Southern Horizons in Time-Domain Astronomy
Proceedings IAU Symposium No. 339, 2019
E. Griffin, ed.

doi:10.1017/S1743921318002478

ANTARES: Time-Domain Discovery in the Era of LSST†

M. Soraisam and T. Matheson

National Optical Astronomy Observatory, Tucson, AZ, USA
email: soraisam@noao.edu

Abstract. The revolution in time-domain astronomy has arrived. Large-scale surveys are detecting events at an unparallelled rate, and discoveries of new and exotic objects abound. In just a few short years, the Large Synoptic Survey Telescope will begin operations in Chile. At that point, the rate of production of time-domain events will jump by a factor of at least a hundred. The traditional techniques of handling each detection individually will not scale to those current and future productions. The *ANTARES* project is a joint venture between NOAO and the University of Arizona Computer Science Department to develop a software infrastructure system to process time-domain events automatically at the scale and rate that LSST will generate them.

Keywords. Methods: statistical, techniques: miscellaneous, surveys

1. Introduction

The Large Synoptic Survey Telescope (LSST) is expected to detect a prodigious number of transient events each night. According to Ridgway *et al.* (2014) the predictions range from 10^5 to 10^8 per night. LSST itself will provide a notification of an event (which is currently defined as a 5-σ deviation – including changes in brightness or position – as quoted in the LSST Data Products Definition Document (http://ls.st/dpdd). While many of those events will not require immediate attention for follow-up observations, there will be a significant number that would benefit from rapid follow-up. To that end, we are developing a software tool that would act as a *broker* (see below) for the alerts from LSST and other surveys. The project, the Arizona-NOAO Temporal Analysis and Response to Events System (*ANTARES*, https://www.noao.edu/ANTARES/), is a joint effort between NOAO and the University of Arizona Computer Science Department; earlier descriptions can be found in Saha *et al.* (2014, 2016).

The software infrastructure necessary to filter alerts acts as an intermediary between the source of alerts and the consumer (e.g., a follow-up system), adding value through annotation from other sources of information and past history, characterising the alerts, applying a ranking of interest to the consumer, and distributing the alerts to the consumer. Such an intermediary in the commercial world has come to be known as a broker. This term has been adopted by the astronomical community; see Borne (2008).

There are many examples of software systems that have performed at least some of the functionality visualised for the *ANTARES* project. The system with the functionality that represents the most general case for a broker is SkyAlert (Williams *et al.* 2009). For PTF, an automated system sorted alerts into three categories (Bloom *et al.* 2012) before they were passed along for human inspection through a web interface called

† Presented by Thomas Matheson

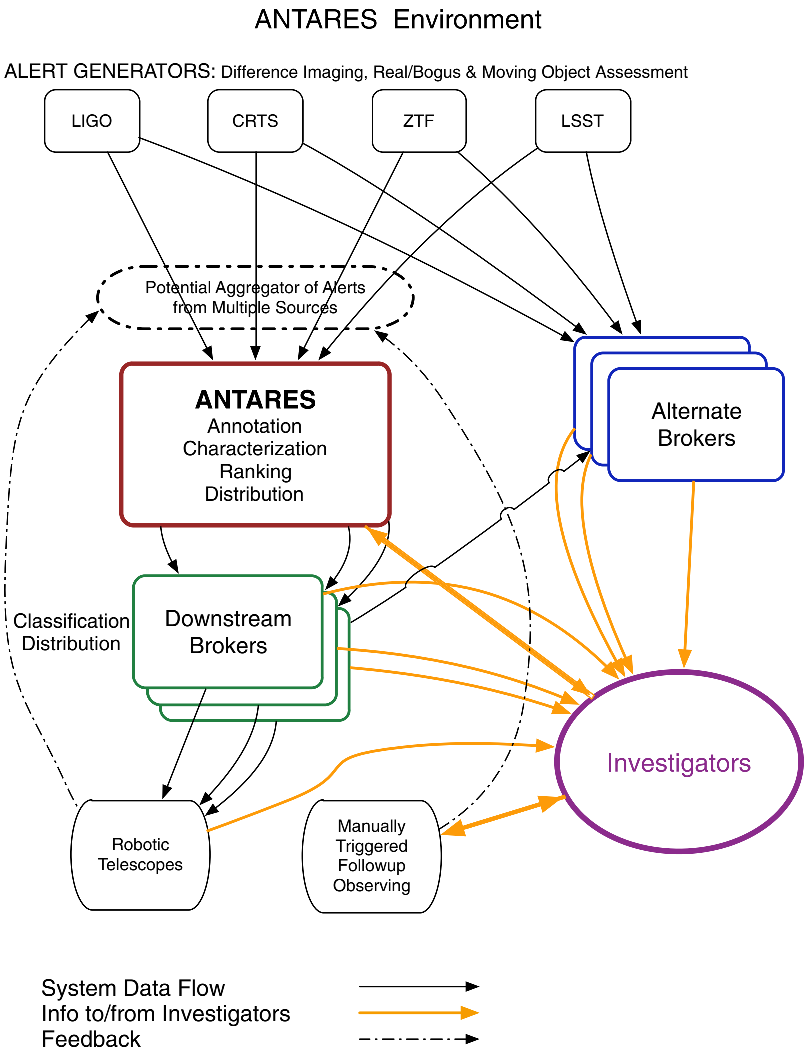

Figure 1. Schematic diagram of how *ANTARES* fits into the larger time-domain ecosystem.

the PTF Marshal. Las Cumbres Observatory, which has become a leader in the development of software tools for time-domain astronomy, hosts the Supernova Exchange (SNEx) at http://supernova.exchange, and the Near-Earth Object Exchange (Lister *et al.* 2016). Other examples include the ExoFOP project (https://exofop.ipac.caltech.edu/), run by NASA's Infrared Processing and Analysis Center for coordinating studies of exoplanets, and the NEO confirmation page, NEOCP, run by the Minor Planet Center (see /www.minorplanetcenter.net/iau/NEO/toconfirm_tabular.html) under the auspices of the IAU.

ANTARES is designed to fit into a larger time-domain infrastructure ecosystem. Fig. 1 illustrates schematically how it does that. The first component is the alert generators, which provide the alerts to the brokering systems. The alert generators take the astronomical images, perform the image subtraction with reference images (e.g., Alard & Lupton 1998), and identify the sources that have changed. Image subtraction is imperfect, so there is often a considerable number of false detections. Distinguishing between a real astrophysical source and an artefact of subtraction is best accomplished by the people

https://doi.org/10.1017/S1743921318002478 Published online by Cambridge University Press

who know well the camera and its characteristics. There has been a real effort to develop techniques for this distinction, sometimes referred to as the real/bogus test, after the methods of one of the pioneers in the use of automatic techniques for evaluating alerts (Bloom *et al.* 2012). There continue to be ongoing developments of tools to distinguish artefacts (e.g., Wozniak 2014; Wright *et al.* 2015; Goldstein *et al.* 2015; du Buisson *et al.* 2015; Klencki *et al.* 2016; Morii *et al.* 2016; Masci *et al.* 2017). Finding moving objects is outside the scope of *ANTARES*, however, and is an on-going task for the LSST project. It requires looking at multiple images from a given night and connecting tracks. (That is a very different approach from how *ANTARES* considers alerts).

Once the *ANTARES* system has performed its tasks of annotation, characterisation, ranking and subsequent distribution, the alerts flow out to the customers of the service. They can include other brokers (perhaps even copies of the *ANTARES* architecture tuned to specific alternate filtering goals), robotic telescopes, or astronomers. The coordination or management of those downstream resources is outside the scope of *ANTARES*. Feedback from the follow-up observations and analyses can eventually flow back into the *ANTARES* system so that future decisions can be refined with more knowledge. That feedback could be ingested as external 'alerts'.

2. The *ANTARES* Event Broker

ANTARES is a distributed computing system running on a cluster of multiple machines. The schematic representation of the *ANTARES* architecture is shown in Fig. 2. Alerts are ingested from a time-domain survey (in this case LSST). There are three main components of the system which then operate on the alerts. First, the alerts are annotated with information from sources external to the survey that generated them. Compilations of astronomical catalogues are incorporated into the *ANTARES* system to facilitate rapid cross-referencing so that alerts can be associated with known astronomical objects via the AstroObject catalogues. Those catalogues include multi-wavelength data. If an alert has occurred at the same position on the sky, any previous association or set of calculated values will be stored by *ANTARES* in the Locus-Aggregated Annotated Alert catalogue, which allows us to recreate the time-history of an object.

Once annotation via association is complete, we begin to characterise the alert using the features associated with it. Features include information (if any) about the object such as the spectral type of the star or the type of galaxy that hosts the alert. The past history of alerts provides other value-added features such as time-scale, amplitude, colour, etc. Some features can be calculated from the other features assigned during object association, such as distance from a nearby galaxy.

The next major task of the system is to characterise and filter the alerts using the features associated with each alert. The main technique is to compare the features of an alert with features of known astronomical objects. We name the database of features of known objects 'the Touchstone'. We use various algorithms to compare the features from a given alert to the features available in the Touchstone to identify what something might be, or (of even more interest) identify something that doesn't match any known object. Various combinations of filters then operate on the features to characterise objects further into broad categories that will be of general interest to astronomers.

These ranked alerts are then distributed back to the astronomical community, either to users, other brokers, or directly to scheduling systems. The goal of the prototype was to find the rarest object in an incoming set of alerts. By tuning the filters, the goals can be reoriented to match any particular interest on the part of the community.

As at the time of writing, we are in the process of expanding the system beyond the current prototype phase and into a production-ready model.

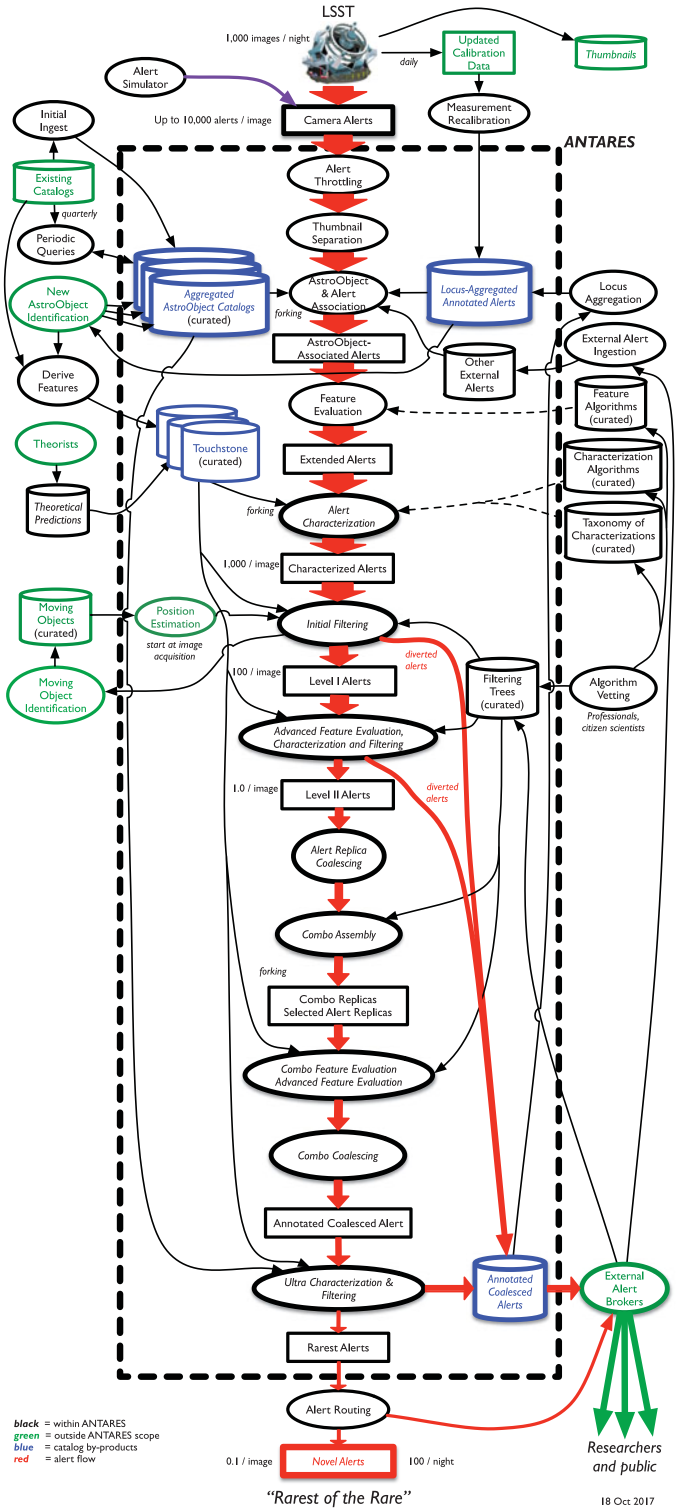

Figure 2. Schematic representation of the *ANTARES* system architecture.

https://doi.org/10.1017/S1743921318002478 Published online by Cambridge University Press

References

Alard, C., & Lupton, R. H. 1998, *ApJ*, 503, 325
Bloom, J. S., *et al.* 2012, *PASP*, 124, 1175
Borne, K. D. 2008, *AN*, 329, 255
du Buisson, L., Sivanandam, N., Bassett, B. A., & Smith, M. 2015, *MNRAS*, 454, 2026
Goldstein, D. A., *et al.* 2015, *AJ*, 150, 82
Klencki, J., Wyrzykowski, L., Kostrzewa-Rutkowska, Z., & Udalski, A. 2016, *AcA*, 66, 15
Lister, T. A., Greenstreet, S., Gomez, E., Christensen, E., & Larson, S. 2016, in: S. R. Chesley, A. Morbidelli, R. Jedicke, & D. Farnocchia (eds.), *Asteroids: New Observations, New Models*, *Proc. IAUS 318* (CUP: Cambridge, UK), p. 321
Masci, F., *et al.* 2017, *PASP*, 129, 4002
Morii, M., *et al.* 2016, *PASJ*, 68, 104
Ridgway, S. T., Matheson, T., Mighell, K. J., Olsen, K. A., & Howell, S. B. 2014, *ApJ*, 796, 53
Saha, A., Matheson, T., Snodgrass, R., Kececioglu, J., Narayan, G., Seaman, R., Jenness, T., & Axelrod, T. 2014, *Proc. SPIE*, 914908
Saha, A., *et al.* 2016, *Proc. SPIE*, 99100F
Williams, R. D., Djorgovski, S. G., Drake, A. J., Graham, M. J., & Mahabal, A. 2009, *ADASS XVIII*, 411, 115
Wozniak, P., 2014, in: P. R. Wozniak, M. J. Graham, A. A. Mahabal, & R. Seaman (eds.), *Proc. Third Hot-wiring the Transient Universe Workshop*, p. 209
Wright, D. E., *et al.* 2015, *MNRAS*, 449, 451