Research notes on Telescope Scheduling

Harpreet Singh

2021

[1] "The zwicky transient facility: Surveys and scheduler"

Introduction and ZTF

ZTF: https://www.ztf.caltech.edu/

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.

Python Implementation: https://github.com/ZwickyTransientFacility/ztf_sim

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. Instead, we use the structure of the optimization algorithm to impose these constraints.

Our optimization algorithm 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,

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

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}.

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.

We construct the observing schedule by dividing the night into a set of temporal blocks T. The set of available filters in the camera is F. The set of Request Sets from all observing programs P is R.

$Y_{rtf} = 1$ if Request Set $r \in R$ has an observation scheduled at time block $t \in T$ using filter $f \in F$, and 0 otherwise

$Y_s = 1$ if the filter changes between time blocks $s \in T$ and $s+1 \in T$, and 0 otherwise.

The optimizer maximizes an objective function which sums the volume-weighted (formula specified in the equation above) number of exposures scheduled through the night. Because of how we constrain the number of exposures in a temporal block, we also penalize for exposures lost due to filter changes. The objective function is thus

$$max\left(\left(\sum_{r\in R}\sum_{t\in T}\sum_{f\in F} V_{rtf}Y_{rtf}\right) - \left(\frac{t_{filt}}{t_{exp}+t_{OH}} w \sum_{t\in T} Y_s\right)\right)$$

where t_{filt} is the time required to change filters and w is a weight factor ($\approx (V_{rtf})$) accounting for the value of each lost exposure.

[9] "Dispatch approaches for scheduling radio telescope observations"

Introduction and related work

We consider strategies for minimising the time required to observe a fixed set of pulsars, which provides an excellent example of scheduling in an unpredictable environment. First, owing to scintillation, the intensity of a pulsar signal is variable and random; therefore, the decision to abort or prolong an observation can be made only after some fraction of the scheduled observation has been completed. Second, observations may be interrupted by radio frequency interference or when the source sets below the horizon. Some sources are visible for more or less time depending on their declination and the latitude of the observing telescope. Formulating the problem in these terms leads to a highly dynamic shortest path problem with uncertainty. Unlike other documented telescope scheduling approaches, we demonstrate how a simple earliest setting policy achieves sets of pulsar observations in a rather short timespan.

This paper contains a lot of really useful information from other papers. Some points from this paper are listed in the *Extra notes* section below. **Definately give this another read**

Telescope arrays have motivated the development of a new generation of scheduling algorithms. ALMA, an array of 66 telescopes, has been operating since 2012, while the construction of the Square Kilometre Array (SKA) is planned to begin in 2020. The SKA has motivated the Master's thesis by Buchner [2], who proposed a number of scheduling policies, such as choosing the task with the highest priority, the task with the smallest observation time, the task that continues from the preceding time slot, and compared them with the performance of a Genetic Algorithm (GA). A Mixed-Integer Linear Program was also applied but abandoned for excessive running time. Buchner's objective function maximises the observation time weighted by the task priorities.

Our study is also motivated by the SKA and the optimal scheduling of large scale pulsar surveys and pulsar monitoring programs that will be undertaken with the next generation of radio telescopes. In this paper, we focus on the problem of monitoring a large number of pulsars in a dynamic environment.

Constraints, variables and assumptions

Two physically-motivated effects are introduced to bring variability to the scheduling problem:

1. Pulsar scintillation impacts on the sensitivity of the observation and may lead to either an extension of the integration time or premature abortion. Scintillation is random and the decision to continue, extend or abort can be made only after some fraction of the scheduled observation has been completed.
2. Interference by satellites can render observations useless and, in extreme cases, damage observatory equipment. Given up-to-date ephemerides, satellite positions can be predicted and observations that would be corrupted by them can be avoided.

Although we focus on pulsars, these two classes of dynamic environmental influences (random and predictable) are quite generic and applicable to other astronomical scheduling problems.

In addition to the introduction of a dynamic environment, several aspects of our work differ from previous studies (such as that by Buchner):

- All approved observations have to be carried out, hence the priorities of observations do not contribute to the objective function.
- Continuous time is assumed rather than slots.
- The initial formulation assumes a single telescope.
- The schedule is simulated in conditions modelled on actual observation conditions to obtain a likely outcome given the uncertainty of the problem.

Consequently, we have chosen to study the observation of a set of pulsars as an example of a highly dynamic telescope scheduling problem with uncertainty.

Problem and objectives

In astronomy, observing programmes can be broadly classified as targeted observations of known sources and systematic scans of areas of the sky, such as surveys that aim to map a large-scale structure or discover new objects.

Astronomers submit proposals for observations to telescope operators who approve proposals based on their merit and allocate telescope time. The proposals detail the level of priority of a target, its location and desired observation time. Generally, proposals are assessed biannually, to be processed over the subsequent 6 months. Solar et al. [11] describe the proposal process in detail.

The observation period can be fully automated, interactive or manual. The goal of this work is to propose a scheduler capable of automating the process and eliminating the need for while leaving open the possibility of human intervention. To evaluate the effectiveness of the scheduler, we assume a data set with targets and observation times and appraise the outcome by the overall duration.

Take a look at point 5 of Extra notes

The optimisation goals of this study are

- Minimisation of the inactivity periods.
- Maximisation of time assigned to observations.
- Maximisation of the quality of the data.

In this study, we investigate how the time spent on collecting a defined set of observations can be minimised. The quality of the data is treated as a constraint: If the scintillation of a target is found to be poor on arrival, the observation is postponed. In cases of mediocre quality, the observation time is extended to compensate by providing more data.

Could also add a *future works* and *summary* section.

[10] "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.

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*

This one is incomplete. There is more to add.

[7] "Cost-efficient scheduling of FAST observations"

This one is incomplete. There is more to add.

Extra notes

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.

2. In astronomy, observing programmes can be broadly classified as targeted observations of known sources and systematic scans of areas of the sky, such as surveys that aim to map a large-scale structure or discover new objects.

3. A 2010 survey by Mora and Solar [8] presents algorithms used by the Hubble Space Telescope, Very Large Telescope in the Chilean desert, the Subaru Telescope on Hawaii, Gemini Observatory, Stratospheric Observatory for Infrared Astronomy mounted on a Boeing 747, the Green Bank Telescope in West Virginia and the Atacama Large Millimetre/submillimetre Array (ALMA). They conclude that 'None of the existing professional astronomical scheduling solutions provides a full automatic scheduler under changing conditions and for several telescopes, and none of the existing algorithms has solved the dynamic priorities problem for this case.

4. A more recent survey by Colome et al. [3] provides a concise listing of all algorithms employed for scheduling in different telescopes. An update was provided by Solar et al. [11] in 2016 with a review of heuristic-based approaches such as Simulated Annealing and Ant Colony Optimisation.

5. Most approaches in the literature describe telescope control software with scheduling components without describing a clear objective function. Lopez-Casado [6] formulated an optimisation goal consisting of a user score and the percentage of observations executed (relative to the planned observations). Colome´ et al. [5] formulated a merit function as a weighted sum of observation conditions (height above the horizon, moon brightness and distance, best observation time, distance from previous target and proposal priority), environment conditions (photometric quality) and proposal history (to counterbalance proposal

priorities by time already spent on the proposal). Colome et al.'s [4] multiobjective approach considers minimising slew time, maximising priority, minimising downtime and minimising zenith angle which affects the image quality in optical telescopes.

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] Johannes Buchner. "Dynamic scheduling and planning parallel observations on large Radio Telescope Arrays with the Square Kilometre Array in mind". PhD thesis. Auckland University of Technology, 2011.

[3] Josep Colome et al. "Research on schedulers for astronomical observatories". In: *Observatory Operations: Strategies, Processes, and Systems IV*. Vol. 8448. International Society for Optics and Photonics. 2012, p. 84481L.

[4] Josep Colomé et al. "Artificial intelligence for the CTA Observatory scheduler". In: *Observatory Operations: Strategies, Processes, and Systems V*. Vol. 9149. International Society for Optics and Photonics. 2014, 91490H.

[5] Josep Colomé et al. "The TJO-OAdM robotic observatory: the scheduler". In: *Software and Cyberinfrastructure for Astronomy*. Vol. 7740. International Society for Optics and Photonics. 2010, 77403K.

[6] Carmen López-Casado, Carlos Pérez-del-Pulgar, and Víctor F Mũnoz. "Development of a Scheduler for Heterogeneous Telescope Networks with Different Decision Algorithms". In: *International Conference on Practical Applications of Agents and Multi-Agent Systems*. Springer. 2016, pp. 375–378.

[7] Qi Luo et al. "Cost-efficient scheduling of FAST observations". In: *Experimental Astronomy* 45.1 (2018), pp. 107–126.

[8] Matias Mora and Mauricio Solar. "A survey on the dynamic scheduling problem in astronomical observations". In: *IFIP International Conference on Artificial Intelligence in Theory and Practice*. Springer. 2010, pp. 111–120.

[9] I Moser and Willem van Straten. "Dispatch approaches for scheduling radio telescope observations". In: *Experimental Astronomy* 46.2 (2018), pp. 285–307.

[10] 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.

[11] M Solar et al. "A scheduling model for astronomy". In: *Astronomy and Computing* 15 (2016), pp. 90–104.