Automation of Coordinated Planning Between Observatories: The Visual Observation Layout Tool (VOLT)

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ABSTRACT

Fulfilling the promise of the era of great observatories, NASA now has more than three space-based astronomical telescopes operating in different wavebands. This situation provides astronomers with the unique opportunity of simultaneously observing a target in multiple wavebands with these observatories. Currently scheduling multiple observatories simultaneously, for coordinated observations, is highly inefficient. Coordinated observations require painstaking manual collaboration among the observatory staff at each observatory. Because they are time-consuming and expensive to schedule, observatories often limit the number of coordinated observations that can be conducted. In order to exploit new paradigms for observatory operation, the Advanced Architectures and Automation Branch of NASA's Goddard Space Flight Center has developed a tool called the Visual Observation Layout Tool (VOLT). The main objective of VOLT is to provide a visual tool to automate the planning of coordinated observations by multiple astronomical observatories. Four of NASA's space-based astronomical observatories – the *Hubble Space Telescope (HST), Far Ultraviolet Spectroscopic Explorer (FUSE), Rossi X-ray Timing Explorer (RXTE)* and *Chandra* – are enthusiastically pursuing the use of VOLT. This paper will focus on the purpose for developing VOLT, as well as the lessons learned during the infusion of VOLT into the planning and scheduling operations of these observatories.

Keywords: coordinated observations, space-based observatory, coordinated planning tool, multi-observatory scheduling, planning and scheduling

1. THE NEED FOR AUTOMATED TOOLS FOR CROSS-MISSION OBSERVING

Coordinated multi-wavelength observations have assisted astronomers in developing more realistic physical models of astronomical phenomenon. For example, studies of interacting binary systems, planets, comets, flare stars, and gamma ray bursts have had big break throughs because of simultaneous or coordinated observations in different energy regions of the electromagnetic spectrum. Coordinated observations fulfill the promise of the era of great observatories, where multiple space-based astronomical telescopes operating in different wavebands can be accessed simultaneously to attack a scientific problem.

Each space-based observatory uses a set of instruments designed to operate in a specific region of the electromagnetic spectrum, and coordinated observations are often conducted by submitting proposals to multiple observatories, with requests to coordinate observation scheduling among themselves. But in the last five years, to facilitate multi-wavelength observations, observatories have started trading telescope time. For example, *Chandra* and the *Hubble Space Telescope* have set aside a certain amount of time for awarding coordinated time between the two telescopes. At present, if an astronomer wants to conduct coordinated X-ray and UV/Optical observations, he/she does not have to submit two different proposals to the two observatories. A single proposal is submitted to one of the two observatories and the proposal peer review committee awards observing time on both telescopes. Once the coordinated observations are approved by the peer review committee, each observatory's staff has to check that the observations are valid and meet all of the constraints not only for their own observatory, but they have to verify that the observations satisfy the constraints of the other observatories as well. The review and analysis of coordinated observation requests is time-consuming, and the outcome is not known until the end, after a great deal of work has taken place. If a solution is not found, this necessitates more human intervention to rework the proposal by communicating with the scientist to determine which constraints may be relaxed. Often, observers and observatory staff perform iterative changes to the proposed observations until satisfactory results are assured. Only then are the proposals incorporated into a long or short-range observing schedule. Due to the lack of available tools for observatory staff to effectively schedule coordinated observations, this process is extremely tedious and error-prone. Obviously, the present strategy of scheduling coordinated observations is very cumbersome and time-consuming, in which neither the observers nor the observatory staff are confident of the outcome.

From the science community perspective, trading of telescope time has been a useful innovation because it increases scientific efficiency. But currently, this coordination demands a great deal of human intervention and/or extensive custom software development efforts to ensure that the observations are scheduled as desired. Hence, observatories limit the number of coordinated observations, even though the number of coordinated proposals continues to increase due to science driven needs. Users themselves are also discouraged from requesting more coordinated observations due to the complexity involved in their scheduling. Hence, to increase observatory operations efficiency, such manpower intensive processes need to undergo re-engineering. The planning and scheduling of coordinated observations needs to be automated so that these observations can be considered routine, rather than special exceptions. Furthermore, if coordinated observations can be optimized and scheduled just as easily as regular observations, there will be no artificial limit placed on the number of coordinated observations an observatory can schedule. This will facilitate scientists in requesting observations that best suit their science needs, and in turn maximize science returns from the observatory.

The Visual Observation Layout Tool (web address: http://pioneer.gsfc.nasa.gov/public/volt/) was developed to assist astronomers and observatory staff in developing and scheduling multi-observatory coordinated observations. The main objective of the VOLT project is to provide visual tools to help automate the planning of coordinated observations, as well as to increase the scheduling probability of all observations. Thus, these tools not only provide the users with the required schedulability data, but also help and guide them in determining the best possible times when the group of observations may be placed in compliance with their coordination goals.

To ensure that VOLT has the functionality desired by its users the VOLT team has worked with potential VOLT customers since the inception of this project. These customers are three space-based observatories: the *Chandra X-Ray Observatory (Chandra)*, the *Hubble Space Telescope (HST)*, and *the Far Ultraviolet Spectroscopic Explorer (FUSE)*.

This paper describes the detailed features and architecture that make VOLT a unique tool, and most importantly the knowledge gained by the VOLT team during the integration of VOLT into the operations of the space-based observatories.

2. EXPECTED IMPACT OF THE VISUAL OBSERVATION LAYOUT TOOL (VOLT)

2.1 More visibility into scheduling for the observer

At present, observers have very little visibility into the schedulability of their scientific program. The feasibility of the observational strategy is determined via discussions with observatory staff at each observatory. There is no way to determine the cross-mission feasibility. The orbital mechanics of the various spacecraft place strict limits on how simultaneous observations can be obtained. For example, in a variability study, all of the heroic efforts taken to schedule simultaneous observations can be wasted if the orbital mechanics do not allow the observations to proceed as desired. The beating of the South Atlantic Anomalies for the two spacecraft can disrupt the timing requirements. For the success of the science program, it is essential to know such limitations during the planning stage.

The VOLT tool facilitates collaboration between astronomers who want to coordinate their observations on different astronomical observatories, as well as to determine the schedulability of their coordinated or stand-alone observations. VOLT retrieves the planning information from the individual mission's planning/scheduling system and presents it to the users in a uniform and consistent manner. VOLT provides users with a means for determining whether their ideas are feasible and will assist them in optimizing their request prior to the submission of a formal proposal. It helps users refine the observing plans in early stages such that coordinated observations can take place more easily. Thus, VOLT can be used as a proposal preparation tool for complicated, time constrained observations.

2.2 Minimizing the manual scheduling process for observatory staff

Presently, there is a lack of automated tools for observatory staff, especially the planning coordinators, to check the schedulability of a coordinated observation requested for a different mission, from their local institutes. Each coordinator is expected to run the proposal, determine its schedulability and then inform the coordinator of the collaborating mission to perform similar steps in parallel. Then manual comparisons have to be made by the coordinators to determine if the observations are schedulable as a set within the allowed time windows. The proposals may have to be modified by either one or both of them, in agreement with their respective observers and the whole process has to be iterated several times before satisfactory results are achieved. Needless to say, this is a slow process with pain-staking phone or email communication, and therefore error-prone.

VOLT also assists the observatory staff responsible for ensuring the schedulability of the coordinated observations requested by astronomers. The visual tools enable the user to check the schedulability of the observations from their local institutes, without contacting the staff of the other mission for information. This is possible because VOLT retrieves the planning information from the individual mission's planning/scheduling system. This complex information is visually displayed so that the coordinated observation opportunities can be easily seen by the mission planning staff so that they may determine the best solution. Additionally, VOLT assists observers/observatory staff with finding potential scheduling solutions for their coordinated observation planning that otherwise would have been difficult or impossible to determine. The visual display in VOLT provides detailed information on how each observational constraint affects the schedulability of the observation, making it easier for the user to determine which constraints need to be relaxed and by how much. VOLT is designed to reduce the manual workload and proposal iteration, and thus the cost, of coordinated and time-constrained observations.

3. BASIC SCHEDULABILITY TERMINOLOGIES

In order to present the detailed functionalities and architecture of the VOLT system, the meaning of the following basic terminology need to be explained here.

- **Schedulability of an Observation**

Schedulability indicates when a specific observation is possible in accordance with the orbital characteristics and inherent constraints of the spacecraft system, as well as due to constraints imposed upon by the observer to meet their science requirements. Examples of such constraints are: orbital viewing restrictions due to earth occlusion, exclusion due to South Atlantic Anomaly, Guide Star availability, Roll angle restriction for the operation of certain instruments, as well as temporal constraints related to other planned observations.

- **Schedulability Timelines**

For a given observation, schedulability data consists of dates and times (time windows) within the observation cycle at which the observation may be scheduled without violating any specified constraint. This timing information is referred to as the schedulability timeline. In general, each constraint specifies its own timeline.

- **Mission Schedulability**

Mission schedulability indicates the schedulability of an observation within a given mission. This comprises of the set of time intervals during which each schedulability constraint is satisfied. This is computed by merging the individual schedulability for mission-specific constraints (that is, it is computed from the intersection of all individual timelines associated with each scheduling constraint). The user may associate weighting factors with each constraint to study change in schedulability of an observation during the scheduling cycle.

- **Coordinated Schedulability**

The schedulability of temporally connected observations is defined as coordinated schedulability. This refers to the schedulability of an observation in conjunction with some other observations, upon which it depends. It is often possible that each observation may be schedulable by itself - by satisfying its mission-specific constraints, but cannot satisfy the temporal or other constraints that indicate the criteria of coordination between observations. Coordinated schedulability of an observation is therefore determined from individual mission schedulability data through the satisfaction of coordination constraints.

- **Constraint Relaxation**

The schedulability of an observation depends on the number of constraints that an observation has to satisfy. The schedulability of an observation may be improved by experimenting with the constraint specifications and selecting the most suitable conditions. It is possible for the scientists to relax certain constraints imposed upon their observations or the coordinated observations such that an observation would become schedulable, although it fails to schedule when all constraints are at their nominal weight. However, to relax constraints, the users (both the scientists and the planning coordinator) require visibility into an observation's schedulability timeline and detailed information on how each constraint affects the schedulability of the specific observation.

4. VISUAL OBSERVATION LAYOUT TOOL: OBJECTIVES AND BACKGROUND

4.1 VOLT Objectives

The primary objective of VOLT is to bridge the gap in the coordinated planning arena of science missions by providing the scientists and planning coordinators with visual tools to help enable better science planning. Specifically, it helps observers and observatory staff to:

- Check the schedulability of an observation in the context of its host observatory, along with that of the coordinating observation(s) by the collaborating mission(s), and find the areas of overlap, indicating feasible time windows.
- Provide feedback on the constraints of the observation, imposed both from science, and from mission health and safety perspective, that limit the schedulability of the observations.
- Help the users to relax these constraints, if permissible, for improved results.
- Detect planning conflicts early by generating coordinated solutions based on observatory schedulability and constraints
- Configure VOLT for use by different categories of users, namely the observers, the coordinators at a local observatory, and the coordinators at a collaborating observatory.

4.2 Background

The intent for developing VOLT has been to provide visual tools to help automate the planning of coordinated observations by multiple astronomical observatories. A related goal is to provide better visibility into planning information for improving the schedulability of a stand-alone observation for any of these observatories. Although the initial version supports a specific set of space-based observatories, it is easily extensible to other missions and queue-based ground observatories. VOLT has taken advantage of the many scheduling tools already provided by individual observatories. Specifically, adapters have been built to integrate with existing scheduling tools for four missions (*HST, FUSE, Chandra, and RXTE*) in order to determine observation schedulability.

VOLT has been developed using the Java programming language in order to support a platform independent solution. It has been designed as a client application, as well as a web application. The client version of the tool offers more robust functionality and has been more thoroughly tested. The web version offers the same core problem solving capabilities as the client tool, and is more easily accessible to remote users through the use of a standard web browser. The purpose for the development of the web version of VOLT was to provide observatories with a light-weight version of the tool that was easier to maintain due to its universal access. The capability to access the web version of VOLT from any location is especially attractive to astronomers whose physical locations may be anywhere in the world. The web version of VOLT also offers smaller observatories with an easier mechanism for maintaining the software. Specifically, it provides a method for them to centrally maintain the software and to ensure version consistency, since all observatories will be accessing the same version of the software from a centralized web server.

VOLT is a mature tool that has been in development for the past two years. It has evolved through the continued communication and involvement of potential users to gather their feedback. The core functionality of this software is now complete, and the remaining work involves user-driven enhancements and mission infusion. Once the critical enhancements are completed, VOLT will be fully operational and used by the staff of the *HST, Chandra, FUSE*, and *RXTE* observatories. VOLT is available to the astronomical community as beta testing software. Formal operational use by the astronomical community will depend on the observatories providing VOLT as a proposal preparation tool.

5. VISUAL OBSERVATION LAYOUT TOOL: CAPABILITIES AND FEATURES

5.1 VOLT system architecture

The VOLT system has been developed using a flexible framework consisting of two major components:

(a) A front end component that interacts with the user to receive observation specifications and provides visualization capabilities for scheduling and related information.

(b) A back end component that may be configurable to interface with an observation data source such as the proposal, and an observatory's planning and scheduling system from where it retrieves relevant information to be presented to the user. In the event it is not feasible to obtain the schedulability data from an observatory facility in a modular fashion, VOLT can interface with a specified external facility that provides the required data with a reasonable degree of accuracy.

The front and back end components of the VOLT system are represented by two separately executable processes, known as the VOLT client and server processes respectively, with the latter providing a configurable gateway for the external planning facilities. The two components communicate with each other through remote calls. The VOLT server interfaces with each mission's planning facility through a mediator object, which transforms the client request to observatory-specific queries, and formats the observatory provided data and timelines into VOLT-specific internal representation. The client performs visual rendering of this data and presents it on the screen in the form of display panels.

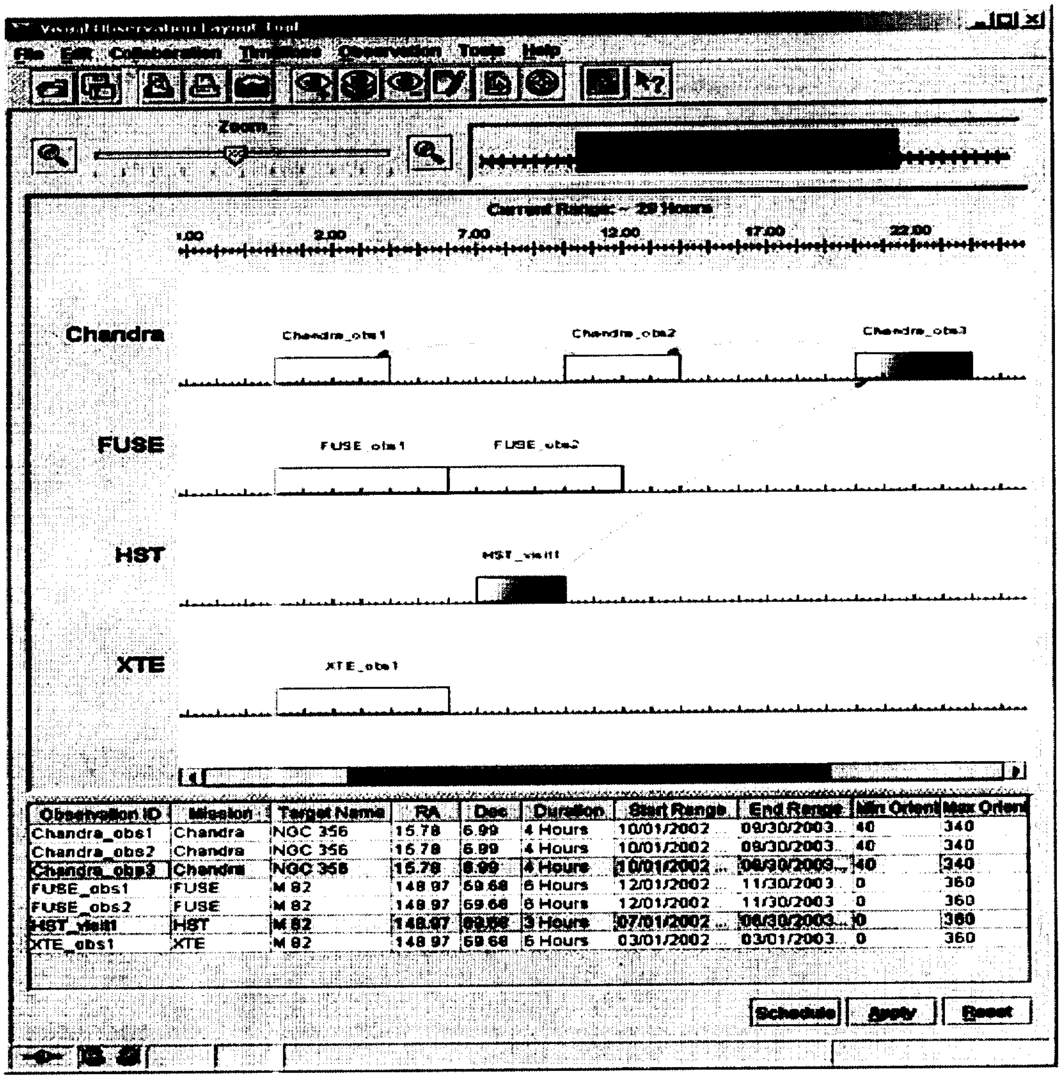
The following sections discuss and present some display screens used by VOLT for receiving user input and for providing visualization of schedulability data.

5.2 Specification of observations and coordination criteria

VOLT may be used as a planning tool to study the schedulability of coordinated as well as individual observations. The user interface provides this flexibility, in which the user may specify a target and select one or more observatories where it would be observed. The user may then indicate coordination between these observations by linking them and specifying desired temporal constraints between them. This is shown in Figure 1, which demonstrates an example of coordinated observations, as well as non-coordinated observations. The arrows between observations represent the temporal constraint relationships (or linking) between them.

VOLT also supports the retrieval and display of observations from already submitted proposals and assists with the modification of these proposals for better schedulability. It is expected that the former scenario would be more useful to the scientists in the original planning, where as the second one is for use by both the observatory planning coordinators and the scientists for iterative changes.

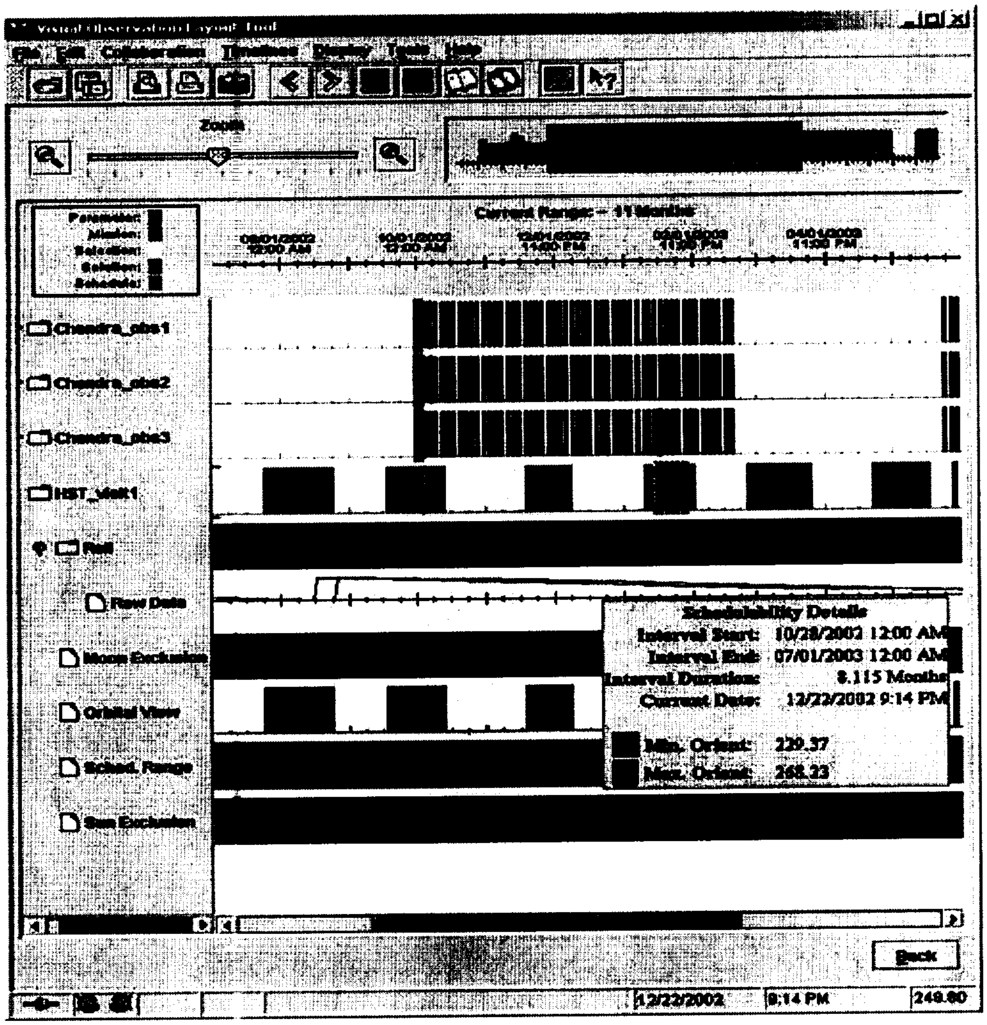
Figure 1 – Observation Setup Panel



5.3 Visualization of schedulability data

Schedulability information for a set of coordinated observations is presented in a bar chart format in the VOLT Schedulability Display Panel, as demonstrated in Figure 2. At the highest level of the display, a coordination timeline for each observation is presented on the screen. The black boxes within each timeline represent schedulable time windows that are available for that individual observation to occur and the white areas represent gaps in the schedulability (these times are not schedulable for the observation). The user may click to the left of the observatory name to expand the display in order to view the attributes that contribute to the schedulability of this observation, such as moon exclusion and orbital view. Each attribute timeline may also be further expanded in order to view the raw data that comprises the attribute timeline. A tool-tip capability is also provided to explain to the user why a certain time gap along a timeline is not schedulable. The magenta line displayed within each observation timeline represents the consolidated solution for the set of coordinated observations, taking into account the constraints that have been identified for each observation, as well as the linked constraints between observations. The user may experiment with various different solutions by clicking the Next and Previous buttons in this display. Additionally, the user may select any area within the schedulable time window of an observation and click the Next button to determine overall schedulability for all observations for the desired time. Once the user is satisfied with a particular solution, the observation set may be scheduled.

Figure 2 – Schedulability Display Panel



5.4 Advanced features

VOLT offers many advanced features that make it a unique and powerful tool for scientists and observatory staff to utilize. Some of the sophisticated features of VOLT are:

- **Wizard tools**

Several wizard tools are provided that facilitate the usability of VOLT by significantly reducing the amount of time and effort required to create observations and their constraints. Some examples are: *a duplication wizard* that easily allows the user to create multiple observations, *a coordination wizard* that allows the user to coordinate groups of observations without having to set up constraints for each observation set individually, and *a suggestion wizard* that assists the user with determining which constraints to relax in order to find a schedulable time window for an observation (this is most useful when no solution has been found for an observation).

- **Collaboration feature**

This feature allows observatories to collaborate with each other to reach a joint solution for a particular observation. Specifically, it allows users to share real-time observation data by connecting to a host server that serves as the data exchange repository. When one user makes a change to the data, visual cues are provided to alert all users of the change, at which point they may synchronize their data and accept the changes. A chat capability is also offered with this feature to allow users to communicate with each other and explain the data that they are sharing.

- **SkyPlot**

This feature was designed for the needs of the astronomer. It will provide users with the capability to find the most schedulable targets for a given time period. It provides a visual layout of the sky with the targets of interest displayed (as entered by the user) and calculates the number of schedulable time windows, the longest time windows, and the total schedulability available for each target.

- **User defined timelines**

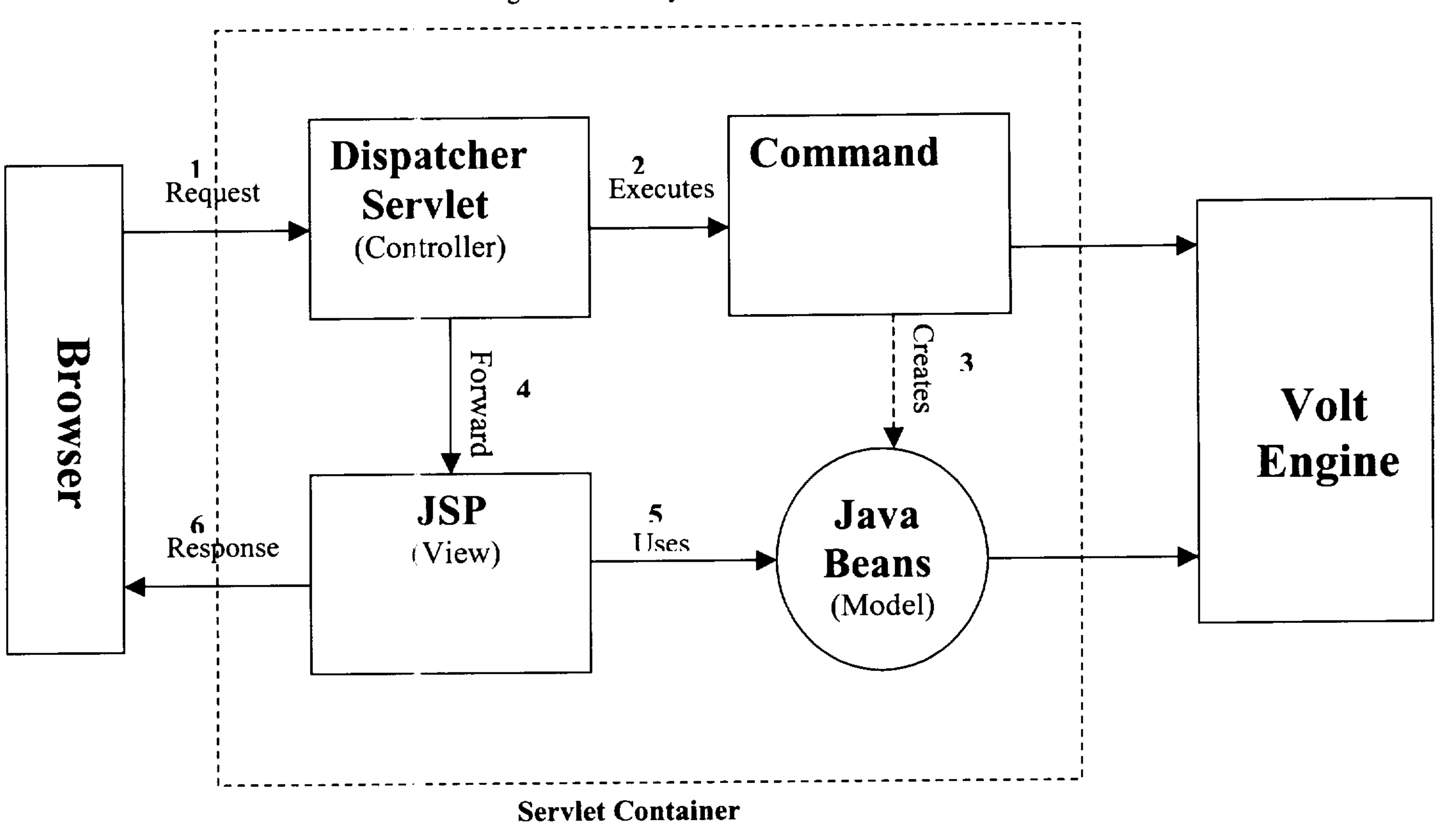
This feature allows the user to specify their own timelines to affect schedulability. For example, if a particular observatory will be off-line due to maintenance of the telescope, it would not be available during this time for observations. In this case, a user could define a timeline that blocks this time period from being schedulable. This timeline may be applied to an observation or more widely applied to all observations for a particular observatory.

5.5 Web system architecture

The Web version of VOLT was originally developed using a Model-View-Controller (MVC) architecture, which cleanly decouples or separates the presentation layer from the rest of the application. A presentation layer generally consists of the user's interface to a given application. This separation of the presentation layer from the core application significantly reduced the complexity of developing a Web version of the tool. The presentation layer was the only component of the software that needed to be replaced when developing the Web version of VOLT after the client application was developed. Essentially, a Hypertext Markup Language (HTML) front-end was used instead of a Java Graphical User Interface (GUI). To accomplish this, a generic framework was created that uses Java Servlets and Java Server Pages (JSPs) to dynamically generate the HTML. This framework is also based on the MVC design pattern.

The framework contains a central Servlet called the Dispatcher that receives all requests from the Web browser. When a request is received from the browser, the Dispatcher determines which command should be executed. The executing command communicates with the VOLT back-end, which is where all of the data processing takes place. After the command has executed, the Dispatcher then determines which Java Server Page should be sent back to the browser. This process is displayed in Figure 3.

Figure 3 – Web system architecture



6.0 MISSION INFUSION

Although VOLT started as a research prototype to exploit new paradigms for observatory operations, it soon developed into a project that could be used in observatory operations currently. Hence, we have diligently made efforts to infuse the VOLT software into the *HST, Chandra, FUSE* and *RXTE* mission planning process.

6.1 Methodology for infusion

The VOLT Project has followed an iterative development methodology in which frequent customer feedback has been encouraged through demonstrations of the software after each release. It has been through this continued communication that we have been successful in building a tool that was designed by the customers. This year we have actively engaged in obtaining the commitment from customers to implement VOLT as their automated solution for coordinated observation planning by the end of the year 2003. Our focus has been mainly on the observatory staff user because this tool will significantly reduce their workload.

To accomplish this goal of mission infusion, in May 2002, we conducted a workshop with all interested observatories in attendance. Planning and scheduling personnel from the *Chandra, HST, FUSE*, and *RXTE* missions were present. Each observatory not only expressed support for VOLT, but also expressed the desire to use the VOLT tool to improve the efficiency of their currently manual process for coordinating observations between observatories. The meeting was highly productive: many specific enhancements to VOLT were suggested and discussed. Some of the major enhancements are listed below in section 6.2. Finally, a plan for mission infusion was developed.

Even though VOLT is not completely operational, the present build already provides the observatory planners with solutions to coordinated observations much faster than their manual process. Therefore, all of the observatories that were present agreed to begin beta testing the software in June 2002 and to begin using it at the beginning of their observatory-specific proposal cycle (all of these begin before January 2003). We concluded that the best approach for conducting testing was to first conduct individual training sessions with each observatory to ensure that the staff members had enough knowledge of the tool to use it effectively. The training sessions consisted of a tutorial of each of the tool's features and were presented to observatories by our experienced VOLT software engineers. These training sessions have also been used for usability testing, so that we can gather feedback to improve VOLT's usability as well. The customers were asked to use the tool, while the software engineer explained each feature, in order for them to learn more from the experience. Training dates were scheduled as per the convenience of the observatory staff, keeping in mind that their heavy workloads and day-to-day activities take precedence over infusion of a new tool. So far, we have held training sessions with *Chandra, RXTE*, and the *HST* observatories. The *FUSE* training session will be held in September, as their heavy workload has prevented them from scheduling training with us until that time.

During the training sessions that have been held, we gathered even more feedback from the observatories for suggested enhancements and also gained insight into their individual planning and scheduling processes. We will use this knowledge to further improve upon the VOLT software. To date, we have incorporated many of the suggestions gathered during the training sessions, and will be scheduling further testing with each group in the August timeframe. The *HST* and *Chandra* observatories will have VOLT fully infused by December 2002. Likewise, the *RXTE* and *FUSE* observatories will have VOLT infused by January 2003.

Once observatories begin using VOLT operationally, they will undoubtedly have many more suggestions for changes. Our plan is to continue making changes to the software in order to make VOLT the solution that will fully meet the customers' needs. We will follow a formal release schedule and after each new release, we will provide each observatory with a training session to demonstrate new features to ensure that we have accurately represented their enhancement suggestions. By the end of 2003, we expect the enhanced VOLT to be successfully infused in all of the four missions.

6.2 Future Enhancements

During the observatory collaboration meeting in May 2002, many enhancements and customization suggestions for the software were gathered. The simple suggestions have already been completed to date. There are some additional fairly large modules that we will be working on over the next year. The modules are:

- ***Ground based observatory timeline.*** Nearly 30% of the *HST* and *Chandra* observations have simultaneous ground based observing implicit in the science justification. Hence, it is extremely useful to have a reliable module that shows the availability of a target to a given ground based observatory.

- ***Standard interface for integrating new missions.*** Once VOLT is operational (present schedule with the various missions implies that this is achievable by January 2003) and an accepted tool by the community, it is evident that we will require a standard interface for integrating new missions.

- ***Full scheduling feature.*** While VOLT retrieves observatory level schedulability constraints for planning observations, it does not currently support the retrieval of schedulability data based on other proposals that have been scheduled with a particular observatory, nor does it support the export of this data back into the observatory planning and scheduling systems to actually schedule the observation. This feature is critical if observatories use VOLT in an operational environment. There are still a number of issues related to firewalls and security that will require additional work. These issues are solvable and need observatories to collaborate much more intimately than they do today.

These modules are in our task plan for the year 2003. Completion of these modules will provide a fully operational solution to the observatory staff, as well as astronomers requesting observations.

6.3 Challenges and Lessons Learned

Through our infusion experiences, we have learned the importance of communication with, and training of our customers. This is a critical element for the successful implementation of a new software tool. The observatory staff have been very supportive of the VOLT project, largely due to our efforts in communicating with them throughout its development. Their support and commendations to the team have made it critical for us to continue providing them with the level of support that they have become accustomed to for effective infusion of VOLT into the observatory operations domain.

Although the observatory staff have been very supportive of our efforts, we must consider their heavy workloads when attempting to infuse VOLT, as their day-to-day activities understandably take precedence over the infusion of a new tool. We are attempting to resolve this issue by assisting our customers as much as possible with training to reduce the effort required on their part for infusion.

It has taken many years to get the many observatories' operational staff to collaborate and agree upon a common software tool. With the VOLT project, we have the unique opportunity of using a standard tool across multiple missions – the first step toward standardized components and packages of functionality, and eventual cost savings for all missions. Prior to the development of the VOLT tool, the cross-mission planning was manual and each observatory had their own individual software tools that they used. For example, with *HST*, we encountered instances where the observatory had developed its own tools, comparable to VOLT, eliminating their need to use VOLT as a coordinated planning solution. However, we have met this challenge by working with their developers to integrate various components of VOLT to reduce some of the duplication in development efforts. Such software reuse and collaboration is essential if missions want to leverage upon each other's efforts and work toward common tools.

Overall, we have learned that VOLT is a necessary solution for observatory staff, as well as scientists, to automate their currently manual coordinated planning efforts. We have learned through our work with the various observatories that coordinated observations are not always encouraged because they are difficult to process. Due to observation planning and scheduling constraints and the workload that coordinated planning entails, some of the larger observatories simply communicate their available time frames for observations to the other observatories that desire coordinated observing time, thereby eliminating the need for coordination between observatory staff.

7. THE FUTURE OF VOLT

The VOLT project's initial efforts have been in the astronomical domain. However, other domains face similar problems that could be addressed by extending VOLT to those domains as well. For example, earth-observing missions are planned and scheduled in much the same way as astronomical observatories. The types of constraints are different, but the fundamental concepts associated with planning are the same. Just as astronomical observatories each serve specific spectral energy regions that complement each other, earth-observing missions are targeted at specific properties or features of the earth. Thus, the ability to coordinate observations between multiple complementary missions is just as important in the earth science domain.

As a result of our success in marketing VOLT within the space science domain, we have recently gained the endorsement of the earth science missions as well. Specifically, we have had discussions with the Earth Observing System (EOS) managers regarding their desire to allow the AM/PM train missions to be used by other earth science missions (such as *UARS, NVSat, SAGE 3, Aqua, TIMED, ADEOS 2, Source,* and *Aura*) as potential coincident imaging opportunities. The mission managers currently do not have a method for determining potential observing times using multiple earth observing spacecraft with specific time constraints. Since VOLT's core functionality is to assist in the planning of coordinated/time constrained observations and to provide conflict resolution, the earth science mission managers have expressed an interest in using it to support the automation of their science planning problem. Our plan is to integrate VOLT with the earth science mission planning tools.

Collaboration and sharing of operational issues between observatory/mission operations staff, research scientists, and software scientists will be critical as we move into the era where automation and spacecraft autonomy will be the norm. But collaboration and sharing are successful only if we have learned how to build the human relationships involved. Although VOLT is a mature tool, it will require many user suggested enhancements over the next year. We will continue working with all our customer observatories to meet our infusion goal over the next year. *Delivering a user-friendly tool that the customer can trust by keeping them involved in our projects is critical to our future.* We are optimistic that we will be successful in our efforts. We anticipate that VOLT will greatly increase observatory staff productivity through the automation of their coordinated observation planning work.

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