Modeling Actions and Operations to Support Mission Preparation

Jane T. Malin
NASA Johnson Space Center
Automation & Robotics Div., MC ER2
Houston, TX 77058
Phone: (713) 483-2046 FAX: (713) 483-3204
malin@aio.jsc.nasa.gov

D. P. Ryan and D. L. Schreckenghost
Metrica, Inc.
NASA JSC, ER2
Houston, TX 77058
Phone: (713) 244-6135 FAX: (713) 483-3204
schreck@aio.jsc.nasa.gov

KEY WORDS AND PHRASES

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ABSTRACT

This paper describes two linked technology development projects to support Space Shuttle ground operations personnel, both during mission preparation analysis and related analyses in missions. The Space Propulsion Robust Analysis Tool (SPRAT) will provide intelligent support and automation for mission analysis set-up, interpretation, reporting and documentation. SPRAT models the actions taken by flight support personnel during mission preparation and uses this model to generate an action plan. CONFIG will provide intelligent automation for procedure analyses and failure impact analyses, by simulating the interactions between operations and systems with embedded failures. CONFIG models the actions taken by crew during space vehicle malfunctions and simulates how the planned action sequences in procedures affect a device model. Jointly the SPRAT and CONFIG projects provide an opportunity to investigate how the nature of a task affects the representation of actions, and to determine a more general action representation supporting a broad range of tasks. This paper describes the problems in representing actions for mission preparation and their relation to planning and scheduling.

INTRODUCTION

We are developing methods and tools to provide intelligent automation and support for mission preparation tasks. These require the representation of mission preparation actions, and this representation is affected by the nature of the task being performed. We are investigating action representations for two distinct types of tasks, propulsion (PROP) consumables analysis and operations procedures evaluation.

The consumables analyses conducted by PROP consumables officers are a complex, time-consuming mission analysis task. Throughout the year preceding a flight, several types of mission changes initiate new cycles of analysis to determine how these changes affect consumables. Iterative evaluations are needed for nominal and contingency situations and for proposed mission plans and objectives, priorities, flight rules and procedures. These mission and situation what-if analyses are used to determine impacts to mission objectives and procedures. During missions, additional analyses are performed as needed.

Procedure evaluation has similar characteristics. It is important both in impact analysis during missions when an anomaly causes space system reconfiguration, and in procedure development and analysis during mission preparation. Operations personnel evaluate procedures against nominal and contingency configurations, to assess which procedures will be impacted and which should be altered. When procedures are altered to fit the current mission configuration, they are again evaluated against the current mission situation and related "next-worst" contingency situations.

These mission preparation tasks have common characteristics and problems. They both involve action representations, but for two distinct types of tasks:

- Scientific and engineering analysis: data generation and interpretation to answer specific questions; e.g., consumables analysis (SPRAT)
- Device operation and process control: monitoring and control of physical devices and processes in operations to achieve specific behaviors and to respond to failures; e.g., procedure evaluation (CONFIG)

Action representations developed for scientific and engineering analysis include the task of developing scientific models [1] and data analysis tasks for geological exploration [4].

Representations developed for device operation and process control tasks include malfunction procedures and process control operations. In the SPRAT and CONFIG projects, we are developing technologies to address both types of tasks, with the goal of developing a more general action representation. A mutual benefit is being gained by deriving an action and procedure representation which embraces both types of task domains.

SPRAT

The goal of the SPRAT project is to provide advanced technology support for flight design personnel and flight controllers to use when conducting analyses prior to a mission, and when performing new analyses in response to anomalous situations that occur during a mission. Initially, the project is focused on tools that support the management of mission preparation actions (the flight controller mission analysis "procedures" performed pre-mission).

Mission preparation actions include the execution of simulation and analysis software, the interpretation of results from these computations, and the generation of mission preparation reports summarizing decisions. Action management consists of creating and modifying an action item list, tracking the outcome of actions on the list, and creating and modifying action descriptions and their relations.

Action list creation can be viewed as form of planning, and action tracking as monitoring plan execution. A knowledge base of domain actions is defined in terms of goals and associated activities. Actions from this knowledge base are selected and placed on a managed list. The execution of actions on this list is monitored to determine how actions are dispositioned and to document the outcome of actions. This tracking information is stored in an action disposition "database". This separation of the knowledge base of available actions and the data base of action tracking objects permits multiple actions of the same type to be managed on one list. The Figure illustrates this distinction.

SPRAT's action representation has two parts:

- Description: goal of the action and conditions that must hold prior to action execution.
- Tracking Record: information about action assignment and disposition. The action tracking information is retained as part of a usage record stored in the action archive.

SPRAT provides for goal hierarchy and levels of abstraction in actions by permitting subactions (with subgoals) to be associated with an action. Subactions are viewed as constituent actions, or actions that must all be completed for a higher level goal to be satisfied.

SPRAT represents action dependencies in terms of inputs required by an action (data and information from other actions) and outputs generated by an action (software and manual). When a change in mission definition data occurs,

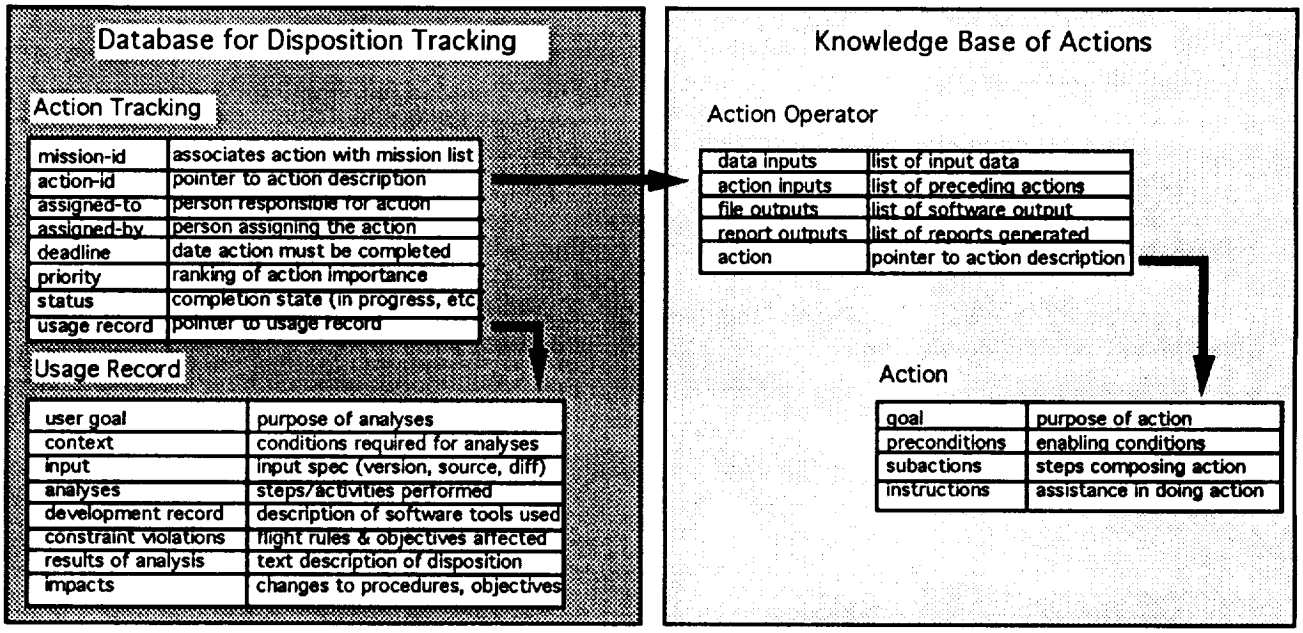

Figure. The SPRAT Action Representation

the dependency constraints are used to determine what new actions must be performed in response to this change. Simple ordering constraints are used to construct a list of actions. These constraints include delivery deadlines and priorities, and software precedence constraints.

The information needed to track the disposition of actions includes information about the intent of the action, the way the action was conducted, and the outcome of the action. The intent of the action is defined by the user's goal or purpose in performing the action and the mission context in which the action is relevant (e.g., rendezvous, mission definition data). The way the action is conducted is characterized by the activities/steps composing the action (e.g., analyses performed) and the characteristics of the tools used when performing these activities/steps (e.g., low fidelity model of gravity used). Information needed to track the action includes information about deadline, priority, completion status, and action responsibility.

The outcome of an action includes the results of the analyses (e.g., computation of consumables usage), the consistency of these results with flight rules and mission objectives, and the impact of these results on flight procedures. It also includes information about the execution of the action (was the action completed and how was it completed, was the action successful and if not why, why was the action canceled or aborted, what was done in response to an unsuccessful action). Information about analyses that were canceled or unsuccessful is useful, since knowledge about why an approach wasn't pursued or what caused it to fail may be useful when performing similar analyses in the future.

The SPRAT prototype is implemented in G2, extended with C routines for the data interface to analysis software. It runs on Unix workstations. Although the initial domain is consumables analysis, the SPRAT project will develop both flight-discipline-specific and generic tools for other disciplines to build similar systems.

CONFIG

CONFIG is a prototype software tool which provides integrated support for the modeling, simulation and analysis of the structure, behavior, failures, and operation of system designs [5,6]. System models are structures of connected component models, with embedded time-related behavior models partitioned into nominal and failure modes. The behavior of each device during a simulation depends on its current mode and on changes in its input caused by operations or from other devices via local connections or global flow path changes. These capabilities enable several types of evaluation of system operability, including analysis of impacts over time of faults, failures, and procedural or environmental difficulties.

CONFIG operations models support analysis of plans and procedures for operation of systems in nominal and contingency configurations. They can also support simulation and analysis of proposed changes (reconfigured systems and revised procedures) that are developed during operations in response to failures. The operations modeling approach integrates both with operations-execution-monitoring representations that are based on device and command states and with goal-based planning representations [3].

CONFIG operations models represent procedure actions and dependencies among these actions. CONFIG operations models are activity structure models that can be developed independently from system models, yet link and dynamically interact during simulation with system models. Activities are the basic components of a CONFIG operations model, and are connected together in action structures. These structures represent procedures or protocols that interact with the system, to control and use it to achieve goals or functions. Relations define sequencing and control between activities and connect devices with device-controlling activities.

CONFIG is implemented in the Common Lisp Object System (CLOS) language, and runs on Unix workstations. The current test model domain for CONFIG is thermal bus systems, including a model of a pump safing procedure.

PLANNING & SCHEDULING ISSUES

Action list management in SPRAT raises a number of issues related to both plan creation and plan repair. An objective of the SPRAT project is to provide a tool that permits the flight controller to create new actions dynamically, and to link those actions into the representation of precedence constraints. Such a capability minimizes domain knowledge engineering, since new actions can be added as needed. The ability for the user to create new types of actions (not yet developed) is related to the work by Martin and Firby [7] on human repair of robot plans

"on the fly".

The dispositioning of actions on the action list includes archiving the outcome of actions for use in future missions. These action archives will be used as starting points for creating action lists for missions with similar issues and constraints. Accessing and modifying these archived actions remains an issue. These archived actions resemble case bases of partial plans [8].

An issue related to the disposition of actions is merging new items onto the list and deleting items on the list that no longer hold. To be added to the list, an action must be consistent with

- the mission definition (e.g., flight design data)
- the phase of the mission preparation
- the intent of the controller performing the analysis (e.g., orbital vs. ascent analyses)

As the mission definition and user intent change throughout mission preparation, actions items on the list may be no longer relevant (e.g., new flight design data). For SPRAT, the challenge is to provide an adaptable plan with a goal structure which models flight controller intent. The intent of an action is needed to track the action (did the action achieve the desired effect? was an observed change intended?), and to provide goals that can be manipulated using traditional replanning techniques [2,3].

Procedure modeling in CONFIG uses an action representation that interfaces with planning systems, and that will be able to use SPRAT-style action management. CONFIG and SPRAT action representations can become more powerful if action representations in planning and scheduling become integrated.

BENEFITS

SPRAT models the actions taken by flight support personnel during mission preparation. CONFIG models the actions taken by crew executing procedures. Jointly the SPRAT and CONFIG projects provide an opportunity to investigate how the nature of a task affects the representation of actions, and to determine a more general action representation supporting a broad range of tasks. Such representations can be applied to other types of activities (such as software development and analysis over large data bases). They also enable the development of more flexible tools for representing and reasoning about actions.

Application of CONFIG and SPRAT can reduce ground operations costs not only on console, but in a large and costly operations area, mission preparation. Increased automation and support for mission analysis and procedure analysis will reduce analysis time, make impact assessment quicker, reduce the number of unnecessary analyses, reduce training time and support better documentation. Common representations for procedures, action lists, plans and schedules can support the integration of several types of operations support tools.

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REFERENCES

[1] Ellman, T., 1993. A toolbox and a record for scientific model development. *Proc. SOAR-93*, (NCP 3240). Houston, TX: NASA-JSC, 1993: 321-328.

[2], Elsaesser, C.; R. MacMillan., 1991. Representation and Algorithms for Multiagent Adversarial Planning. *MITRE Tech Report* 91W000207.

[3] Georgeff, M.; A. Lansky., 1987. Reactive reasoning and planning.*Proc AAAI,* 1987: 677-682.

[4] Kant, E., 1988. Interactive problem solving using task configuration and control.*IEEE Expert,* Winter 1988.

[5] Malin, J.; B.Basham; R. Harris., 1990. Use of qualitative models in discrete event simulation for analysis of malfunctions in continuous processing systems.*AI in Process Engineering*, M. Mavrovouniotis, ed., Academic Press: 37-79.

[6] Malin, J.; D. Ryan; L. Fleming., 1993. CONFIG - Integrated Engineering of Systems and their Operation, *Proc. 4th Nat'l Tech. Transfer Conf.*, Anaheim, CA, Forthcoming.

[7] Martin, C.; J. Firby., 1991. An integrated architecture for Planning and Learning. *SigArt Bulletin* 2(4): 125-129.

[8] Zito-Wolf, R.; R. Alterman., 1993. A framework and an analysis of current proposals for case-based organization and representation of procedural knowledge. *Proc AAAI*: 73-78.