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Applying Artificial Intelligence to the Control of Space Telescopes

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Applying Artificial Intelligence to the Control of Space Telescopes

(Extended Abstract)

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Background

The field of astronomy has recently benefited from the availability of space telescopes. The Hubble Space Telescope, for instance, despite its problems, provides a unique and valuable view on the universe. However, unlike HST, a telescope need not be in low Earth orbit to escape our thickening atmosphere: it is currently technologically feasible to put a telescope on the moon, and there are excellent reasons for doing so (Genet, *et al*, 1991). Either in low Earth orbit or on the moon, a space telescope represents an expensive and sought-after resource. Thus, the planning, scheduling, and control of these telescopes is an important problem that must be seriously studied.

The recurrent costs involved with space telescope management can be enormous, so it makes sense to attempt to automate infrastructure operations wherever possible. Automation can be expected to lead to lower operating costs, greater safety, and, if properly implemented, greater freedom for astronomers to pursue their scientific goals. In one sense, we seek to enhance existing operations by reducing cost, by increasing safety, and by increasing accountability. We also seek to enable a greater diversity of operational modes by providing an opportunity for scientists to interact with telescopes in new and productive ways.

Recurrent Operations

In abstract terms, the management infrastructure that surrounds a space telescope is responsible for the planning, scheduling, and control of the telescope's operations. The business of planning is that of selecting particular observation activities that are likely to gather desired data (to prove an hypothesis, perhaps). Thus, planning is about selecting observations to achieve goals. Scheduling is the task of sequencing a pre-selected set of observations. A scheduling system must take into account all constraints on observation ordering, and find a (hopefully) optimal schedule that satisfies all constraints. This is not an easy task, as the observation requests are typically generated by a variety of astronomers, and the constraints on their ordering are subtle and complex. Telescope control (at a high level) is the business of executing a schedule, carrying out desired observations, and gathering data.

Existing automation does address some subset of these functions. For instance, scheduling has been studied for many years, and a number of scheduling systems are commercially available. Various shortcomings of most available products have given rise to a "new generation" of scheduling systems and tools (for instance, Zweben, Deale, & Gargan, 1990; Liu, 1988; Biefeld & Cooper, 1991), and some of these have been applied to the problem of scheduling observations on space telescopes (for instance, Johnston, 1990; Muscettola, *et al*, 1992). While some of these systems have achieved great success on the isolated scheduling problem, they do not completely address the prior problem of telescope observation planning. This is not surprising, since planning, in its full generality, is an extremely hard problem. However, some successes have been achieved (Currie & Tate, 1991; Muscettola, *et al*, 1992), and we feel that it is now possible to design and build a combined planning and scheduling system for integrated telescope operations.

Outstanding Research Problems

There are a number of outstanding research problems, grounded in functionality not provided by the current generation of scheduling systems. Existing schedulers cannot manage the disjunction that is inherent in conditional schedules. One requires a conditional schedule whenever the future cannot be precisely predicted. For instance, an astronomer might wish to execute one of a given set of observations, the exact observation to be selected depending on the results of an immediately prior observation. This is not possible in a scheduler that commits to a single, non-disjunctive representation of time. There are other issues that are unaddressed by current technology, but space precludes detailed discussion. These problems include effective control of the search required to build a schedule, probabilistic estimates of schedule robustness, and tracking relevant environmental conditions to enable automatic rescheduling as required by exogenous environmental change.

Project Goals

We are seeking to demonstrate a number of new functional capabilities in this project. Space precludes a detailed discussion, so this section attempts to describe only one particular functional goal.

In terms of planning, we are initially concentrating on photometry; that is, measuring light-quanta as a function of time. We are working with an astronomer who is looking for Earth-sized planets around Sun-sized stars. Our astronomer uses photometric techniques to detect when a planet moves between its local star and the Earth. As observed from Earth, such a transit would give rise to a characteristic light curve. Thus, our astronomer can express an hypothesis about a given planet and star as such a light curve: if data can be gathered that is consistent with this hypothesis, then to some extent the hypothesis has been proven; however, if data is gathered that deviates significantly from the prediction, then the hypothesis must be revised. The traditional mechanism for proving or disproving such an hypothesis is for the astronomer to translate the simple light curve into a long list of desired observations. Each observation corresponds to a point on the light curve where there is currently insufficient data. Since the light curve repeats infinitely into the future, our astronomer is forced to produce a potentially large number of observation requests that correspond to precisely the same point on his hypothesized light curve. Traditional scheduling techniques require this conversion from light curve to observation set, since scheduling is the business of sequencing the elements of such sets. Traditional scheduling techniques have nothing useful to say about a light curve hypothesis, since the number of observation requests that can be generated by such a curve cannot be bounded in advance.

We are proposing a system that can accept a light curve hypothesis from an astronomer and use this light curve to generate and schedule observation requests. Our system should be able to compare data obtained under previous observations with what is predicted by the hypothesis. At a given point in time the data gathered up to this point will give rise to one of two cases: either the data is consistent with the hypothesis, in which case some next observation should be generated and scheduled; or the data is inconsistent with the hypothesis, in which case the astronomer should be notified and asked for a new hypothesis. This approach suggests that the business of scheduling is not simply looking ahead and sequencing pre-selected actions. A scheduler must additionally "remember behind" so that it can select observing actions that are relevant to the scientific task at hand.

Filling out light curves is simply one example illustrating the importance of having a model of the scientist's goals, hypotheses, or expectations. Previous work in planning has studied the use of experiment templates, or "skeletal plans", and demonstrated that science often operates according to a small number of highly parameterized procedures (Friedland & Iwasaki, 1985). While this skeletal planning work was done in the domain of molecular genetics, we feel that the same insight applies to astronomy. We expect to be able to find a reasonably small number of procedural templates, and will study how these can be used as a specification language for our planning and scheduling system.

Current Status, Plans

We plan to implement an integrated planning, scheduling, and control system for a 16-inch photoelectric telescope. We are using our existing theory and general architecture as a guide (Bresina & Drummond, 1990; Drummond, Bresina, & Kedar, 1991; Drummond & Bresina, 1990a; Drummond & Bresina, 1990b). To keep things simple, we are initially focusing purely on photometry (Genet & Hayes, 1989; Hall & Genet, 1988). We are doing this to better focus the class of scientific goals considered. Since we are attempting to implement automation that addresses the entire telescope planning, scheduling, and control problem, we feel it is reasonable to simplify the science goals somewhat. We have access to a telescope simulator and plan on evaluating our system's performance against this in the first instance. Once the system achieves acceptable levels of performance on the simulator, we plan to deploy it on the real telescope, and we will make this telescope available to the astronomical community. Our goal is to have our system available via the InterNet, such that interested astronomers can simply Email observation request files; we hope to be able to provide overnight results from the telescope via return Email. Interested parties should contact the authors for more information.

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