necessary to continue the ride.

Interrelationship with Dialogue Planning: The actions specified by plan operators get verbalized by dialogue planning for example in the form of instructions. As basis for this process those plan operators for whose actions a (direct) verbalization should be possible, comprise references to *linguistic knowledge* about the actions (cf. the approach in Eugenio, 1993). This knowledge serves in dialogue planning to realize a concrete verbalization; while doing so further information can be taken into account, for example about *how* an action is to be taken (e.g., where to find a cover to open or what it looks like). This aspect will be treated in greater detail in the context of dialogue planning (see Section 3).

Plan operator: Close_roof_mechanically
Postconditions: *"sliding roof closed"* & ...
Applicability conditions: *"mechanical emergency device / crank exists"* & ...
Action description:
- resource-related characteristics: *"time consumption: high"*; *"execution quality: high, robust"*; *"difficulty: high for beginners, low for experts"*; ...
- linguistic information: *"Close the sliding roof [by means of the mechanical emergency crank in the luggage compartment]!"* (example of a verbalization)
Subgoals: *"Open luggage compartment"* & *"Open crank cover"* & *"Operate crank"* &
"Close crank cover" & *"Close luggage compartments"*

Fig. 2. Plan operator for mechanically closing of a faulty electric sliding roof (shortened informal description).

Example: For closing the electric sliding roof there are two alternative proceedings: (a) assuming a faulty electric fuse this device can be checked and replaced if necessary to close the roof by motor; (b) the roof could be closed using a mechanical emergency crank located in the luggage compartment of the car. These two alternative action plans are represented in the system on top level by two plan operators which achieve the goal of closing in their respective way. Figure 2 exemplarily shows the operator for alternative (b).

The planning tree for closing the sliding roof is presented in Figure 3. It does not only represent the two general alternatives *Put_electrical_circuit_into_operation* and *Close_roof_mechanically*, but also their variants emerging for example from omitting optional (sub)goals or from a differing expansion depth of abstract goals such as *Check_fuse*. This goal can be verbalized either directly or be described in its single steps in a more time-consuming way (e.g., to be sure to be understood by a technically untalented driver). The evaluation of the alternative action plans will be captured by the next section.

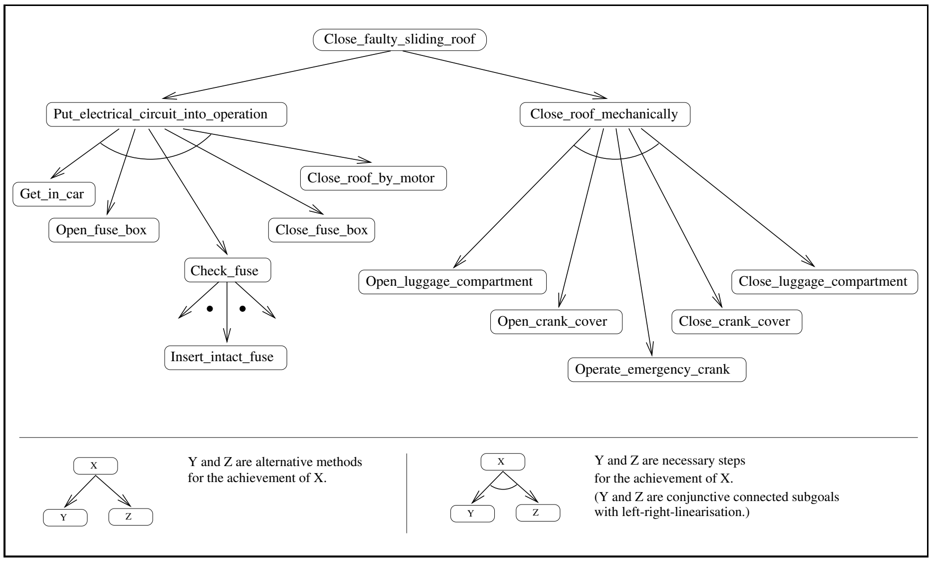

Fig. 3. Scheme of a planning structure for closing a faulty electric sliding roof (excerpt).

2.4 Resource-Related Evaluation of Action Plans

In order to be usable in a resource-adaptive system the presented approach to action planning has to be augmented by information about performance aspects of the represented action knowledge. In the case of READY not only the actual time required by the dialogue partner $\mathcal{P}$ to implement actions is of importance, but also—among other things— the extent to which $\mathcal{P}$ will be cognitively strained by this implementation. At first we describe the resource-related characteristics of abstract and elementary actions and then give an explanation on how action plans can be evaluated on this basis.

Resource-Related Characteristics of Elementary Actions:

- **Time Consumption:** How long will it probably take for $\mathcal{P}$ to implement an single action? This duration also covers the time $\mathcal{P}$ requires to recall the procedural knowledge required to implement an action, e.g., knowledge about course of motion when cranking. In this case some dependencies exist for example on $\mathcal{P}$'s AWMC (How good can $\mathcal{P}$ focus himself on an action?), on the time pressure (Will $\mathcal{P}$ hurry up?), and also of $\mathcal{P}$'s knowledge level in the domain. In the example the crank procedure will always be regarded as comparatively time-consuming.
- **Execution Difficulty:** The difficulty of an action for $\mathcal{P}$ depends—in addition to the aforementioned factors—on $\mathcal{P}$'s motor and sensory skills in relation to the respective requirements of an action. E.g., recognizing a faulty electric fuse *can* sometimes be difficult.
- **$\mathcal{P}$'s Error Rate** for executing the actions depends on the aforementioned factors likewise. In the current example the mechanical cranking to close the sliding roof is expected to be less error-prone than putting the electric circuit into operation.
- **Quality** of the results: Here the inherent characteristics of actions as described in Section 2.2 are of importance; for example the quality, reliability, and robustness of success of an action execution.

Resource-Related Characteristics of Abstract Actions: They are defined in a similar way as elementary actions; therefore only the substantial differences are named here.

- **Time Consumption** comprises $\mathcal{P}$'s planning time for independently realizing an abstract action; it has to be added to the actual run time of the elementary actions. As before—and probably even to a higher degree—a high AWMC will probably increase $\mathcal{P}$'s time consumption.
- **Execution Difficulty:** How cognitively straining is it for $\mathcal{P}$ to plan an abstract action independently? Here $\mathcal{P}$ is generally more strongly strained by an increased necessity to make inferences in content and by recalling information from the long-term memory (cf. Kintsch & Vipond, 1979; Britton, Glynn, & Smith, 1985).
  In the example, the steps for mechanically closing the sliding roof might be hardly derivable—in particular for a technically untalented driver; thus they will better be explained to him in detail.
- **$\mathcal{P}$'s Error Rate** for planning the elementary steps in order to execute an abstract action: Is $\mathcal{P}$ able to find a correct plan on his own? This judgment affects the expected success, and it also depends on $\mathcal{P}$'s knowledge level, besides his AWMC.
- **Quality** of the results of implementing an abstract action means how well the action will achieve its goal—independent of sub-steps by which it is realized . E.g., the mechanical closing of the sliding roof will reliably and robustly succeed, whereas the success of replacing the electric fuse is questionable.

Resource-Related Characteristics of Subgoals: Certain characteristics of actions cannot be *statically* assigned to them, since they depend on the context in which the actions are placed.

Therefore such characteristics are associated with those subgoals in plan operators for whose achievement the actions are used. In this way the context is given by the superordinate goals of the plan operators in each case.

– **Inferability:** How difficult is it for $\mathcal{P}$ to independently recognize a subgoal which is not explicitly addressed, but is to be inferred from the context? For example, $\mathcal{P}$ will probably close the fuse box after having replaced an electric fuse even when he is not explicitly told to do so.
– **Importance:** How important is it for the success of the superordinate goal that a subgoal is (correctly) realized? This question is relevant to the decision whether the system should pursue an optional goal at all; and it is also of importance to whether an inferable subgoal is explicitly verbalized or omitted for time reasons. An example of such an optional goal is the closing of the crank cover.

Resource-Related Evaluation of Action Plans: The approach presented so far permits the construction of alternative action plans. Now we will describe how to come up with resource-related evaluations for these plans—on the basis of the characteristics of the actions occurring in the plans. As a first step, the different characteristics of actions (as described in the previous section) are combined separately for each action into an evaluation with respect to the two pragmatic evaluation criteria *Time Consumption* and *Success*.

The derivation of overall evaluations for action *plans* is based on the fact that the plans are constructed through the composition of subplans (which correspond to subgoals in plan operators). Accordingly, when an action in a plan is evaluated, not only the properties of the action itself are taken into account but also the evaluations of its subplans. By contrast, elementary actions can be evaluated directly. Thus there is a flow of information from the elementary actions in the leaves of a planning tree up to the abstract action in the root, for which the overall evaluation of the plan is determined. For the *aggregation* of the evaluations of subplans, different metrics are applicable, depending on the evaluation criterion: For the evaluation of *Time Consumption*, a reasonable approximation is to aggregate additively on the basis of the following assumptions: (a) linear cost function for time (cf. Section 2.2); (b) no parallel execution or other temporal interaction among subtasks. For the evaluation of *Success*, the minimum metric is chosen, the idea being that the failure of part of a plan endangers the entire plan.[12]

[12] With respect to the cognitive load imposed by an action plan—an important factor influencing its success—this metric corresponds to the maximum metric, given the following assumptions: no simultaneous demands on working memory by two steps; clearing of working memory at the end of each step.

3 Resource-Adaptive Dialogue Planning

Because of space restrictions, with regard to the related area of dialogue planning we can only sketch briefly, by way of example, our approach to the resource-adaptive formulation of instructions.

3.1 Issues Addressed

- According to what pragmatic criteria should the system design its utterances?
- In connection with the verbalization of instructions, which are the factors that have an impact on $\mathcal{P}$'s cognitive processing?
- In what ways can dialogue planning influence action planning, i.e. the planning of the to-be-verbalized actions?

3.2 Evaluation Criteria for Utterance Design

As in the area of action planning, the criteria *Time Consumption* and *Success* can be applied to the evaluation of formulations. *Time Consumption* refers to the time that $\mathcal{P}$ will require in order to understand an utterance. The result depends not only on the length of an utterance but also on its difficulty. The *Success* of $\mathcal{P}$'s understanding forms the basis for $\mathcal{P}$'s execution of the instructions in question.

3.3 Decision Variables in Resource-Adaptive Dialogue Planning

$\mathcal{P}$'s comprehension of an utterance can be influenced by a number of properties of the utterance. If the consequences of these properties with respect to the various evaluation criteria are taken into account, the generation of utterances can be resource-adaptive. Since the influence of a given property usually depends on $\mathcal{P}$'s cognitive strengths and limitations, an evaluation should always take the current partner model into account. Here are some of the important properties of utterances:[13].

- *Level of detail:* Relatively detailed instructions seldom result in errors of comprehension, but they take a comparatively long time to verbalize and may overload $\mathcal{P}$ with information. Example: "Open the square gray cover of the fuse box in the upper right-hand part of the area in front of the driver's seat!".
- *Technical terms:* Such terms can lead to considerably more concise and precise descriptions; but they can also cause cognitive overload—especially if $\mathcal{P}$ lacks the relevant knowledge and is suffering from working memory limitations (cf. Clark & Marshall, 1981; Berg & Imhof, 1996). For example, a technically untalented driver will have difficulty in understanding the instruction "Open the fuse box!" unless it is further explained, simply because he does not know this box.
- *Syntactic complexity:* Nested relative clauses and long lists cause special problems for listeners with working memory limitations (cf. Kemper et al., 1993, for relevant research concerning the comprehension of written texts).

[13] A more comprehensive overview of research relevant to the problem of taking a dialogue partner's working memory limitations into account is given by Jameson (1997)

3.4 Dependencies Between Action and Dialogue Planning

In order to perform the actions suggested by the system successfully, the dialogue partner $\mathcal{P}$ has to accomplish two tasks: (a) understanding the system's utterances; and (b) executing the proposed actions. Trade-offs between these two tasks may arise: For example, a long, easily comprehensible instruction by $\mathcal{S}$ is worthless if it leaves $\mathcal{P}$ with no time to execute the action. The system can handle such trade-offs by computing an overall evaluation for the pair of tasks with respect to the criteria of *Time Consumption* and *Success*.

4 Conclusions and Future Work

The main contribution of the present paper is a framework for evaluating action plans and utterances to verbalize them. This forms the basis for resource-adaptive action and dialogue planning. Our approaches to action planning and utterance design were presented mainly with reference to the task of generating instructions for the dialogue partner $\mathcal{P}$. The other main task of a help system, diagnosis, involves a higher degree of interactivity, since $\mathcal{S}$ can obtain information only by asking $\mathcal{P}$ questions. For example, when $\mathcal{S}$ is evaluating alternative plans, the problem may arise that the applicability of particular solution steps is unknown, so that $\mathcal{S}$ has to invest resources in order to determine the possible actions in the first place. There are also cases in which such information only becomes available during the execution of a plan. For example, if a hidden part of a device has to be checked, several other parts may have to be removed first. One possible approach to this problem is a decision-theoretic approach that makes use of expected values.

Another problem not dealt with in this paper concerns the relationships among different dialogue contributions: Coherence among utterances can influence their comprehensibility strongly. Some of the previous research in this area (see, e.g., Mann & Thompson, 1987; Grosz & Sidner, 1990) offers a good framework within which cognitive resource limitations can be taken into account.

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