HSTDEK: Developing a Methodology for Construction of Large-Scale, Multi-Use Knowledge Bases

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Abstract

Marshall Space Flight Center is the lead center for the Hubble Space Telescope Design/Engineering Knowledgebase (HSTDEK) Project which is being funded by NASA's Office Of Aeronautics and Space Technology (OAST) as an element in the Core Technology Research effort of the Systems Autonomy Technology Program (SATP). The primary research objectives of HSTDEK are to develop a methodology for constructing and maintaining large scale knowledge bases which can be used to support multiple applications. To insure the validity of its results this research is being pursued in the context of a real-world system, the Hubble Space Telescope. This paper will describe the HSTDEK objectives in more detail, briefly discuss the history and motivation behind the project, outline the technical challenges faced by the project, and present the approach which is being taken to achieve its goals.

Introduction

The capture of design data and, to a lesser extent, design knowledge is already an integral part of large-scale development programs within NASA. However, it is primarily a manual and paper-based process. Even where design data is developed or stored in an electronic medium, there is no common framework or representation which permits the results of the traditional engineering activities comprising the development effort to support an integrated application. With regard to design data, for example, design of the structural components of a system may be done using a Computer Aided Design tool but the weight and center of gravity of the components are not directly available to the computer based tools used by the mass properties analyst to calculate integrated system values. Nor is the expertise of the thermal expert directly available to the electrical engineer designing some power consuming (and thus heat generating) component of the system.

At present, design data is shared through the development of an enormous set of paper documents on any major project, and expertise is shared by means of design reviews based on these documents. These reviews are very costly, involving dozens of experts, and typically identify hundreds of discrepancies which must then be corrected in the design. Most of these discrepancies could be avoided if each expert had the benefit of the other experts' related expertise throughout their design instead of only at checkpoints such as Preliminary and Critical Design Reviews. If that expertise exists only in the heads of our engineers, we will not be able to effectively share it even within a project, much less between projects. But it is now possible to capture that design knowledge in a form which will make much of it constantly available. The capture of such knowledge and the design data to which it refers in a particular domain, however, will result in a knowledge base whose scale greatly exceeds that of current knowledge engineering efforts. It also implies an ability, not currently available, to utilize knowledge about the design of a system to support multiple engineering activities such as evolutionary design, fault diagnosis, planning for operations and maintenance, training, etc.

The primary objective of the HSTDEK project is to develop a methodology for constructing knowledge bases on the scale required to support NASA projects and for making the diverse types of design data and design knowledge found in these projects available for use by multiple knowledge based systems performing different functions. That NASA projects in particular are excellent domains for the use of knowledge based systems technology has been known for some time [1]. This fact is now being recognized by NASA management as critical to achieving the goals we have set for the 1990's and beyond, especially in the Space Station.

The Advanced Technology Assessment Committee (ATAC), which Congress mandated in Public Law 98-371 to identify specific Space Station systems which advance automation and robotics, has formed a subcommittee to assess the state of the art in design knowledge capture. Its recently released report concluded with the following recommendation.

"NASA has an exceptional opportunity for both technology benefit and technology transfer, which can succeed if NASA:

o Determines a firm course of action, and assigns responsibility for execution of each step

o Provides the supportive environment needed for community-oriented development

o Establishes and enforces community guidelines for and standards for information exchange

o Encourages the effective development of emerging DKC technology to a stage of readiness, while adopting a discerning posture towards its use." [2]

An Automation and Robotics program has been established in OAST to achieve the goals set for NASA by ATAC in these areas. The Systems Autonomy Technology Program (SATP), of which HSTDEK is an element, is the primary vehicle for pursuing the ATAC automation goals.

The Systems Autonomy Technology Program

The overall program goal of the SATP is to develop, integrate, and demonstrate the technology required to enable intelligent autonomous systems for future NASA missions [3]. It is managed by the Chief of the Information Sciences Division at NASA/Ames Research Center, with the advice of representatives from each NASA center who comprise the Systems Autonomy Intercenter Working Group (SAIWG), and has a planning horizon of about ten years. Within the Core Technology Research effort of the SATP, the HSTDEK Project is an element of the Knowledge Acquisition task in the Planning and Reasoning area. The goals of this task are defined as follows.

"The objectives are to develop the ability to preserve the 'corporate memory', i.e., to ensure that all the facts, heuristics, and other information gained during the design, construction, and testing of a device are available in a practically usable form during the operational lifetime of the device." [4]

The HSTDEK project has been established in direct response to these objectives.

The HSTDEK Project

The HSTDEK Project is managed out of the Space Systems Division in the Systems Analysis and Integration Laboratory of Marshall Space Flight Center (MSFC). This Division has Systems Engineering responsibility for the Hubble Space Telescope (HST) at MSFC, which is the NASA lead center for HST development. The project has four main tasks, to be accomplished over a five year period, each of which involves collaborative efforts with other organizations.

o Development of a methodology for construction of large-scale knowledge bases which can each be used to support multiple knowledge based applications.

o Assessment of the data products of the traditional engineering activities which composed the HST development process as sources of design data and design knowledge, as well as insertion points for knowledge engineering technology.

o Construction of the HST Design/Engineering Knowledgebase itself.

o Construction of two knowledge based systems which validate the methodology used to construct HSTDEK by performing multiple functions in support of HST verification and operations.

This approach is based on the principle that research into the use of knowledge engineering technology will be most effective if it is done in the context of a "real world" application such as support of the Hubble Space Telescope. Each of these tasks will be discussed in more detail below, but it is worthwhile at this point to discuss the characteristics of the HST which led to its use as the domain for this project.

The Hubble Space Telescope Domain

It may seem odd, at first, to select a mature project such as HST as a domain in which to develop methods for design data and design knowledge capture. The fact that the design activities are essentially complete, however, offers a number of advantages to this project. On a new program, it might be necessary to wait several years for access to some design products and activities. Using a mature project, these inputs are all available immediately and can be analyzed as a whole system of activities. The refinement of the design products over the development cycle could also result in a large amount of wasted effort in construction of a knowledge base. This would not be a consideration if the goal was to use knowledge based systems to support the development process. The goal here, though, is to develop a methodology which will be useful in capturing the design data and knowledge rather than a knowledge based system to assist in the design process. It is therefore preferable to work from a set of design data and knowledge which is truly representative of that produced in NASA development projects. In addition to the data products of HST development, many of the experts involved in its design will still be available to contribute their expertise to the project through HST launch and checkout. Finally, NASA is about to initiate a number of major development projects; Space Station, Advanced X-Ray Astronomical Facility (AXAF), the Orbital Maneuvering Vehicle (OMV), etc. To select any of these projects, as the domain in which to pursue this research would mean that the technology developed would not be available for use during those projects. As described above, technology transfer into the Space Station project is a major driver for this research and such delays are not acceptable.

In addition to the benefits offered by the timing of the HST project, there are technical characteristics of the HST which recommend it as a framework for research into design knowledge capture. It is a major NASA project, whose design, construction, and test have taken many years to complete. It is typical of large-scale NASA development projects in that it involves many technical disciplines, and the integration of a design developed by a number of different contractors. As the Project Management center, MSFC has responsibility for meeting cost, schedule, and technical performance goals. Goddard Space Flight Center is responsible for the HST Science Instruments, the Data Management system, the ground system, and the Science Institute. The Lockheed Missiles and Space Company is the prime contractor for the Support Systems Module (SSM), including its design, development, fabrication, assembly and verification; integration of systems engineering and analysis for the overall HST; and support to NASA for planning and implementing ground, flight, and orbital operations support. Perkin-Elmer Corporation is responsible for the Optical Telescope Assembly (OTA). Finally, the European Space Agency (ESA) is responsible for the HST Solar Arrays. [5] This distribution of HST expertise across a large number of experts in different organizations and at different geographical locations, makes it a very difficult and unusual problem from the knowledge engineering perspective, but also is typical of the NASA design domain. A methodology which can handle the complexity of the HST domain is likely to be useful in most NASA projects. Finally, the knowledge base developed in this project will benefit the HST project itself throughout its fifteen year operational lifetime. This will be a significant "spin-off" of what is, in itself, valuable research.

Project Planning

The funding of the HSTDEK Project as an element of the Systems Autonomy Technology Program implies a collaboration between MSFC and ARC. As the NASA lead center for automation, ARC acts as a consultant to MSFC in planning the knowledge engineering activities in HSTDEK including the selection of appropriate development and delivery systems for knowledge based systems, as well as knowledge engineering training for MSFC participants in the project. The four tasks identified earlier as comprising the HSTDEK Project also involve collaborations among several organizations, as discussed below.

The most fundamental task to be performed in the HSTDEK project is the development of a methodology for construction of large-scale knowledge bases which can each be used to support multiple knowledge based applications. These are areas of basic research in knowledge engineering. The scope and complexity of the design data and design knowledge to be captured in this project far exceeds that of current knowledge bases. Current knowledge bases also are typically focused on a single aspect of a system, with little knowledge of other subsystems or technical disciplines. A necessary component of this task is the establishment of a framework within which different types of knowledge about the HST can be accommodated. This will allow knowledge based systems utilizing HSTDEK to reason from a deeper and more basic understanding of the system. The use of a comprehensive knowledge base like HSTDEK to support several applications will raise another major research issue; the design of multi-user knowledge bases. This is an extremely difficult technical problem [6,7], and will probably have to be addressed as a separate research project. It should be noted that this goal of developing a methodology for constructing a knowledge base which can accommodate the variety and quantity of design knowledge required by NASA projects is not the same as developing a methodology for capturing all the types of design knowledge typically generated in such projects, but complements such efforts.

The research required to accomplish this task will be performed at the Knowledge Systems Laboratory of Stanford University. The first year's effort will have three major results; a small prototype of a multi-use knowledge base in the HST domain, a set of knowledge representations to support the construction of a larger multi-use knowledge base, and the preliminary specification of a methodology for constructing large-scale, multi-use knowledge bases. The prototype will cover two subsystems of the HST (the Pointing and Control System and the Electrical Power System), one constructed at Stanford and one constructed at MSFC using the knowledge representations developed at Stanford. It will support two applications, probably fault diagnosis and a scheduling function. The knowledge acquisition effort at Stanford will draw primarily on the expertise available in the HST designers at the LMSC facility in Sunnyvale California, as well as work at the Lockheed Artificial Intelligence (AI) Center. Knowledge base construction at MSFC is discussed below.

The second main task in HSTDEK is to assess the data products of the traditional engineering activities which make up a NASA development project as sources of design data and expertise, as well as processes which could directly benefit from use of knowledge based systems technology. This is planned as joint research between MSFC and the Computer Science Department of the University of Alabama in Huntsville. The first product of this activity will be a prioritized list of HST data products as knowledge sources which will assist MSFC knowledge engineers in attempting to acquire as much design data and expertise as possible from them. This will be refined and generalized based on experience with other development projects at MSFC. The other main product of this activity will be a recommended approach for including knowledge engineering in NASA's traditional engineering activities.

The third main task in HSTDEK is actual construction of a large-scale knowledge base which can support multiple applications. Initially, traditional knowledge engineering methods will be utilized. As the Stanford research develops improved approaches to the problem, they will be incorporated in this effort. Several organizations will be involved in construction of HSTDEK, in addition to the Stanford researchers. It is expected that the bulk of the actual knowledge engineering will be done by MSFC personnel. To enable that effort, a six month knowledge engineer training program at the Lockheed AI Center is planned for as many as ten MSFC participants over the five year duration of the HSTDEK Project. This will have the highly beneficial side effect of creating a significant knowledge engineering capability at MSFC. The participation of Lockheed personnel as knowledge engineers as well as domain experts is also being investigated, both through the Lockheed AI Center and LMSC/Sunnyvale. The Lockheed AI Center has already been pursuing several projects in the HST domain, and it is highly desirable to find a means of incorporating these efforts into HSTDEK. Similarly, agreements with GSFC and the HST Science Institute will be sought to enable their participation in HSTDEK. Coordination of these efforts will be the responsibility of MSFC.

In order to confirm that knowledge bases constructed using the methodology developed in this project can actually be used in multiple real-world applications, two knowledge based systems will be built and demonstrated by MSFC in operational environments. First, the HST Operational Readiness Expert (HSTORE) system will utilize an early version of HSTDEK to support checkout of the HST during the Orbital Verification phase immediately following HST launch. HSTORE is planned to provide a fault diagnosis capability based on HSTDEK to MSFC engineers in the Huntsville Operational Support Center. A second knowledge based system called GESST (Ground-based Expert System for Space Telescope) will be made available for use in the Space Telescope Operational Control Center at GSFC in 1992 using a more complete version of HSTDEK. It is intended to fully demonstrate a large-scale, multi-use knowledge base.

Conclusions

In its third progress report, the ATAC voiced concerns that NASA was not pursuing the development of automation technology rapidly enough to adequately support Space Station design, and urged that NASA include a requirement for design knowledge capture specifically in its detailed design and development phase proposal requests for Space Station [8]. An earlier staff study by the Office of Technology Assessment stated similar concerns and concluded that aggressive research should be initiated without delay into advanced automation and robotics technology [9]. The HSTDEK Project directly addresses these concerns by establishing collaborations with members of the AI community, both in industry and academia, to effectively pursue the research necessary to enable the capture of design data and knowledge in major NASA projects, demonstrating this technology in the real-world domain of the Hubble Space Telescope, and developing NASA's in-house ability to utilize such technology.

References

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