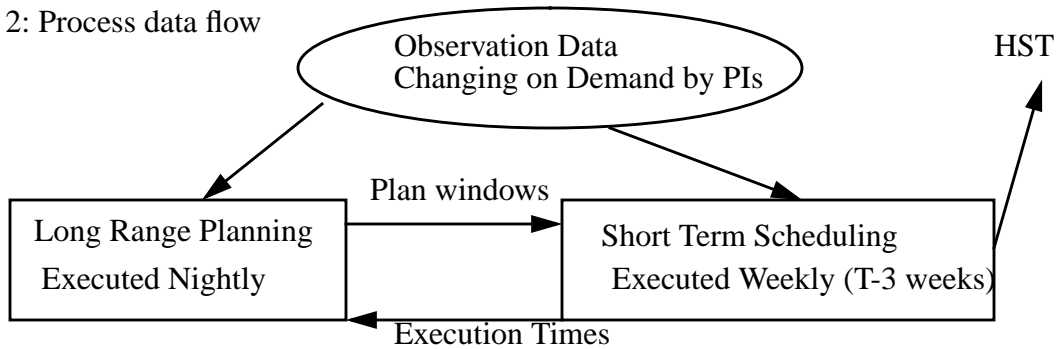


for OB1 from 1-20 will ensure that the minimum size window for OB2 is 10 days long.

Figure 2: Process data flow



#### 4.0 Evaluation/Comparison With other Approaches

Using plan windows to communicate between long range planning and short term scheduling has many advantages. The advantages are highlighted by contrasting the approach with other approaches. Alternate approaches are: 1) Short term schedule on demand one week at a time. Do not long range plan; 2) Short term schedule the whole cycle in advance. Do not long range plan; 3) Long range plan to non overlapping bins. Short term schedule using the bin schedule as input.

Short term scheduling on demand does not meet the requirement that PIs be informed in advance of the approximate time of the observation. In addition, the approach may run into resource problems as greedy algorithms may schedule all the easy observations first. Short term scheduling the whole cycle in advance does, in principle, tell the PIs when observations will be scheduled. However, the schedule would be very brittle. Changing a single observation may require the whole cycle to be rescheduled. As a result the schedule would be changing constantly causing problems for PIs and creating extra work for operations staff. This approach results in a combinatorial explosion in the search space effectively preventing global resource allocation.

Long range planning to week long bins was the approach used in the first four HST observation cycles. The approach was not successful. The approach requires the short term scheduler to create a week schedule from just those observations placed in the bin by the long range planner. In most cases the long range planner would put either too few or too many observations in the week bin. As a result some week schedules would not be filled to capacity resulting in inefficient use of the HST. Other weeks would contain too many observations for the short term schedule to place in a single week. In this case observations would have to be rescheduled leading to an unstable long range plan. This approach requires the LRP to know constraint details about short term scheduling in order to get the right mix of observations in a bin.

The plan window approach has advantages over the other approaches. First, the short term scheduler is given a large pool of observations to select from. By having a large pool to select the short term scheduler can get the right mix of observations to create an efficient schedule. A second advantage of this approach is stability. Changes made to an observation may change its schedulability by a week or two. However, changes may not shift the schedulability of the window over an entire plan window. A third advantage of this approach is that it divides the problem into tractable components.

### 3.0 Scheduling as a Process.

The scheduling process, as illustrated in Figure 2, is an ongoing effort. The long range planner is executed nightly to incorporate the changes made to observing programs during the day. Each week a short term schedule is created which is executed on HST 3 weeks later.

Although the long range planner is executed nightly it must ensure that the resulting plan is stable. Stability is achieved by considering the long range planner as a function which maps a set of input observing programs, search criteria, and a previous long range plan into a new long range plan. On execution of a long range plan the observations are partitioned into those which have windows assigned in the input LRP and those which do not have input windows. In general the scheduler will assign new windows to those observations which are not scheduled in the input plan and will pass through windows for observations which are scheduled in the input plan. The system assigns windows for observations which are not scheduled in the input plan in two steps. First, the system uses user defined criteria to greedily find the best window for each observation. In the second step a stochastic search is used to adjust the resource levels.

There are two cases where an observation which was planned in the input plan is changed. First, the system has a special case for linked observations (e.g. OB1 after OB2 by 10-20 days). When the first observation of a link set is executed the system will automatically adjust the plan window for the subsequent observations based on the actual time the first observation scheduled. A second case occurs when the constraints for an observation changes. The system measures the percentage of the plan window in the observations current plan window. If the percentage is below a threshold then, based on a user flag, either the observation is replanned from scratch or no plan window is written and a status flag is set in the output plan. If the percentage is above a threshold (but some of the plan window is no longer in the constraint window) then the plan window is reduced so that it overlaps with the plan window. The idea is that the long range plan is stable with respect to small changes in constraint windows for an observation.

The long range planner must deal with several anomalous cases. First, it may be possible that loading an observation into the system causes a crash or an error. A second anomaly occurs when the input products for an observation are not ready. In either case the error is caught by the system and any existing plan windows are written to the output plan. A status field is marked so that the anomaly can be investigated. This approach has the added advantage that a crash in one proposal does not crash the entire process.

When the long range planner creates plan windows for linked observations it needs to ensure that the windows allow flexible scheduling of all observations in the set. Consider the following example: OB2 is after OB1 by 20-30 days. OB1 is planned to days 1-30. OB2 is planned to days 21-50. If OB1 is scheduled on day 1 then OB2 is schedulable days 21-31. In this case the full link tolerance is available. In contrast, if OB1 is scheduled on day 30 then OB2 is only schedulable on day 50. Including day 30 in the plan window for OB1 creates a situation where OB2 can have an inflexible window. In general the long range planner creates plan windows which maximizes the guaranteed minimum window size of the entire link set. In the above example creating a window

## 2.0 An Architecture for Creating Efficient and Stable Schedules

Efficient and stable observation schedules are created by dividing the scheduling process into long range planning and short term scheduling. The long term planner creates approximate schedules for observations and handles global optimization criteria such as resource and stability issues. The short term scheduler produces precise one week schedules using the approximate schedule produced by the long term scheduler as input.

The long range planner creates approximate 4-8 week **plan windows** for observations. A plan window is a subset of an observation's **constraint windows**, and represents a best effort commitment to schedule in the window. Plan windows for different observations can be overlapping. In addition the windows for a single observation can be non-contiguous. Figure 1 shows sample plan windows for six observations. Constraint windows include sun avoidance, moon avoidance, at constraints, phase constraints, roll constraints, guide star constraints, and time linkages between observations. The long range planner picks plan windows based on balancing resources (e.g. observing time, observations which can hide the SAA), optimizing observation criteria (e.g. maximizing orbital visibility, maximizing CVZ opportunities, maximizing plan window size, minimizing stray light, minimizing off nominal roll), Packing observations together (e.g. scheduling observations early.)

The short term scheduler builds efficient week long observation schedules by selecting observations which have plan windows open within the week. The short term scheduler is responsible for keeping track of which observations have already been scheduled in previous weeks.

Figure 1. Plan windows for observations 1-6 in weeks 1-8. Week 4 windows are highlighted.

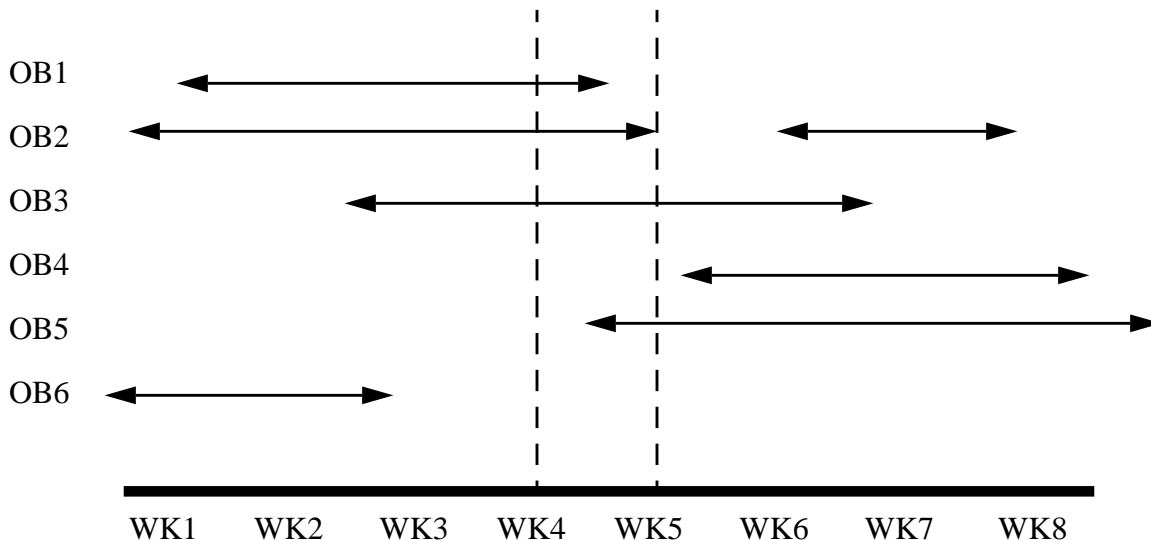


Figure 1 shows a schedule with 6 observations with windows in weeks 1-8. The figure shows that observations 1,2,3, and 5 are potential candidates for scheduling in week 4. Note that observations 1,3 may actually have been scheduled in earlier weeks. In contrast week 4 is the first week in the plan window for observation 5.

# Achieving Stable Observing Schedules in an Unstable World

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## Abstract

Operations of the Hubble Space Telescope (HST) require the creation of stable and efficient observation schedules in an environment where inputs to the plan can change daily. A process and architecture is presented which supports the creation of efficient and stable plans by dividing scheduling into long term and short term components.

## 1.0 Introduction

Operations of the Hubble Space Telescope (HST) require the creation and publication of stable and efficient observation schedules in an environment where inputs to the plan can change daily. Efficient schedules are required to ensure that we get a high scientific return from a costly instrument. Stable schedules are required so that PIs can plan for coordinated observations and data analysis. Several factors complicate creating efficient and stable plans. HST proposals are solicited and executed in multi-year cycles. Nominally all the accepted proposals in a cycle are submitted in a working form at the beginning of the cycle. However, in practice most proposals are reworked based on other observations, or updated knowledge of HST capabilities. Another source of instability is due to changes in HST capabilities. As HST is used the capabilities of some components degrade (e.g. the solar panel rotation engines), and some components perform better than expected (e.g. guide star detectors). Changes in component performance lead to different operation scenarios and different constraints on observations. As a result a plan created with one set of constraints may no longer be valid with the new constraints. A final source of plan instability is that the precise ephemeris for HST is not known more than a few months in advance. As a result very constrained observations cannot be scheduled with accuracy until the precise ephemeris is known. Given these constraints, it is not possible to create a single static schedule of observations. Instead scheduling is considered as an ongoing process which creates and refines schedules as required.

A process and software architecture is presented which achieves stable and efficient observation schedules by dividing scheduling into long term and short term components. The process and architecture have in part helped HST obtain sustained efficiencies of over 45 percent when pre-launch estimates indicated a maximum of 35 percent efficiency. The remainder of the paper reads as follows. Section 2 presents the architecture. Section 3 discusses observation planning as a process and discusses more details on the long range planner as implemented by the SPIKE software system. Section 3 evaluates the approach by comparing the system to other approaches.