Research notes on Telescope Scheduling

Harpreet Singh

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“A Framework for Telescope Schedulers: With Applications to the Large Synoptic Survey Telescope”

LSST

The Large Synoptic Survey Telescope (LSST) is a large, ground-based optical survey that will image half of the sky every few nights from Cerro Pachon in Northern Chile. LSST comprises an 8.4 m primary mirror and a 3.2 gigapixel camera. With a 9.6 deg^2 field of view, it will visit each part of its 18,000 deg^2 primary survey area about 1000 times over the course of 10 yr. Each visit will likely comprise a 15 s pair of exposures with a single-visit depth of about 24.5 mag (AB) (in the six bands u, g, r, i, z, and y). The revolutionary role of this telescope calls for no less than optimal operation.

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There are four primary science drivers for the LSST project: the characterization of dark energy through the multiple cosmological probes (e.g., gravitational weak lensing, luminosity distances from Type Ia supernovae, and baryon acoustic oscillations), mapping the 3D distribution of stars within our Galaxy, a census of solar system objects within the solar system, and a detailed study of the transient and variable universe. Each of these objectives has a different set of constraints and requirements on how the observations are made (e.g., the cadence of the observations, the number of filters as a function of time, the acceptable air-mass range for an observation).

Problem Defination and Constraints

Earlier algorithmic approaches to the scheduling of groundbased telescopes are heavily based on observation proposals. Proposals are handcrafted sequences of scripted astronomical observations. They are generally tested only for feasibility (e.g., that a set of fields were visible, or lie within a specified air-mass range, or within a window in time), but not necessarily for optimality.

More recently, the development of more expensive groundbased instruments with complex missions made it impossible to rely solely on handcrafted proposals. The need for more efficient use of the instrument’s time led to the development of decision-making algorithms to optimize their science output. The scheduling at the single-visit level is referred to as optimal scheduling and it is stated that the optimal scheduling requires reevaluating the future sequence of observations once it is interrupted, but the necessary extra computation is neither affordable nor fast enough. However, in this paper we show that the scheduling in the single-visit level, optimal scheduling, can be quickly recovered after an interruption, if a memoryless framework is used. Thus, the optimality does not necessarily need to be sacrificed because of the limited computational resources.

To run a ground-based telescope with multiple science objectives, such as LSST, the scheduler has to offer *controllability*, *adjustability*, and *recoverability*

MORE TO ADD!!!!!!!!!!!!

“The zwicky transient facility: Surveys and scheduler”

Introduction and ZTF

In this work we consider the specific scheduling problem of a single-telescope ground-based wide-field imaging survey. We are focused on its application to the Zwicky Transient Facility project, which imposes some specific requirements, but our formalism is relevant for other time-domain surveys, such as those conducted with the LSST, the Dark Energy Camera, and Hyper Suprime-cam. Minor modifications would enable its use by multi-telescope surveys such as the Asteroid Terrestrialimpact Last Alert System, PanSTARRS, the All-sky Automated Survey for Supernovae, and BlackGEM.

Simply stated, the scheduling problem to be solved is to determine which fields to observe in what order, with a goal of maximizing an objective function while achieving the desired temporal spacing of observations (“cadence”). Optimizing the survey schedule provides a greater quantity of high-quality data, increasing the scientific output of the survey.

Specific requirements imposed on the ZTF scheduler included the following:

1. Select pointings from a fixed field grid
2. Operate in both simulation mode and on-sky using the same scheduling code.
3. Conduct several surveys, maintaining strict independence of their observations and balancing observing time between programs.
4. Provide interfaces for conducting TOO observations and monitoring scheduler status.
5. Recover appropriately from interruptions and weather losses.
6. Maximize an observing efficiency metric and prioritize cadence control.

Problem

The ZTF scheduler attempts to maximize the total number of exposures taken per night, weighted by the spatial volume probed by each, and subject to the constraints imposed by program balance and cadence. If the observing cadences are well chosen, maximizing this quantity will maximize the transient discovery rate. Bellm explores the relationship between the chosen observing cadences, a survey's volumetric and areal survey rates, and the transient detection rate.

Neglecting cosmological effects, the volume V_{lim} probed by a given exposure is proportional to the cube of the limiting distance d_{lim} a transient of fiducial absolute magnitude M can be detected given the limiting magnitude $m_{lim} : V_{lim} \propto d_{lim}^3$, where $d = 10^{0.2(m_{lim}-M+5)}$pc. The volumetric weighting per exposure is thus

$$V = 10^{0.6(m_{lim}-21)},$$

where we have absorbed constant factors and normalized to a convenient limiting magnitude for ZTF.

Constraints

This weighting combines in a self-consistent way many factors that are intuitively relevant for assessing whether an image is "good": the limiting magnitude depends on the filter, seeing, airmass, and sky brightness. We use a model to predict the variation in limiting magnitude and hence our metric as a function of these time-varying inputs. Accordingly, our optimization will naturally select exposures near zenith and away from the moon; but by combining them in a single scalar the optimization can coherently trade these factors against one another as they change through the night.

Our metric deliberately does not contain factors that account for relative scientific priority or cadence. These concerns have no general quantitative relationship to our objective function or each other.14 Instead, we use the structure of the optimization algorithm (Section 4) to impose these constraints.

Our optimization algorithm (Section 4) maximizes the summed metric over an entire night. In cases where a greedy algorithm is more convenient, it is simple to define an instantaneous volumetric survey speed,

$$V \propto 10^{0.6m_{lim}}/(t_{exp} + t_{OH})$$

that normalizes the volume probed in an exposure by the time required to obtain it, a sum of the exposure time t_{exp} and any readout or slew overheads t_{OH}.

Future Improvements

Extra notes and observations

1. In a lot of papers, it was observed that the observation requests were weighted by a priority assigned to them by a committee or group.

References

[1] Eric C Bellm et al. “The zwicky transient facility: Surveys and scheduler”. In: *Publications of the Astronomical Society of the Pacific* 131.1000 (2019), p. 068003.

[2] Elahesadat Naghib et al. “A Framework for Telescope Schedulers: With Applications to the Large Synoptic Survey Telescope”. In: *The Astronomical Journal* 157.4 (2019), p. 151.