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AN EXPLANATION ORIENTED DIALOGUE APPROACH AND ITS APPLICATION TO WICKED PLANNING PROBLEMS

Gengshen Du

University of Calgary, 2500 University Dr. NW
Calgary, AB, T2N 1N4, Canada
e-mail: dug@cpsc.ucalgary.ca

Michael M. Richter

TU Kaiserslautern, FB Informatik
P. O. Box 3049
67653 Kaiserslautern, Germany
e-mail: richter@informatik.uni-kl.de

Guenther Ruhe

University of Calgary, 2500 University Dr. NW
Calgary, AB, T2N 1N4, Canada
e-mail: ruhe@cpsc.ucalgary.ca

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Abstract. In this paper we consider an interactive and explanation based dialogue approach to complex and 'wicked' planning problems. Wicked problems are essentially imprecisely formulated problems having no clearly defined goals and constraints. The dialogue approach is aimed at reducing the problem complexity during interaction with the human expert. The involved software agents are mostly optimization procedures. The approach contains the following steps: (1) Selection of a specific concern in a proposed solution; (2) Calculation of a stakeholder defined ideal plan; and (3) Comparing the actually generated plan and the prototype based on a similarity measure. The comparison of the actual and the ideal plan looks at aspects of interest for the stakeholder such as resource consumptions or structural properties of the plan.

The proposed approach is generic and was applied and customized to three classes of wicked problems: release planning, investment planning, and urban planning. All three applications are described and illustrated in the paper.

Keywords: Wicked planning problems, explanations, dialogues

1 INTRODUCTION

Although wicked planning problems do not have a precise definition, they have several common properties [21, 22]:

- There is no definite goal of a wicked problem.
- There is no stopping rule and therefore one can always improve the solution.
- Solutions are not true-or-false but good-or-bad (a release or investment plan has no absolute truth value).
- The problem is not static but changes dynamically (customers get new ideas, prices and urban laws may change).
- The view on problems and their solutions is subjective and context dependent (e.g. depending on different customers).
- One has different participants (called stakeholders) with different preferences and this makes it problematic to judge the quality of the solution.

'Wicked' is not the same as complex. For instance, chess is complex but not wicked because there are clearly defined goals and precisely defined moves. Complex problems can usually be solved (at least theoretically) by computer support.

Solving wicked problems calls for deep human insight into these problems. On the other hand, the complexity of the problems we consider necessitate tool support. As a result, we get a situation where human and software agents must cooperate. For a useful cooperation among agents they need to communicate.

In this paper we consider an interactive and explanation supported approach to planning problems that are both wicked and complex. The involved software agents are mostly optimization procedures. In our approach we concentrate on the communication between the different agents. There are two types of communication: between humans and between humans and software agents. For both types of communication, computer support is useful.

The first case – communication between humans – mainly involves protocols, knowledge support and guidelines. In the second case – between humans and software agents – communication is supported by an additional software agent who has insight into the activities of both humans and software agents participating in the communication. Although we will also comment on the first communication type our main concern is on the second one.

A main problem with this communication is that humans can think intuitively while software agents need exact rules. The support is organized in the form of a dialogue between the agents that has an explanatory character.

Our explanation approach essentially differs from the methods used in traditional expert systems. During the dialogue, stakeholder opinions can be changed or withdrawn, even if they are formulated as hard constraints (i.e. the constraints that traditionally cannot change).

For the communication between humans and software agents, this method has a generic character and can, in principle, be applied to many other wicked and complex planning problems. We will illustrate our approach in applications from very different areas: release planning, investment planning, and urban planning. The last application is much more complex than the other two. It contains communications of both types and computer support is less developed. Nevertheless, all of these applications share several essential properties. In particular, there is a special stakeholder who is responsible for the final decision; this is the lead project manager or the lead architect; we simply call this person the manager.

In summary, the mentioned three applications all have the following participants:

- the stakeholders
- a particular stakeholder, the manager
- one or more software agents called planners
- if a human deals with a software agent we also refer to this human as the user.

The user is presented with the discrepancy between ideal solutions (from a certain point of view) and the actual solution suggested by planners. The discrepancy is formulated using similarity measures. This allows a problem reduction so that stakeholders can get an overview of the situation and change their opinions.

In our approach, presented later, we consider the discussion between the manager and one particular stakeholder. This is a necessary step that simplifies the procedure but can only be regarded as a first step towards the overall solution. This solution, in the future, will require an integration of individual views and preferences from more than just one stakeholder, but this future implementation is not addressed in this paper.

The goals of explanations are to increase the degree of acceptance of a solution and to allow for improvement of the solution by increasing cooperation of the stakeholders. In order to achieve these goals we have to investigate the wicked planning problems themselves more deeply. This allows us to provide domain and problem specific explanations.

2 MODELING OF WICKED PLANNING PROBLEMS

Because of the nature of wicked planning problems, their modeling is an important but difficult issue. In order to get computer support for modeling one has to map all concepts, relations and intentions of the real world situation to a mathematical model. Specifically:

$$\text{Intuitive utility and preferences} \rightarrow \text{Model parameters.}$$

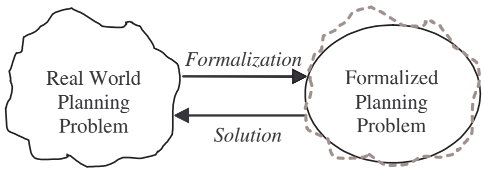

Fig. 1. Mapping between real world situation and formalized situation

This mapping is based on the hope that the planner will generate a useful or at least acceptable plan. To some degree this plan is only a guess because if the planning problem contains the difficulties described above one cannot anticipate in which way the planner will use the parameter values in order to generate the plan. In addition, certain real world aspects may not be covered at all.

In such a situation a major problem arises. The user often has no insight into the major reasons that lead to the presented solution. In particular, if the solution is somewhat surprising he/she has difficulties accepting it. Therefore the user may not trust and may not accept the solution.

Because of the lack of understanding, the feedback from the user is mainly twofold:

- asking for more (detailed) information
- objecting to (parts of) the plan.

The support needed here involves bridging the gap between the human and the software agent. A better understanding between cooperating partners always requires one partner to explain motivations and results to the other. We concentrate on explaining the results of a software agent to a human. This cannot usually be done in one step and therefore we apply a dialogue approach.

3 INTERACTIVE PLANNING, COMMUNICATION AND DIALOGUES

The simplest planning strategy, and the one applied in artificial intelligence in the past, is the sequential one [13]. This means that there is a strict order: first the requirements are collected, then the planning itself takes place, and at the end the plan is executed. For many applications, in particular for wicked problems, this strategy is not applicable. One has to cope with incomplete, imprecise and sometimes incorrect requirements and has to start with planning and partial execution on such a basis. In addition, correcting requirements is often only possible if the plan is partially executed. Because execution in reality is expensive it is often replaced by simulation. Three types of planning are discussed later in this paper. For release planning and investment planning, these plans would be realized in practice, e.g. real resources would be established. For urban planning, e.g. streets would really be built and the traffic would really be observed. In a simulation all of this would happen virtually on the computer.

Because of the interleaving of the activities in interactive planning the generation of a plan is not the end of planning; it is, rather, considered a step in the overall planning process. A plan may be changed or completed and at the same time the requirements in the plan may also undergo the same treatment.

In addition, it is often useful not to present a single plan but to offer several feasible alternatives [23]. This whole process is a joint effort of the participating agents. As mentioned above, it requires communication between agents who exchange information and explain to each other their motivations and decisions.

An important point in any explanation is that it has to be simple enough to provide a general overview, otherwise the information may not be understood. For this purpose we employ techniques that reduce the complexity of problem formulations.

4 BACKGROUND OF EXPLANATIONS

4.1 General

Explanation is studied in many disciplines such as philosophy, artificial intelligence, and teaching [5]. The general background of the explanation methodology has its roots in these areas; we will not discuss this here, however.

If different agents participate in a scenario, those agents need to communicate with each other. To a large degree this means that they explain their decisions to each other. Such an explanation has two major parts:

- information to other agents about facts
- information to other agents about opinions and motivations.

The communication can take place between humans and between humans and software agents.

In this paper we concentrate mainly on situations where a result produced by a software agent is explained to a human. Explanations of activities by software agents play an essential role in interactive processes. An overview is given in [27]. As examples we mention several systems. EDGE (Explanatory Discourse GEnerator) is a task-based explanation system that explains electronic circuit operations [5]. It contains a partner model between an expert and a novice. The explanation is generated incrementally. The explanation is only continued on the basis of the interaction with the user. RED is a diagnostic system that performs antibody identification activity for blood banks. One version of RED is implemented as a generic task. The subtasks are also generic tasks, and each element contains explanation components for its individual part of the solution [25]. QEX (Quantitative EXplainer) is an expert system that was designed to explain the results of a scheduling system [24]. An important aspect is that it employs quantitative reasoning and can address a user who does not have quantitative abilities. This means it contains a partner model for a mathematician and a non-mathematician.

In the explanation scenario there are three participants:

- The system or a system agent that provides the plan or decision.
- One or more users who are the addressees of the explanation.
- The explainer who presents the explanation to the user(s). The user applies the explanation in some way and the explainer is interested in the way this is done. With this application a utility is associated either for the user or for the explainer.

In our applications where the results of a software agent have to be explained the explainer is itself a software agent. This agent is based on the computational elements presented in the section on formalizations.

In principle, and in particular in a dialogue, explanations are always answers to questions, whether they are raised or not. The fundamental approach for the logic of question and answer is given in [2]. It should be noted that explanations need not to be literally correct. What counts as a good explanation in a certain situation is determined by context-dependent criteria [7].

The approach of Case Based Reasoning (CBR, see e.g. [19]) also has some explanatory character built in. This has been elaborated in e.g. [20]. Its central concepts are the similarity measure and the nearest neighbor notion. There is no explanation about the nearest neighbor itself, but rather an explanation as to why an object was chosen as a nearest neighbor. There are, however, some restrictions on what makes a convincing explanation. The major restrictions are:

- There should only be few attributes of high importance.
- The nearest neighbor selection should essentially rely on those attributes.

This allows to reduce the complexity in problem formulations and to draw the attention of the user to a few essential aspects. Here we make use of the fact that the similarity measure (in particular the weights) contains knowledge about the importance of attributes that allows the user to concentrate on important aspects.

Our main concern is explanations in the context of problem solving and decision making, in particular to 'Why' and 'Why not' questions of the form:

$$\text{Q} = \text{Why did you do/not do X?}$$

We introduce a new classification of explanation that is intuitively understandable and also useful for implementation issues. When dealing with wicked problems we introduce two methods below that may be combined.

4.2 Backward Explanations

Backward explanations refer to something that happened in the past. A (backward) answer to Q is: Because you forced me to do/not do X. This can be formulated in the form of a constraint or rule. The purpose of backward explanations is to increase the acceptance of a solution.

Beside this cognitive science view there is a pragmatic computer science view. This type of explanation was the traditional approach when dealing with knowledge based systems using declarative programming languages. In such systems constraints and rules have been stated explicitly; a condition was that the search for these constraints and rules was sufficiently efficient. In many classical knowledge based systems this was the case and backward explanations were made popular by following the parsing paradigm.

This approach was, however, not possible for procedural programs because the rules and constraints were implicit and hidden in the program. As a consequence, explanation components for procedural programs as optimization procedures were almost nonexistent.

4.3 Forward Explanations

Forward explanations look into the future. The (forward) answer to a 'Why' question Q is: If I would have done/not done X then the following unwanted consequence Y would have occurred. The forward explanation can, in certain situations, also increase the acceptance of decisions or solutions.

In addition, forward explanations can be used to improve and complete the solution itself. The reason is that such explanations can be employed during the interactive problem formulation and solution process. In this respect they are closely related to the 'What-If' analysis technique that is guided by the stakeholder.

A technical advantage is that such explanations are not restricted to any kind of programming language or style. In particular, they can be used for optimization procedures.

A general restriction for both types of explanations is that they have to be simple and easy to understand, sometimes even at the cost of sacrificing some of the explanation's correctness.

Because computer support for wicked problems uses a variety of programs, backward as well as forward explanations may be useful and applicable. In our applications we have emphasized forward explanations, but backward explanations will also occur.

5 A VIEW ON CONSTRAINTS

In some respects wicked problems can be viewed as Constraint Satisfaction Problems (CSP, see [26]). Traditionally, one distinguishes between hard and weak (sometimes called soft) constraints. The hard ones are not changeable while the weak ones, which give rise to optimization issues, can be changed in order to result in better optimization.

In situations where stakeholders are not sure about their opinions and may revise them, another distinction is useful:

- Factual constraints are constraints that cannot be weakened or withdrawn. They arise from logic, mathematics, physics, moral laws or anything that can never be revised under any circumstances.
- Normative constraints are the result of decisions by certain persons or organizations. Despite the fact that they are stated as being 'hard' or 'weak' they can be changed by withdrawing previous decisions and making new ones.

In wicked problem solving, normative constraints and their underlying decisions rarely contain value in themselves. Normative constraints are stated, rather, in the hope that they have a positive influence on the problem solution and the real utilities of the solution are maximally satisfied.

This is closely related to the difference between values and goals. Values are the aspects in which one is really interested and goals are the aspects that are subject to optimization. These two are usually not the same. What makes the problems wicked is that the values are difficult to grasp. In [17] deep insights into this area were given but the practical solutions provided were more of an art than the results of a systematic development.

A particular kind of normative constraint occurs when the user wants to change a solution. This is done by fixing the value of a solution parameter, and this change should be formulated as a hard (but of course normative) constraint. It should be mentioned, however, that not all constraint solvers accept such input.

Constraints are partially ordered by logical deduction. This allows for the removal of some factual constraints by going up the hierarchy until one finds a normative constraint where the responsible agent is willing to withdraw it.

The role of normative constraints in solving wicked problems is that a (forward) explanation may convince a stakeholder to withdraw a constraint because certain unwanted consequences become visible.

6 THE GENERIC APPROACH

6.1 Overview

We consider a wicked planning problem and look for a solution that is acceptable to a set of given stakeholders. There may be one or more software systems involved;

here we restrict ourselves to one system at a time, called the planner. We also restrict ourselves to one stakeholder at a time. In order to cover more planners and stakeholders one has to repeat the approach. Next we mention the applications for which our approach is intended to be generic.

For the planner we have the following assumptions:

- The planner can accept modifications of the solution as input.
- The planner presents several solution alternatives.
- The system is stable in the sense that small modifications of the input result in small modifications of the result.
- For each plan change the consequences of changing the hard factual constraints can be independently computed, and for each such consequence the responsible constraints can be named (this is a partial backward explanation).

We assume that some stakeholder (or the manager who takes his/her position) discusses a presented plan with the system. This stakeholder (the user) is assumed to like certain plans, possibly from different perspectives. The collection of these plans that the stakeholder likes is not clearly defined and hence is not a set in the classical sense. It is rather a category (see [18]) that has no membership function but certain ideal elements that are called prototypes. We call the perspective of some stakeholder a concern C and denote a prototype with respect to C by $prot(C)$. In an abstract setting the concerns form a set. For the stakeholders we assume:

- A stakeholder is able to define a prototype $prot(C)$ for each concern C.

A simple example for a prototype comes from release planning (see Section 7.1). In release planning one wants to associate release options to requirements and it may be the plan has to realize such associations. Hence a prototype for some stakeholder is simply the associations that would be optimal from his/her point of view. A prototype for release planning would be a plan that specifies which release each requirement desirably ends up in. An example of such a prototype is shown in Table 6, in the row called 'Desired Release in Prototype'. In investment planning the prototype reflects the opinions how much money should be spent for which purposes.

In order to discuss a solution with a stakeholder the actual solution should be compared with the prototype the stakeholder has in mind. If the solution looks fairly good then no objection will take place, otherwise the stakeholder will oppose the solution. In order to measure degrees of coincidence and distance between plans we use similarity measures [4].

The generic approach proposed in this paper is called EXPLAIN-DIALOGUE. This system is the explainer in the explanation scenario. It carries out a dialogue between a system (planner) and one stakeholder, as mentioned in the introduction. The main steps of the approach are:

Step 1: Generate one or more solution alternatives from the planner.

Step 2: The stakeholders formulate the values of some input parameters to the planner. We call the set of these values a 'vote' of the stakeholders. The voting is done for each concern C.

Step 3: Transform the votes into prototypes $prot(C)$. Here we assume that this can easily be done (Step 3.1). Select one of the best solutions from the solution alternatives generated in Step 1. If there is only one solution generated by the planner, it is already the best one (Step 3.2).

Step 4: Compare the prototype for C and the best solution chosen in Step 3.2 by a similarity measure sim_c. In order to simplify the situation the system shows a reduced form of the best plan to the user that just contains the attributes that are relevant and where the prototype and the actual plan differ significantly.

Step 5: Allow the user to propose a minimum number of possible changes in the solution and to remove or weaken normative constraints which are the decisions made by humans.

Step 6: Show the consequences of the changes that are stated explicitly under the hard factual constraints and the participating constraints.

Step 7: Generate one or more solutions and again choose one among them. Go to Step 5 if no feasible plan can be generated. Otherwise, repeat the process. The presentation of the new plan and the reduced comparison with the old plan and the prototype is a forward explanation. The user may now react in three different ways: (1) prefer the new plan or (2) still accept the old plan because the reasons are now understood better or (3) choose another concern and iterate the process.

If desired, the process can be repeated with another concern.
The complexity reduction in this approach is performed in two ways:

- By focusing on one concern at a time. This can be repeated, but only one concern is handled at a time (Step 2).
- Simplifying the comparison of plans by presenting only the relevant attributes (Step 4).

In addition, the use of qualitative descriptions also contributes to a better understanding and to focus the attention of the user on a specific but important view (the concern). In particular, the forward explanation is shown in a reduced way by showing major qualitative consequences of proposed plan changes.

6.2 Formalization

In this section we will present a formal basis of the dialogue approach. It is the basis of the explainer, a software agent.

First we introduce the dialogue approach, without going into too many details (see Section 7.1). The user interface of the dialogue is standard. The user is presented with a template with questions or answers where the user can enter information. Examples are shown in Section 7. From the implementation point of view the user interactions are events. Events are handled in the standard way using Event-Condition-Action (ECA) rules (see e.g. [8]).

We start with the introduction of the major functions and predicates that are called in the dialogue. If many applications are to be covered, it is important that only a few undefined and application-dependent terms occur while the remaining dependent terms have application-independent definitions.

For simplicity, we model plans as an attribute-value representation, hence a plan is represented as

$$plan \;=\; (p_i | i \;\in\; I).$$

$PLANS$ is a set of plans and we assume similarity measures that compare plans:

$$sim_C : PLANS \times PLANS \rightarrow [0, 1].$$

The similarity measures are, in general, concern-dependent. They are formulated as weighted sums with a weight vector

$$w = (w_1, \ldots, w_n)$$

of non-negative coefficients and local similarity measures $sim_{C,i}$; i.e. we take the most common form of similarity measures (see [4]):

$$sim_C((a_1, \ldots, a_n), (b_1, \ldots, b_n)) = \sum(w_i \times sim_{C,i}(a_i, b_i) | 1 \leq i \leq n)$$

where a_i and b_i (1≤ i≤ n) represent the given plans.

The following similarity measure functions are essential for the dialogue approach. Two plans may differ significantly and may violate the interests of the stakeholder. If these are in conflict we refer to the prototype as being 'in danger'. The comparison can take place in a numerical as well as in a qualitative way:

- $DangerDegree(C, plan) = 1 - sim_C(plan, prot(C))$.
- $QualitativeDanger(C, plan)$ is introduced by taking three qualitative regions $0 < \alpha < \beta < 1$ in which the function takes the values low, medium and high, respectively.
- The predicate DangerC is defined by

$$Danger_C(plan) \leftrightarrow QualitativeDanger(C, plan) = high.$$

Next, the user is shown a reduced view on the danger that still contains the essential elements:

- The function $compare_{red}(plan_1, plan_2, sim_C)$ takes two plans and computes their similarities and produces the reduced comparison. The reduced comparison of two plans $plan_1$ and $plan_2$ is:

$$compare_{red}(plan_1, plan_2, sim_C) =$$

$$((plan_{1i}, plan_{2i})|i \in I, sim_{C,i}(plan_{1i}, plan_{2i})) < s, w_i > t)).$$

- Given a concern C the reduced representation of a plan p is obtained by comparison with the prototype:

$$plan_{red}(p, C) = (p_i|i \in I, sim_{C,i}(p_i, prot(C)_i) < s, w_i > t))$$

  The thresholds s and t are user determined. This means the reduced plan shows those attributes that are the major reasons for the deviations from the prototype.

Finally the consequences and the hard factual constraints are computed. These are the absolutely necessary consequences, independent of any opinions or optimizations:

- The function $computeConsequences()$ takes as input the values of some changed solution variables and the hard factual constraints. It generates the logical consequences of fixed values for the variables under the constraints.
- The function $involvedConstraints(changes)$ are those explicitly formulated constraints that were involved in the computation of $computeConsequences()$.

7 APPLICATIONS

7.1 Release Planning

7.1.1 Release Planning as a Wicked Problem

This example is relatively less 'wicked' than other wicked problems, in particular not all properties of wicked problems are present. This is due to the fact that the number of stakeholders as well as the number of technical constraints is quite limited. Nevertheless, release planning presents a problem that currently is not solved, overall, in a satisfactory way. Quite a number of partial problems can be formalized but creative aspects remain. Complex optimization procedures are applied but it is not clear how to formulate the input and to see a priori what the significance of the result is. It is typical (also for other problems like investment planning, see below) that formalisms lack the ability to completely encode the equivalent of the analytical mind with which the human decision-maker evaluates problem situations.

Release planning is conducted in early stages of software development to generate release plans. A release plan assigns requirements (the tasks) $\{R\} = \{R_1, \ldots, R_n\}$

to be developed for a (large) software product to release options $k \in \{1, 2, \ldots, K\}$, and an option $K + 1$ if the requirement is postponed:

$$\text{Requirements} \rightarrow \text{Release options.}$$

The releases are usually executed in a temporal order. Here we assume $K = 2$.

A release contains a maximum number of requirements so that the total effort of the segment fits into the effort constraints allowed for a release, all the technology constraints (see below) are met, and the stakeholders' satisfaction is maximized according the objective function of the planner.

Release planning is a problem that has many of the previously mentioned properties of the wicked planning problems. Specifically, its difficulties are [23]:

- Many aspects, even the objectives, are not stated explicitly and precisely in a formal way and are, in addition, context dependent. Hence the planner may not have a true image of the real world problem.
- There are different stakeholders who have diverging and unclearly formulated interests. The customers have a complex cost structure in their minds (consisting of direct and many types of indirect costs) that it is difficult to map onto the input parameters of the planner.
- The complex interactions between the constraints are difficult to understand.
- The demands of the customers are often in conflict with each other and the demands of the manager.
- There are uncertain estimates concerning effort (this is a standard problem in software development).

We consider two types of stakeholders. In reality there are many more:

- The customers: They do not know each other and have no communication.
- Members of the company, in particular the manager: As mentioned in the introduction, the manager knows the customers and communicates with them.

In this paper we refer to a web-based decision support system ReleasePlanner (`http://www.releaseplanner.com`). It is based on the hybrid intelligence approach proposed by [23]. The overall architecture of this approach, called EVOLVE*, is designed as an iterative and evolutionary procedure mediating between the real world problem of software release planning and the available tools of computational intelligence (optimization).

The planner uses an objective function that has to be maximized. The optimization itself takes care of the weak constraints. The optimization deals with the interests of the company and preferences of the stakeholders expressed in terms of votes (see below). These different aspects give rise to different objective functions that are integrated by the planner. To address the inherent uncertainty, the system offers a set of qualified alternative solutions. These solutions form the starting point for the dialog with the user of the system.

For our purposes, namely to illustrate the dialogue component, we have simplified the voting and do not go into further technical aspects of the planner.

The planner considers the following constraints [23] which are formulated explicitly:

- Precedence constraints between requirements R_i and R_j that specify R_i must be implemented before R_j (hard, factual).
- Coupling constraints between requirements R_i and R_j that specify that R_i and R_j must be implemented in the same release (hard, factual).
- Resource constraints that indicate the available capacity for each release and the needed capacity for each requirement (hard, factual).
- Pre-assignments that fix the release of a requirement (hard, normative). They are employed in plan changes. Only the manager can perform pre-assignments, but they can be demanded by customers.

The other stakeholders are customers that do not communicate with each other (usually they do not even know each other). The only communication that takes place is between customers and the manager. Customers do not exchange information but they rather may object to a given plan and express these decisions in terms of demands for pre-assignments. These demands may contradict earlier votes.

In addition, other weak constraints reflect opinions and preferences of different stakeholders involved in voting.

7.1.2 Release Planning as an Instance of the Generic Approach

We assume that ReleasePlanner has generated a set of five alternative release plans summarized in the set $PLANS$. $PLANS$ is represented in the following form, as mentioned above. Each requirement R_i ($1 \leq i \leq n$, n is the total number of requirements) gives rise to some attribute that assigns a release $rel(R_i)$ to R_i. Therefore a plan P from $PLANS$ is represented to the customer as a vector:

$$P = (rel(R_1), \ldots, rel(R_n))$$

Additional attributes of importance to the manager depend on the specific situation. An example attribute is resource, i.e. how to balance resource consumptions Res_i over K releases.

The concerns are expressed as a voting of the stakeholders or aspects of the company management, such as balancing of resources. An example concern in release planning may be 'balance of resource Res'_1. That means that ideally there should be a relatively stable level of resource consumption for the K releases. To date, the optimization done for ReleasePlanner focuses mainly on maximizing stakeholder satisfaction. However, less attention has been placed on balancing resources. Therefore, in this example we take the concern as 'balance of resources' and this, with the explanation component, provides added value to the current release planning.

For the releases, we assume a temporal ordering and we also assume that stakeholders prefer, in general, earlier releases.

The votes of the stakeholders indicate the priority of requirements which a stakeholder wants to see released as early as possible. ReleasePlanner offers many possible stakeholder voting options, such as value-based or urgency-based voting. For a more detailed description and motivation see [23]. One typical format of votes by one stakeholder is of the form shown in Table 1.

Requirement	R_1	R_2	...	R_n
Priority	7	8	...	5

Table 1. Stakeholder votes

With 'balance of resource' as the concern, a best plan P_{best} with the best resource balance is chosen from $PLANS$ set $\{S\}$. Table 2 shows the resource Res_1's consumption in each release of P_{best}.

Release	Release 1	Release 2
Res_1 Consumption in P_{best}	87.2 %	73.6 %

Table 2. Res_1 Consumption in P_{best}

A greedy algorithm is used to generate a prototype, based on the concerns and the votes of one stakeholder. A prototype for this concern is a plan in which the balance is ideal. Particularly, there are two ways to use the votes to come up with a prototype plan (this can also be used to generate prototypes for investment planning mentioned in Section 7.2):

- Rank requirements according to one stakeholder's votes: the higher the vote is for a requirement, the earlier the release it should be put in.
- Rank requirements according to combined votes from more than one stakeholder: similarly, the higher the combined vote is for a requirement, the earlier release it should be put in. However, different stakeholders have different votes and therefore different similarity measures on the prototype.

No matter which of the above two ways is used, before assigning a requirement to a feature, feasibility in terms of available resources and other hard constraints are checked.

For the similarity measure sim_C, used to compare P_{best} and the prototype, we take a very simple approach:

- The local measures have only the values 1 (in case of equality) and 0 otherwise.
- The weights correspond to the priority to develop a requirement in release 1. As mentioned above, earlier releases are always preferred over later ones.

The stakeholder may now object to the plan. This is done by demanding certain new pre-assignments in ReleasePlanner. The number of new pre-assignments should be as low as possible because the results generated by ReleasePlanner are near optimal. These near optimal plans may be in conflict with a stakeholder's votes and indirectly the stakeholders wish to revise them. For this purpose they are shown in the form of Table 3.

Name requirements to move to another release:
Move requirement R_1 to release 1

Table 3. Identify changes

This corresponds to the question Q: Why is R not in release 1? For the answer several computations have to be performed. The answer will be presented to the customer in the form shown in Table 4.

The following requirements are connected with R_1 by: Precedent constraints: (R_3, R_1), (R_4,R_1) Coupling constraints: R_5
In addition to R_1, the planner has moved: R_6, R_7, R_8
These requirements have been moved out of release 1 despite of their high votes: R_2

Table 4. Consequences of the changes

Upon the request of new requirement pre-assignment, a set of new feasible plans are generated by ReleasePlanner and P'_{best} is chosen as the best plan in terms of the concern.

Finally, the result is summarized where the plans are compared, as shown in Table 5.

Release	Release 1	Release 2
Res_1 Consumption in P_{best}	87.2 %	73.6 %
Res_1 Consumption in P_{best}'	92.2 %	81.3 %

Table 5. Comparison of two plans in terms of the concern

Table 6 is also provided to the user to show the differences in the assignment of requirements between P_{best} and P_{best}'.

As a summary for Table 5 and Table 6, the tables not only show the improvement of P_{best} in terms of the chosen concern, but also highlight the consequential changes in terms of requirement assignment to releases.

The user sees, however, only that part of the explanations where differences on attributes of high importance occur. These are forward explanations for the original decision of the planner, P_{best}. The user can now react in different ways:

- accepting the new plan
- staying with the old plan
- selecting a new concern and iterating the procedure.

Requirement	R_1	R_2	...	R_n
Priority	7	8	...	5
Desired Release in Prototype	1	1	...	postponed
Actual Release in P_{best}	2	1	...	release 2
Actual Release in P_{best}'	1	2	...	postponed

Table 6. Comparison of two plans in terms of requirement assignment

In the first two situations, some normative constraints have to be revised.

This view on release planning can be refined in many different ways in order to have a more detailed view on the preferences of the stakeholders. For example, the value or urgency of requirements can be considered directly; here we have summarized them in terms of a single vote. Similar arguments apply for constraints concerning the internal preferences of the company.

Figure 2 shows the instantiated EXPLAIN-DIALOGUE procedure within the context of release planning.

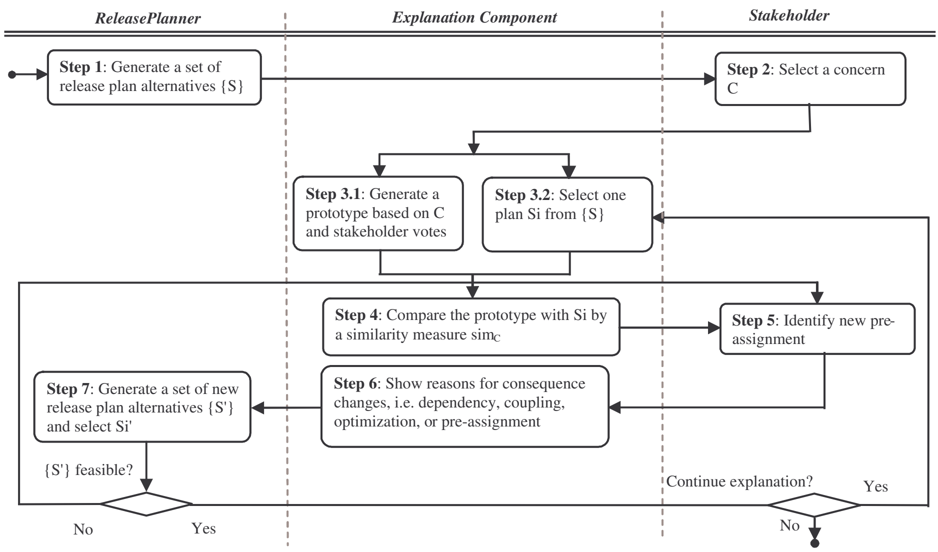

Fig. 2. Instantiated EXPLAIN-DIALOGUE procedure for release planning

The approach just described exclusively looks at one specific stakeholder without considering the impact to other stakeholders. This more general approach would need additional negotiation components to find a solution all involved stakeholders agree on [9].

7.2 Investment

7.2.1 Investment Planning as a Wicked Problem

In investment planning [3] the task is to invest resources into projects, i.e. a plan is mapping:

$$\text{Resources} \rightarrow \text{Projects.}$$

There are many factual constraints, e.g. one investment can necessitate others. In addition, there are usually many personal opinions of the participating stakeholders. The economic purpose of investment is ultimately to increase profit (ROI, Return On Investment). This is the difference between benefit and costs where one distinguishes the following aspects:

- predictable consequences
- consequences that can be estimated
- unpredictable and unforeseen consequences.

The two latter aspects can only be evaluated in the future and give rise to various kinds of risks. A particular difficult aspect is concerned with the strategic influence of the investment and this is a point where stakeholders often have quite different opinions.

The benefits are almost always in the future and hard to predict. Costs are also often invisible. In sequel our discussion will be limited to costs.

Investments can be classified into different types. A popular classification is:

- new business (completely new company or new branch)
- investment in extensions (more capacity, avoiding outsourcing)
- investment for change (replacing old equipment by new equipment that is more economical). An example is investment into the IT infrastructure of the company.
- investment in ecology
- long range investment (diversification in order to be equipped for changing demands, to get closer to the market (e.g. in foreign countries). There are direct and indirect costs involved and all these aspects that give rise to different kinds of constraints to be reflected in the voting.

Not only uncertainties but also different opinions and interests of the participating stakeholders are involved. Often the uncertainties are modeled as probabilities but it should be mentioned that they are not based on a model. Rather, they are subjective probabilities and therefore depend on the person (see [12]). There are many kinds of constraints. Three important ones are:

- Coupling constraints: Two investments are only possible if made together.

- Consequence constraints: One investment necessitates another one (possibly at a later time).
- Predecessor constraints: One investment necessitates that another investment was made earlier.

The difficulty that arises with these constraints is that the second involved investment may be invisible at a later time and may be difficult to predict. This may result in a change of the plan.

There are different approaches to describe cost. A simple example was given by the Gartner group (see [11]). The term Total Cost of Ownership was introduced and described for investment in IT- business, as shown in Figure 3.

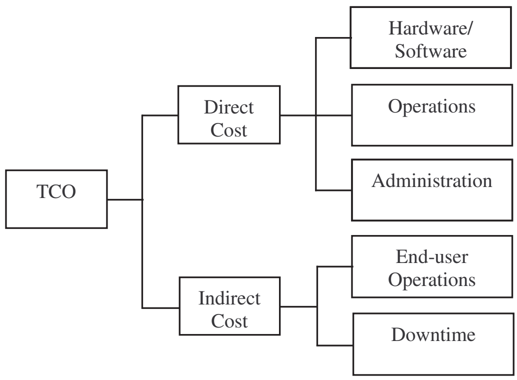

Fig. 3. TCO overview

The indirect costs are often invisible and there are different opinions about their size. Experimentation with the TCO model shows that in IT investment direct costs involve, on an average, 50 % of the costs, and are often much higher.

In practice there exists quite a number of optimization algorithms for investment planning. Here we do not refer to a specific one in detail but will rather mention a few:

- The Black/Scholes model [15]. It considers buying and selling as options and has various input parameters for statistical computations.
- Various tools that support the TCO model.
- The Balanced Scorecard tool [16]. It combines financial measures with non-financial measures, such as customer satisfaction, internal processes and innovation. An important property of the scoreboard is that it can be extended at a later time.

As far as financial computations using exact input are concerned, all of these tools are precise but cover only part of the situation. The non-financial considerations are based on subjective input and are subject to revision. They are not only imprecise but also depend on the interests of the stakeholder. This gives rise to discussions among stakeholders and also to discussions between humans and software agents representing the tools used. For this purpose we suggest another instance of the generic explanation method.

7.2.2 Investment Planning as an Instance of the Generic Approach

In order to clarify that investment planning and release planning are instances of the same abstract view (with different properties) that can both be treated by our generic approach, both deal with the problem of distributing objects to boxes under a number of constraints:

$$\text{Objects} \rightarrow \text{Boxes}.$$

Some stakeholders have preferences for putting certain objects in specific boxes while other stakeholders take care of the internal management of the boxes (that are assumed to be of limited capacity for release planning). The real motivations for this distribution may not be clear and easy to formulate.

In a simple setting of investment planning we can assume that there are only financial resources in the form of monetary units, each unit can be used for every project and the set of potential projects for investment is fixed. This means that the monetary units are the objects and the projects are the boxes.

Such a view opens the eyes for applications that are closely related. First, there are two ways of optimization, depending on where the shortage is:

Type 1: There is a limited capacity in the boxes.

Type 2: There are a limited number of objects to distribute.

In both cases one wants to put as many objects into the boxes as possible, respecting the demands of the stakeholders.

There are two major differences between release planning and investment planning that play roles in our considerations. Release planning is of Type 1, a box can only contain a limited number of requirements while this is not the case in investment planning. In investment planning there is no natural order of the boxes (like a temporal order), i.e. the projects, while release planning has this ordering.

Because the shortages are just the opposite as in release planning it is suitable to reverse the roles of attributes and values. Hence the attributes are of the form $project(investment)$, where $investment$ denotes a number of monetary units.

Given n projects $project_i$ $(1 \leq i \leq n)$ and a number of N monetary units, an investment plan is represented as a vector:

$$plan = (project_i(investment_i) | 1 \leq i \leq n).$$

In analogy to Section 7.1 a plan is called feasible if the sum of all investments is no more than N. In the sequel only feasible plans are considered. The prototypes of stakeholders are just their votes; they describe simply how much money the stakeholders want to invest in various projects.

$$vote = (project_i(investment_i, w_i)|1 \leq i \leq n)$$

where w_i is a an integer between 1 and 10.

The corresponding prototype is:

$$prot(project_i(investment_i)|1 \leq i \leq n).$$

The similarity measures are asymmetric. The first argument is always the query that is demanded by a stakeholder, i.e. the prototype. The local measures are of the form:

- if $(investment_1) \leq (investment_2)$

$$sim_{C,i}(project_i(investment_1)project_i(investment_2)) = 1$$

- if $(investment1) \geq (investment2)$ (i.e. higher investment is always better in the view of the stakeholder)

$$sim_{C,i}(project_i(investment_1), project_i(investment_2)) = \frac{(investment_2)}{(investment_1)}.$$

For the global similarity the votes are just the weights. In our simplified approach the voting is very easy because the stakeholders can directly name the weight in the form of the importance of the project.

The remaining parts of the formalism can be instantiated as for release planning.

7.3 Urban Planning

Urban planning belongs to the earliest types of wicked planning problems, and made this term popular [21, 22]. The use of a dialogue component arose from discussions with Karsten Droste from the ETH Zurich. We present mainly perspectives for applications here. There are several differences between urban planning and release planning as well as investment planning which we will shortly mention.

In urban planning many stakeholders are participating who all know or can know each other. There are three major types of stakeholders:

- active stakeholders that perform urban planning (usually architects and technicians, civil engineers)
- active stakeholders that must be asked about their opinions (e.g. local authorities, railway companies, churches, and business organizations)
- passive stakeholders who watch the planning process. These are usually citizens. However, citizens may switch to the active stakeholders group.

Figure 4 gives a view of major stakeholders involved in an urban planning problem in the city of London.

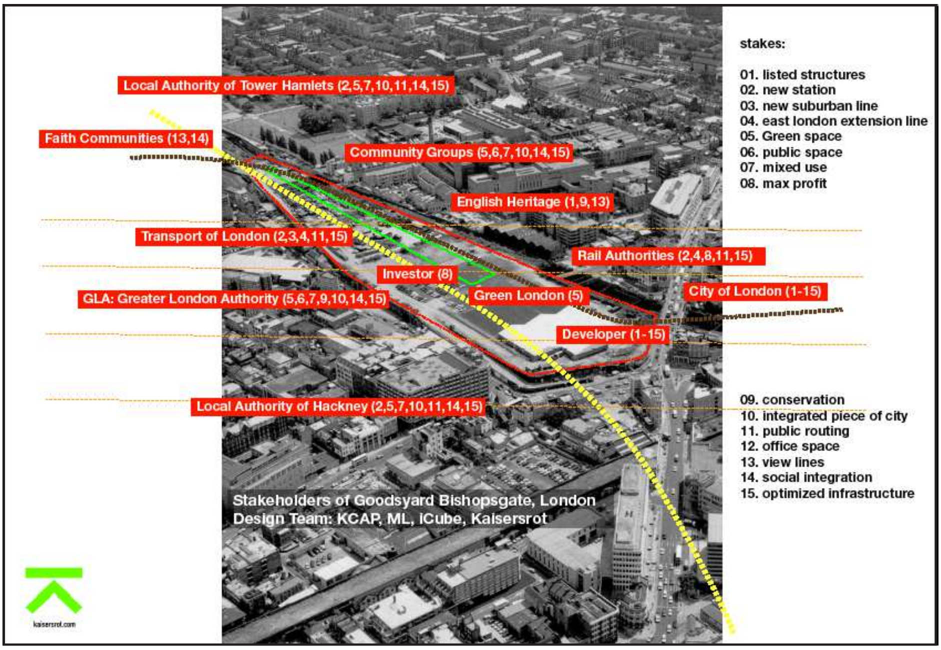

Fig. 4. Some stakeholders in an urban planning project [6] (City of London)

All of these stakeholders communicate with each other. Technically, the desired way of communication by urban planners is via a web portal (although this is rarely realized). For an example see [14]; we will not discuss this here. In human conversations and documents many factual constraints occur, such as legal arguments. If properly recorded, backward explanations are quite helpful in this situation.

The stakeholders usually have clear opinions on what they ultimately want but it is not easy to formulate this directly in terms of votes. They can usually formulate an ideal prototype in terms of the resulting system that can be the input to an optimization procedure as a hard constraint, where the distance from the actual plan is measured by a similarity measure. In practice, this is actually done, but only manually.

Presently the dialogue among humans in this application is done with very little computer support. The dialogue component must have more knowledge of different kinds of constraints than in release planning because it is not possible that all the stakeholders present a vote in the beginning of the dialogue.

Another major difference to release planning is that there is (presently) no universal software agent that acts as a planner and optimizer. Instead, there are usually many software agents and each of them causes the same problems as a single planner.

Some of the problems that need software agents are:

- Classical planning aspects like planning resources or establishing schedules: This is, in principle, an optimization problem such as release planning, although it is more complex because specification, planning and execution are more interleaved. Urban planners make heavy use of optimization algorithms. Here interactive planning is used, in particular the technique of 'What-If' analysis which is a rudimentary form of forward explanation.
- Shortest paths: Planning should observe that citizens can reach public facilities, such as supermarkets, schools, and offices, in the shortest possible time. This is again an optimization problem.
- Waste optimization: Simulation is used in [1].
- The shade problem: High buildings throw shade on neighboring buildings. The shade problem is intended to minimize this kind of shade. However, there are other constraints when buildings are moved, e.g. arising from railway organizations or churches [6].

Present computer support for the man-machine communication is quite limited, despite the fact that many optimization algorithms exist. The only advanced support is done by offering simulations. A twofold support is needed:

- Support for communication among humans. A first step was done in [14] where a web portal for urban planning was introduced. Presently an extension to more powerful support is in progress.
- Support for the human-machine interaction, e.g. with a dialogue system as proposed here. This has not been done yet but urban planners have seen the need for it.

8 IMPLEMENTATION AND EVALUATION

In [10], the formal approach was preliminarily implemented for release planning using ReleasePlanner as a release planning tool. It essentially uses (modifications of) the templates mentioned in Section 7.1 and has in particular Table 6 as the final template.

A real statistically valid evaluation is not yet completed. However, the approach was qualitatively tested in a graduate course at the University of Calgary. In this course the students (6 groups of four students each) had to simulate a company with three customers of different importance. These customers, together with the project manager, voted and these votes were the input to ReleasePlanner. In this experiment three releases were considered, release 1, release 2 and release 'postponed'.

The groups considered between 23 and 62 requirements. The concerns considered were mostly from the viewpoint of a hypothetical customer, but the view of the project manager was also considered. The analysis of the generated output used the dialog method discussed in Section 7.1. The following observations were made:

- The plan initially generated always gave rise to objections from the perspective of concerns.
- The system was stable in the sense that only new pre-assignments were demanded and they led to few new changes in the plans.
- In three experiments, one new plan had to be generated, in one experiment two new plans had to be generated, and in one experiment five new plans had to be generated.
- In half of the experiments the old plan was preferred because the new plans showed unexpected and unwanted results.
- In one experiment there were two plans with large differences between the concern of two customers, and the project manager had to make a decision.

Although most of the explanation procedure was performed manually, the usefulness of the procedure became evident.

9 CONCLUSION

We presented an explanation based dialogue approach to improve solutions of wicked planning problems. The approach is based on the observation of the properties of wicked problems: Humans with unclear and contradicting opinions as well as software agents are involved. For the dialogue we focused on the communication between human and software agents. Such dialogue has an explanatory character that gives some insight into decisions so that the user may change previous opinions or may stay with existing decisions. For this we proposed the dialogue using forward explanations.

In our approach a stakeholder is actively involved. First the stakeholder presents an ideal plan called a prototype. This plan is then compared with the actual plan using a similarity measure. The result is shown to the stakeholder in a simplified form and the stakeholder is asked for changes to the plan. These changes are given to the problem solver and the results are made visible in the same way. This then leads either to an improved plan or a better understanding of the old plan.

Therefore the proposed generic approach aims not only at increasing user trust in wicked planning results but also at improving the plans interactively. This approach can be instantiated and applied to many applications, e.g. release planning, investment planning and urban planning. Release planning was the original motivation for our approach, and was the application where it was worked out in most detail and partially implemented.

Future work is concerned with the fact that the presented approach focuses on only one stakeholders votes. A future improved approach should be able to integrate different stakeholders' votes together and the explanations (via dialogues) should reflect this overall view. A second and theoretically important aspect is that presently there is no use made of the dialogues for future problems. A learning support feature for this approach is underway, by the authors, which could contribute to bridging the gap between explanation and learning.

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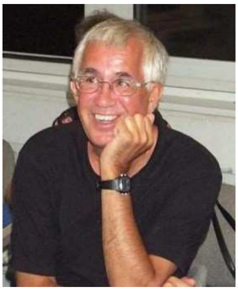
Gengshen Du received her M. Sc. degree in computer science in 2004 from the University of Calgary, Canada. She is now a Ph. D. student in computer science at the University of Calgary. She is also a member in Software Engineering Decision Support Laboratory at the University of Calgary. Her main research interest includes software engineering, software engineering decision support, empirical software engineering, and artificial intelligence.



Michael M. Richter received his Doctoral Degree in mathematics in 1968 from the University of Freiburg, Germany. He was Professor of Mathematics at the RWTH Aachen from 1975 to 1986 and Professor of Computer Science at the University of Kaiserslautern from 1986 to 2003. He was president of the German Association for Mathematical Logic from 1981 to 1985 and served as Scientific Director at the German Research Center for Artificial Intelligence from 1989 to 1993. Presently he is mainly teaching at University of Calgary. His present research interests are in artificial intelligence and software engineering.

Guenther Ruhe holds an Industrial Research Chair in Software Engineering at University of Calgary and is an iCORE Professor since July 2001. His main results and publications are in software engineering decision support, software release planning, requirements and COTS selection, measurement, simulation and empirical research. From 1996 until 2001 he was deputy director of the Fraunhofer Institute for Experimental Software Engineering. He is the author of two books, several book chapters and more than 120 publications. Dr. Ruhe is a member of the ACM, the IEEE Computer Society and the German Computer Society GI.