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Hybrid Rationale and Controlled Natural Language for Shared Understanding

***Abstract*—Understanding the reasoning of others is a key aspect to achieving a shared understanding when collaboratively solving a problem, such as the generation of a plan, and recent observations of military planners suggest that it plays a key role in the planning process. An example of rationale is described where a misunderstanding is only resolved by the joint exploration and cross-challenging of the rationale. A prototype tool is described that permits the creation and visualization of the basic rationale via the use of a Controlled Natural Language derived from Common Logic Controlled English. Using the example, the paper explores mechanisms that could potentially make more effective use of rationale.**

I. INTRODUCTION

Understanding the reasoning of others is a key aspect to achieving a shared understanding [8] when collaboratively solving a problem, such as the generation of a plan. Informal observations of military planners when constructing plans, suggest that rationale is important to the process, and is available in the mind of the planners. For example:

- in the evaluation [1] of the Collaborative Planning Model (CPM) [3], it was reported that one of the UK planners maintained a constant stream of explanation as to why he was constructing the plan
- for UK planners undertaking training, it was observed that rationale was extensively used to support presentation of plans to the group and to the commander; and processes are taught that explicitly captured rationale for the construction of plans
- in discussion with US planners, they stated that rationale in the form of task dependencies was important; and the presentation of plans was accompanied by rationale
- a UK military expert noted that the concept of “in order to” (or IOT) was a key part in constructing the plan.

Although these observations are informal, it seems reasonable to conclude that rationale plays a key part in the planning process, and to suppose that other problem solving situations may utilize rationale in a similar way. Whether rationale is used only in communication, or during internal creative problem solving, is not clear. However we believe it is of benefit to capture and model rationale, and to conduct experiments on the effects of communicating rationale amongst the participants of collaborative problem solving.

We define rationale as the result of applying reasoning steps to generate inferences from premises or assumptions, where a premise is a known (or inferred) statement, and an assumption is a statement that is not known to be true, but is presumed so by an agent. These reasoning steps may be derived from logical inference or from more intuitive human inference not necessarily grounded in formal logic. The sequence of reasoning steps defines a network of rationale, leading from premises or assumptions to inferred conclusions. Such a network, in planning, captures dependencies between plan inputs (requirements, constraints, higher level decisions, assumptions, context) and plan solutions (tasks, resource allocations). In collaborative planning, these rationale networks may be shared and built upon in order to construct a valid collaborative plan.

In the International Technology Alliance (ITA) programme, we are researching how shared understanding may be achieved in the context of how collaborative military operations may be supported and enhanced by network technologies. Previous work [6] shows how rationale is represented within the CPM and visualized, and how rationale is linked to logical inferences and to the use of ITA Controlled English (CE) [2, 4]. The CPM is an OWL ontology representing collaborative problem solving and the artifacts that are produced. It is organized in layers, including basic logic, time, space, resources, goals, activities, through to military planning concepts such as mission, task, plan, military units, and terrain.

Recent work in a UK transition project has indicated the importance of hybrid reasoning, where the human constructs the reasoning steps but is assisted by automated reasoning, leading to rationale that combines human and automated reasoning. Combining the precision of automated logic with the flexibility of human reasoning seems highly desirable, but their integration requires many issues to be addressed.

This paper explores hybrid rationale, using an example of rationale used in a collaborative military planning context to share an understanding of a problem arising in the plan and to reveal a misunderstanding between two planners. This has been reviewed with a military planner and is realistic and representative of a wide range of problems. A prototype extension of the IBM visualiser [6] has been constructed to visualize and input rationale, using Controlled English, and to explore some of the issues of capturing and visualizing hybrid rationale. As a result we suggest some possible mechanisms to benefit from rationale in solving collaborative problems

II. SCENARIO

We introduce an example in which rationale seems beneficial, based upon the scenario for the evaluation of the CPM [1]. The original CPM scenario was constructed with the help of UK military experts, and has been extended in order to provide this realistic (but made up) example of the use of rationale. The scenario is represented in the CPM [3], and we use the terminology of the CPM. It focuses on the planning interaction between a staff officer (BG) supporting a Battle Group commander and a fire support officer (FIRES).

1. A Battle Group commander has been given an objective by superior command (ARRC) to destroy the enemy in a certain area by time 11h. (Here, times are stated relative to an initial start time, thus 11h is the 11th hour after start time). BG constructs tasks to meet the ARRC objective of destroying the enemy by 11h. The enemy is on the other side of a river, so it is necessary to send troops across a bridge, thus the plan has two tasks, crossing the bridge and destroying the enemy. BG considers that it will take 3 hours to destroy the enemy and 2 hours to cross the bridge, thus the crossing task must occur between 6h and 8h.
2. To protect the troops when crossing, BG needs artillery support in the area of the crossing. Such support must be provided by FIRES who controls three Field Artillery (FA) units: FA1, FA2 and FA3. BG requests artillery support from FIRES from 6h to 8h.
3. FIRES receives the request and considers which resource can be allocated to support the crossing task between 6h and 8h. Consideration indicates that FA1 is not powerful enough to deter the enemy, FA2 is already allocated to another task and FA3 is not with range of the enemy. FIRES therefore states that support cannot be given between 6h and 8h.
4. BG realises that this lack of support will jeopardise the crossing, which would cause ARRC's objective to destroy the enemy by 11h not to be met. This is not acceptable to the BG commander, so BG communicates with FIRES to seek the rationale for this lack of support.
5. BG and FIRES explore the rationale and discover that a misunderstanding has occurred in the communication between the BG and FIRES. After the realisation of this miscommunication, FIRES determines that a suitable FA is available, and allocates this to the crossing task. This permits the completion of plan for the BG commander.

The seeking of a common understanding of the rationale for the problem, and hence the exposure and resolution of the problem, is described below.

III. COLLABORATIVE HYBRID RATIONALE

A. *Diagramming the Rationale*

The "rough" high level rationale for the reasoning in the previous section may be diagrammed using a prototype tool extending the CPM visualiser [6]. This combines:

- A machine-readable CPM representation of rationale, using propositions, reasoning steps and assumptions.
- A human-readable textual representation of the rationale, using Controlled English.
- A graphical visualisation of the rationale network with nodes representing propositions and links representing the reasoning steps.

The rough rationale uses unstructured statements such as:

…the agent BG states that "need firesupport between 6-8" because "must cross bridge between 6-8" and "troops vulnerable on bridge" .

The rationale statements are shown in Figure 5, where boxes are propositions and circles are reasoning steps, leading from premises to conclusions. Some propositions are supported by direct information; these are shown with the label "[srcXXX] AGENT states that". Unsupported propositions are taken to be assumptions. This rough rationale is reasonably easy to understand and shows that the ARRC objective cannot be met.

B. *Challenging the rationale*

Planner BG does not accept the failure to support the crossing task, and challenges the rationale from FIRES to determine why there is no suitable FA. We assume that BG and FIRES have accepted the non-availability of FA1 and FA2, and now come to discuss FA3. BG challenges "why cant we use FA3?". This challenge is added to the rationale graph:

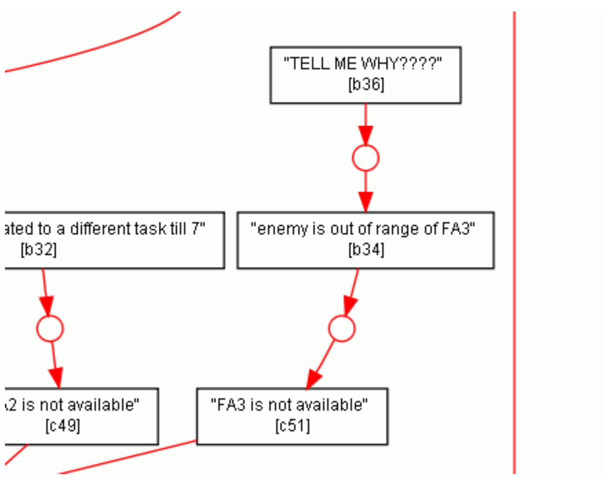

Figure 1 Challenge to an assumption

To describe the discussion about FA3, it is first necessary to give some geographic context:

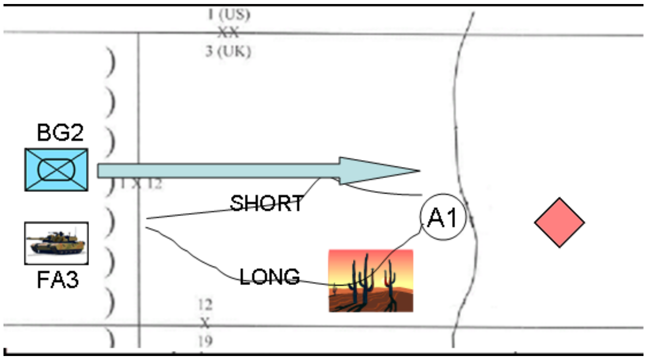

Figure 2 Geographical context

The enemy location is shown as a diamond. The river crossing is near to area A1, and if FA3 is to be used, it must be in A1 to be in range. Currently FA3 is behind the lines on the left and must be moved to A1. There are two routes, "SHORT" and "LONG". LONG has desert terrain, which slows down FA3, so take a longer time. The BG commanders orders state that another battle group BG1 will use the SHORT route during the time when FA3 must move (4h to 6h).

The minimum time to traverse a route depends on the maximum speed of the FA, which depends in part on the terrain. FIRES calculates the maximum average speed on SHORT as 20kph, on LONG as 10kph, and the distance to A1 as 30km. It will take FA3 3 hours to travel LONG and 1.5 hours to travel SHORT. The time of the planning discussion is time 4h, giving two hours from the current time to the start of the river crossing.

To answer the challenge, FIRES constructs the rationale, based on the location of the enemy, the range of FA3, the time that FA3 must be at A1, and the maximum speed of the LONG route, concluding that the enemy is out of range of FA3, as shown in Figure 6. FIRES presents this to BG, who notes the assumption that SHORT is not available between 4h and 6h and challenges it.

FIRES rationalises that BG1 is using SHORT throughout the day. Doctrine states that it is not possible to move a Battlegroup and a Field Artillery simultaneously on this route, so it is not available to FA3 between 4h and 6h:

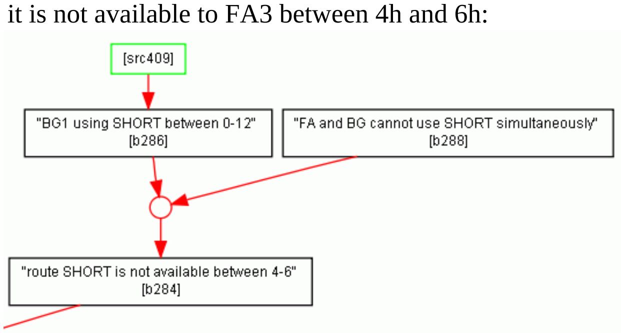

Figure 3 rationale for non availabilty of SHORT

C. *The solution*

BG accepts the route doctrine and that FIRE's assumption of SHORT being unavailable is reasonable. However, it is clear there is a tactical imperative to move FA3 move SHORT, otherwise fire support cannot be given. BG (via the commander) is given a waiver of the doctrine permitting FA3 to move. FIRES accepts that the assumption of the non-availability of SHORT was invalid, and allocates FA3 to support the river crossing from 6h-8h. BG completes the plan to achieve the ARRC objective to destroy the enemy by 11h.

The exploration of the rationale via a challenge and response has led to the uncovering of a not-unreasonable but erroneous assumption. As a result an apparently impossible task has been made achievable. Discussion with a military planner indicates that this is typical.

IV. Constructing Rationale

The example suggests that collaborative exploration of rationale can lead to the development of mutual understanding between collaborative problem solvers. However there are issues in achieving this in a real situation, such as obtaining and visualising the rationale to humans.

A. *Sources of Rationale*

Rationale is a record of reasoning steps between statements and assumptions. These may be generated "manually" by a human reasoner, or automatically by automated inference. Automated reasoning can provide the more "administrative" reasoning steps, such as propagation of timing constraints, whereas human reasoning can provide the more "creative" reasoning steps which cannot be easily modelled by an automated system. Human reasoners, such as military planners, may also have concerns about relying totally on automated reasoning. Thus a hybrid combination of automated and human reasoning could have advantages.

However the reasoning undertaken by hybrid systems must visualised and represented in an integrated way, so that it may be seamlessly explored. If some aspect of the reasoning is performed remotely and shared electronically, this communication should include the rationale. The CPM contains a format for exchanging rationale.

Reasoning may require mathematical calculation or table lookup, for example in the effect of the terrain on the maximum speed of FA3. Such information may be derived from computer systems or spreadsheets, and the calculations should be integrated automatically into the rationale network.

Processes for human problem solving may also facilitate eliciting and capturing rationale. In the generation of plans, a tool based on a structured whiteboard is used. Such tools and processes could potentially be integrated into the capturing and visualisation of rationale graphs.

Thus sources of rationale should be integrated into a single stream, reducing the likelihood that key reasoning steps are missed as information is shared between collaborative problem solvers, and providing an holistic view of problem solving.

B. *Structured vs Unstructured Rationale*

The example (see Figure 5) shows "unstructured" rationale, as quoted text ("must cross bridge between 6-8") rather than structured Controlled English statements (the task cross_river has ‘8’ as latest completion time). Unstructured text is quick to write, and does not require attention to correct syntax.

However quoted text does not permit automated analysis of the structure (such as the actual time of 11h) and no automated inferences may be undertaken (such as the propagation of temporal constraints). In contrast structured sentences may be analysed by machine and automated inferences may be made. Thus there is a trade off between ease of writing and utility for automated reasoning, and a rationale tool should be able to work with both structured and unstructured statements. Initially an unstructured approach could be taken as the user seeks to articulate their rationale; this may be quicker but may contain flaws due to the lack of rigour, although the act of formalisation may cause the user to detect missing steps in the argument. Then a tool might help the user to turn the unstructured into structured statements, allowing automated reasoning to add conclusions or to critique the rationale.

C. Patterns of rationale

Experience of using rationale and literature in this area [9] suggests there are patterns for constructing rationale, or forming arguments. For example, someone may believe they have proved something with a rationale, but may be challenged to look for counter evidence; or another user may look for and present other negative evidence. Such a challenge results in the search for negative support (i.e. rationale for the falsity of the statement) to be added to the rationale network. The exploration of such patterns could be assisted by automation.

In the example there does seem to be a pattern, although this pattern is specific to a particular type of reasoning. The pattern relates to the reaction of the FIRES to the request for support, and is diagrammed in abstract form below:

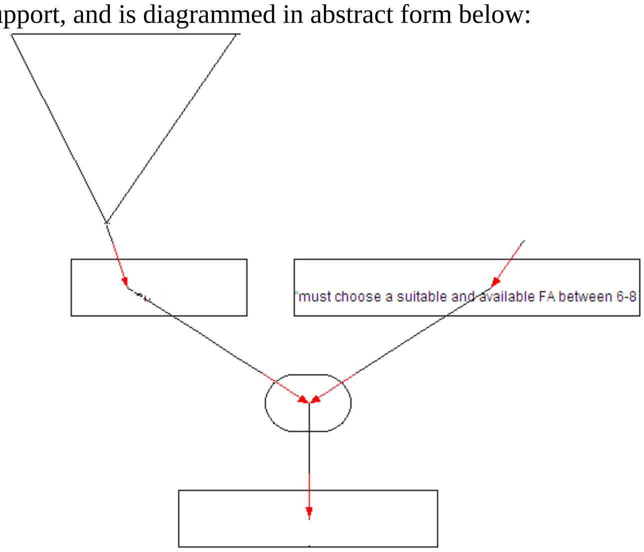

Figure 4 pattern of rationale

The request for an FA between 6h-8h (on the right) triggers a search by FIRES for a suitable allocation (triangle on left). The result (under the triangle) is either an allocation or a failure, which links to the request to a conclusion of success or failure (bottom node). This is a general pattern relating to the attempt to satisfy a goal.

Such patterns may permit automated assistance for a user to construct rationale, to ensure correct reasoning or to assist training new users who do not necessarily know how to reason in specialist domains. Patterns could also provide support for argumentation [9], and some initial work has been done in the use of CE for representing arguments and their relation to the semantics of defeasible reasoning.

D. Use of Context

When creating the rough rationale graph for the example it is clear that context plays a part. For the purpose of this discussion, we define “context” as that which is required for the reasoning but which is not explicitly stated. For example, we state “FA1 is not available” rather than the full explicit form “FA1 is not available for the task of crossing the bridge between 6-8”. The reduced statement is preferable since less effort is required to construct it (as appropriate for the “rough” rationale) but is made intelligible only due to the context in which it occurs, and it is suggested that the context for a statement is derived from the set of preconditions of the rationale for that statement (in this case the missing information is contained in the request for the support). When converting from the unstructured to the structured statements it may be necessary to explicitly add the context to the structured statement. An alternative might be to permit the Controlled English to be sensitive to context, where the context is taken to be the precondition rationale; however this would require a significant reworking of the semantics and implementation of Controlled English.

E. Relation to Ontologies

There is a strong relationship between the rationale and the ontology on which the rationale is based. Specifically the ontology defines logical relations between the entities as well as the structural relations between classes. In effect these ontology concepts define useful “patterns” of logic and generic rationale, for example that a subtask is necessary in order to achieve a higher level task, that a resource request is necessary in order to achieve a task, or temporal relations between tasks.

These patterns are the basis for specific reasoning steps that could be derived from the ontology (e.g. the propagation of timing constraints across related tasks or the calculation of achievement of tasks) when specific entities are added to a plan. Thus there should be a relationship between the instances of an ontology (such as a specific plan) and the rationale formed from reasoning steps across the logical relations. It should therefore be possible to cross-link information from a visualization of the domain-specific entities (the plan) and the visualization of the rationale, and these cross links can occur in both directions.

The link from domain entities to rationale is exampled in the prototype rationale tool. The CPM visualiser allows the construction of a plan via tasks, objectives and resource allocations, via a domain-specific drag-and-drop editor. When a specific temporal relationship is added to the plan, and the ontology logical rules are executed, then rationale is created and added to the overall rationale graph. This allows the construction of the rationale graph to be generated by a mixture of automatic reasoning and manual input of rationale.

For example, the tasks from the example may be entered in the CPM visualiser, as shown in Figure 7. This shows the ARRC objective (pentagon), the subtasks (triangle), the relationships between them and some manually entered rationale for the existence of these entities. This is turned automatically into rationale about the timing constraints on the object and tasks, and this rationale is then integrated to the manual rationale for the resource allocation. A portion of this integration is shown in Figure 8, where the automated reasoning about timings is shown as nodes with no text, and the manual rationale is shown as blank nodes.

It is proposed, although not yet demonstrated, that the cross-links may also go in the direction from rationale to ontology, by generalization of specific rationale into more general rules. It is suggested that a developer of an ontology (rather than a user of an existing ontology) might wish to explore the most suitable formulation of a particular concept, and for this purpose might wish to focus on a specific example, and use the rough unstructured rationale input capability to quickly try out different formulations. This is how some of the example rationale was constructed, and this actually led to a change in one of the CPM concepts. Once a satisfactory formulation is found, then it is suggested that the rough rationale graph be turned by the user into a structured form, and then this be turned automatically into a proposal for a more generic logical rule. This rule could then be added to the ontology.

F. Use of Controlled English and extensions

Ongoing work in the ITA is developing techniques to use a Controlled Natural Language (specifically an ITA variant [2] of Common Logic Controlled English (CLCE) [14]) for expressing facts and logical rules in a reduced version of English, that is both understandable by human and easily parsed by machine, using a commonly agreed lexicon and grammatical structure. Mappings between CE and other representation languages, including Common Logic Interchange Format [15], RIF [16] and OWL allow the representation of information in different formats according to need. Although CE is a limited subset of English (and indeed a limited subset of CLCE) it has been found to be useful and relatively easy to write. Our experience in developing systems using CE has suggested that CE may be used to express conceptual models, logical rules, queries, and rationale in a manner that is easier to understand (for non logicians) than the equivalent logical formulae.

Further techniques are being developed to allow the user to extend ITA CE, see [6], to allow a more expressive language to express domain concepts. Such extensions define a linguistic transform rule that turns a single extended CE sentence into a longer set of basic CE sentences It is proposed, but not yet demonstrated, that this mechanism could assist the visualization of more complex rationale graphs, since an extended CE sentence in effect captures several steps in a rationale, and might be used to guide how the graph may be collapsed into a simpler form.

V. MDMP, REHEARSAL, AND HUMAN REASONING

This section describes the US military decision making process (MDMP), a planning model that focuses on human reasoning, and notes areas where rationale is important. The commander uses the MDMP, a proven analytical planning model, to analyze the mission, compare friendly and enemy courses of action (COA), select an optimum friendly COA, and produce a plan or OPORD [13]. The MDMP is a creative problem solving technique for coordination and sychronization of plans and orders that enables the commander to identify unforeseen events for branch and sequel development. The commander's "visualization" is expressed in the MDMP through the commander's intent, planning guidance, and commander's critical information requirements (CCIR). There are seven sequential steps to the MDMP, receipt of the mission, mission analysis, COA development, analysis, comparison and approval, and orders production. If there are time constraints, these steps can be conducted concurrently through the use of fragmentary orders (FRAGOs) and warning orders (WARNOs). Mission analysis, the second MDMP step, is an essential part of planning in that it helps improve shared situational understanding through collaborative problem solving and verification of the mission. Mission analysis addresses steps that are fundamental to the development of a plan representation in CPM, such as determining specified, implied, and essential tasks, constraints, and available assets, and identifying facts and assumptions. In our scenario, mission analysis provides the first opportunity for the commander and staff to challenge the rationale from FIRES to determine why there is no suitable FA, develop a shared understanding of the constraints of route doctrine (or higher headquarters) and how this influences force availability within the recommended timeline (FA3 to support the river crossing from 6h-8h). Mission analysis is fundamental to developing the initial CCIRs and commander's intent, and issuing the commander's planning guidance. The commander's planning guidance includes the desired effects, tempo, and simultaneous or sequential actions. Once the staff receives the restated mission, commander's intent, and commander's planning guidance, they develop COAs. COA development includes the concept of operations, how to accomplish the mission within the commander's intent and where the commander will accept tactical risk. COA analysis or war gaming is time consuming but it enables the staff to synchronize the Battlefield Operating Systems (BOS) (e.g. FIRES). The staff compares distinct COAs and recommends a COA to the commander. The commander decides on the best COA for the area of operation (AO) and issues the final planning guidance and OPORD. Other COAs are retained for use in contingency plans [11]. COA analysis provides a second opportunity for the exploration of rationale via a challenge and response. During the sychronization of the BOS, a challenge of rationale for not using FA3 would have led to the shared understanding of the constraints of route doctrine. The commander could respond with a waiver of doctrine in favor of the COA permitting FA3 to support the river crossing from 6h-8h.

Once the MDMP is complete and the OPORD is produced, the commander, staff, and subordinates rehearse the commander's chosen COA [13]. Rehearsal is key to collaborative problem solving and shared situational understanding as it enables the commander to ensure that the staff and subordinates understand the commander's intent and visualize the concept of operations [13,12]. They practice essential tasks, identify problems with the plan, and coordinate actions [12]. The concept of operations is synchronized by identifying times and locations where coordination is critical to mission success, as well as solutions for coordinating actions. Rehearsal provides a third opportunity to identify erroneous assumptions via a challenge to rationale and response. Rehearsals enable the commander, staff, and subordinates to query current events, real time decision, and information to ascertain how incomplete tasks affect subsequent tasks [personal communication, 18 March, 2010]. Rehearsal enables planners to "talk through" the tasks and the rationale for tasks one to two echelons up. The commander's rationale is communicated in the command intent for effects. During rehearsal, dependencies, such as "clear, destroy, capture," convey rationale and "In Order To" functions identify the context (e.g. "Clear route of enemy forces.") Rehearsals enable planners to identify problems, challenge rationale, and propose changes. Unresolved problems are presented to the commander for resolution [12].

There are five rehearsal types: confirmation brief, backbrief, combined arms rehearsal, support rehearsal, and Battle drills or SOP rehearsals. Confirmation and backbriefs provide subordinate commanders with an opportunity to communicate their understanding of commander's intent to their commander and specify their tasks and purpose relative to the other units. Combined arms rehearsal are executed by the maneuver unit headquarters to ensure subordinate units synchronize their plans with each other. Support rehearsal ensures the BOS can support the OPORD and are synchronized with the maneuver plan [10, 12]. Battle drills or SOP rehearsals are used to practice specific technique or procedure [12]. Rehearsal techniques run the gambit from full dress to map depending on time constraints, the echelons involved, resources, and other factors. Rehearsal techniques, such as the Rehearsal of Concept (ROC) drill enables subordinate commanders to "talk through" the mission, critical tasks, actions, and decisions, and confirm or deny assumptions, while simultaneously acting out their missions to identify problems in synchronization [12]. US and UK planners emphasize the importance of rehearsal techniques, such as ROC drills for developing a shared understanding of each others' actions and available resources, as well as for identifying differences in US and UK planning processes [personal communication, 18 March, 2010]. While the ROC drill and other rehearsal techniques enable humans to identify not-unreasonable but erroneous assumptions by acting out the plan and exploring the rationale via a challenge and response, these are not flawless techniques. In some cases, erroneous assumptions are not identified until after the rehearsal during the after action review (AAR) led by the commander. One planner described the AAR as the most effective means of capturing rationale through case-based reasoning and lessons learned.

Thus rationale has a key formal role in several stages of the MDMP; mission analysis, the choice of the COA, the rehearsal backbriefings and ROC drills, and in the AAR. The MDMP provides a record of reasoning steps between statements and assumptions that are manually generated by the human reasoner but the entire process may take days, weeks, or even months to complete. In some cases, selected MDMP tasks may be shortened or skipped to meet the time constraints for mission completion. The administrative reasoning steps that automated reasoning could provide in a short period of time make a strong justification for a hybrid combination of human and automated reasoning.

VI. Conclusion

We believe that the use of rationale is of benefit to collaborative problem solving:

- it assists the sharing of understanding of different parts of the problem by exposing the sequence of reasoning steps, assumptions and decisions leading to conclusions
- it can expose reasoning flaws such as hidden assumptions
- it can serve as part of the process in formulating solutions to the problem

There remain significant issues in the use of rationale. It is necessary to combine the power of logical formality (ability for automated reasoning, clarity of thought and specification, reduction of errors) with the power of informal human reasoning (naturalness, ease of use, ease of flexibility to think in different ways, context knowledge). We believe that these mechanisms may go towards providing some assistance:

- the combination of human and automated reasoning, leveraging the advantages of both
- the integration of formal ontologies to rationale graphs
- the use of Controlled English and extensions, as the "human face" of logical rules, permitting the easier understanding of rationale graphs
- the use of patterns of rationale
- a machine-readable common representation of rationale

It is necessary to provide visualizations that are clear, robust and very easy to use. The prototype provides some facilities such as the input of rationale via Controlled English, point-and-click on the graph and the domain specific planning visualiser, the display of rationale and the agents that created the reasoning steps, and limited collapsing of the rationale for clarity. However this is a long way from the robust, easy to use capabilities that would be required for realistic use of rationale in a military context, especially for large rationale graphs.

Nevertheless we believe that the use of rationale is important and we are working to address these issues. We also recognize the need to evaluate the utility of rationale in a realistic military context, and we include this as part of the future CPM evaluation. A key focus of Project 12 is to assist the "human grasp" of logic. We have proposed Controlled English as a start in this direction, and we believe that the further exploration of rationale may be another significant component to facilitate human shared understanding of the logical inferences needing in collaborative problem solving.

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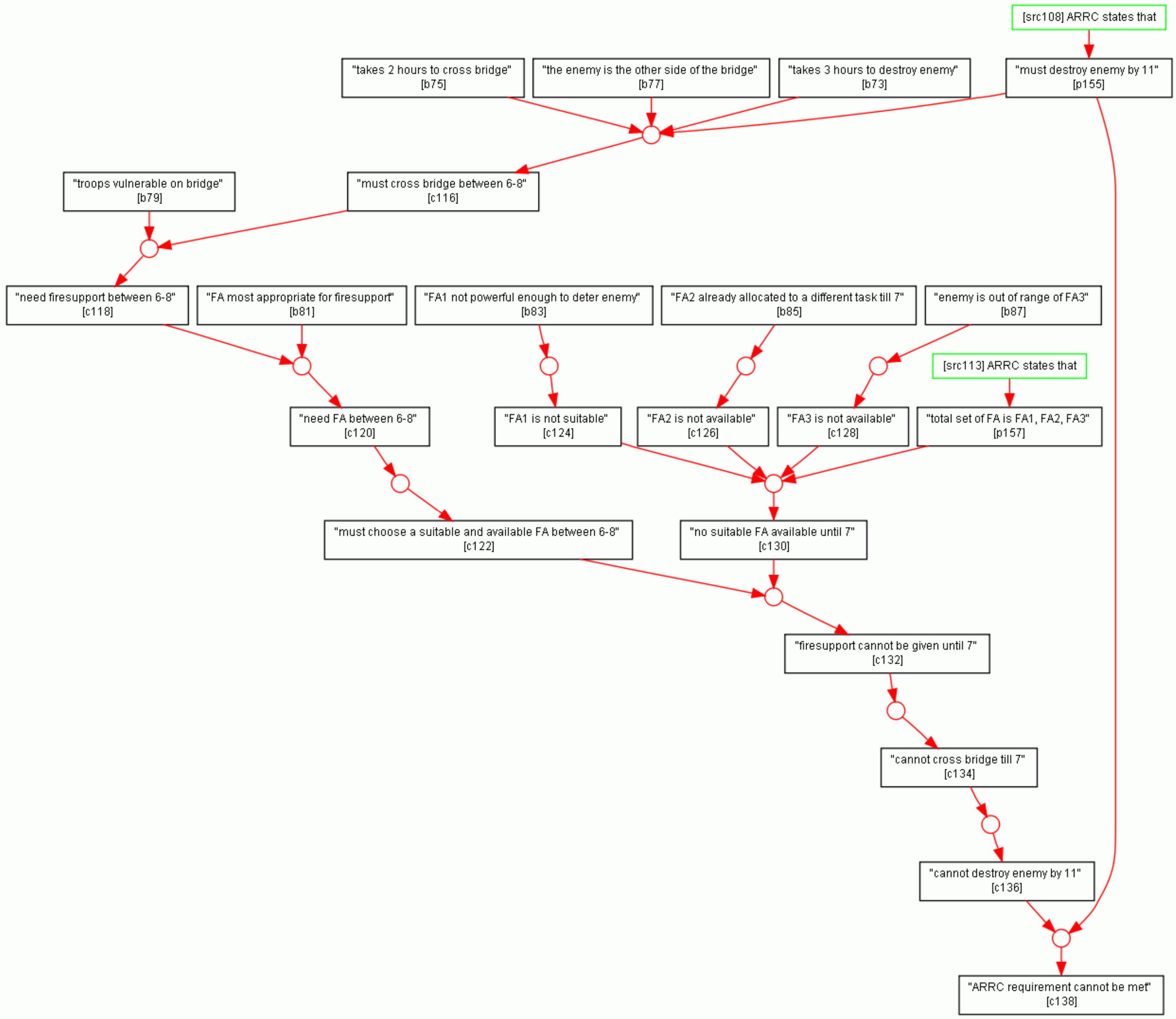

Figure 5 “Rough” rationale

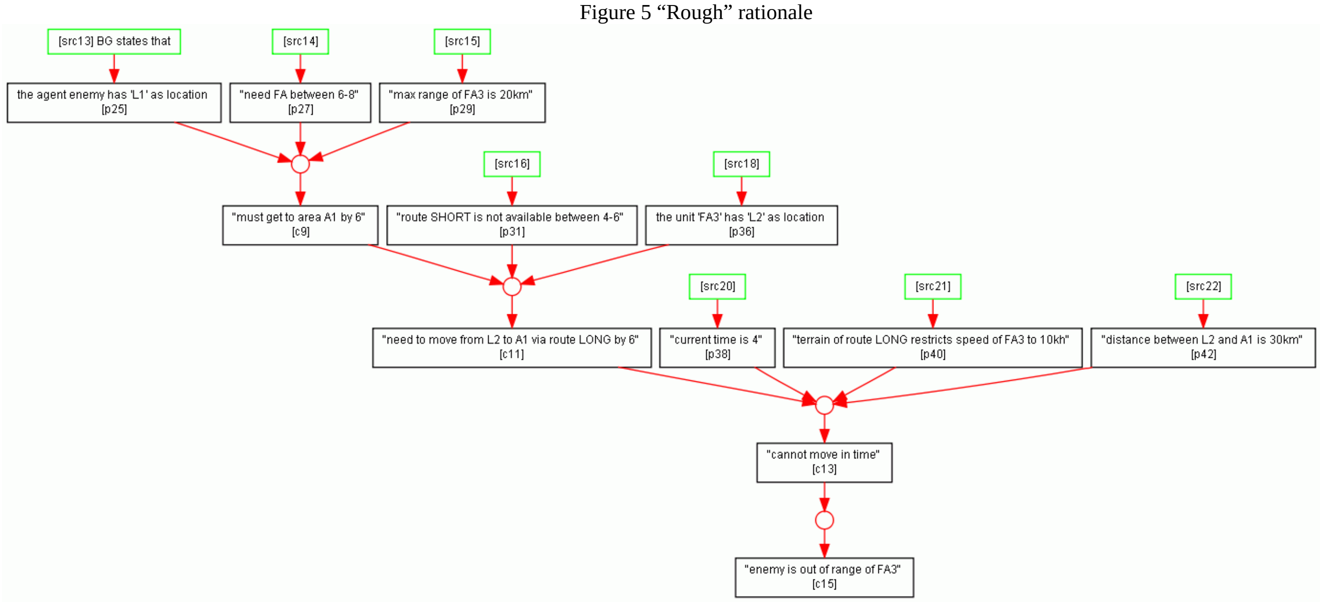

Figure 6 FIRES rationale for being unable to support

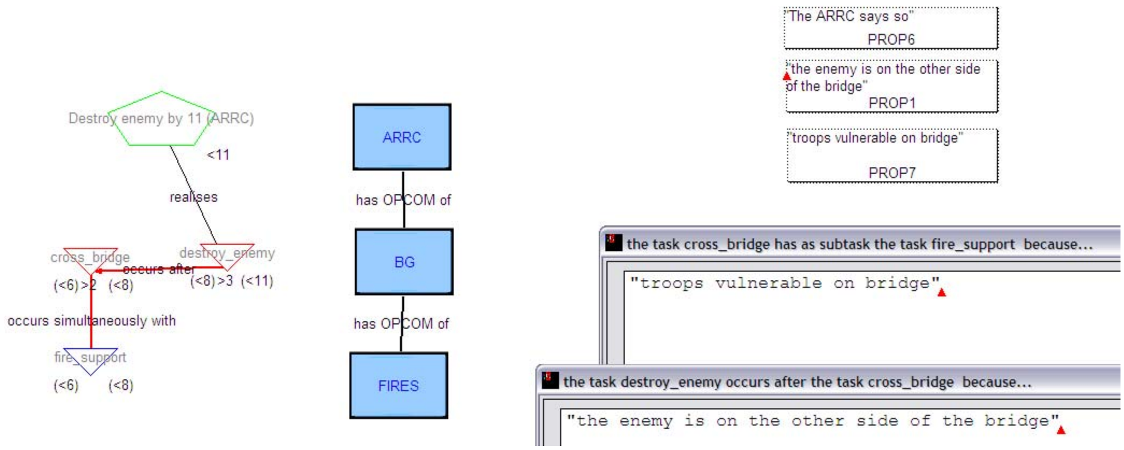

Figure 7 CPM visualization of planning tasks

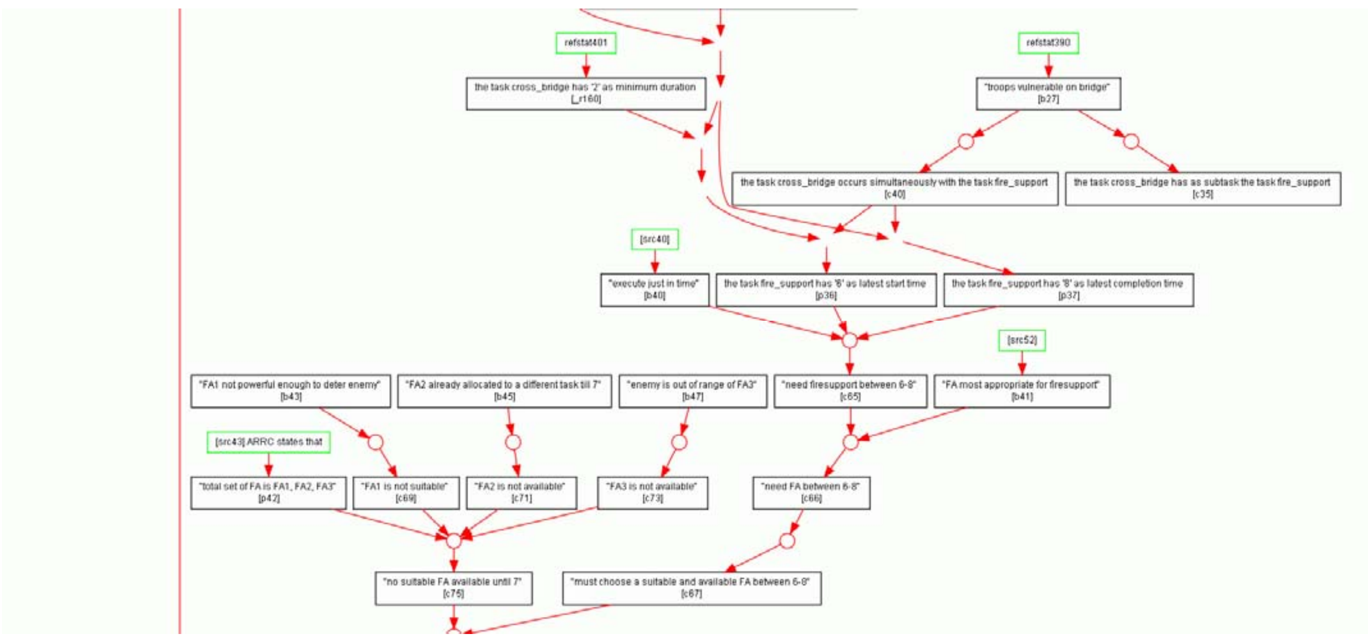

Figure 8 hybrid user & machine rationale (partial diagram)