ANTARES: The Arizona-NOAO Temporal Analysis and Response to Events System

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1 Introduction

The Arizona-NOAO Temporal Analysis and Response to Events System (ANTARES) is a joint project of the National Optical Astronomy Observatory and the Department of Computer Science at the University of Arizona. The goal is to build the software infrastructure necessary to process and filter alerts produced by time-domain surveys, with the ultimate source of such alerts being the Large Synoptic Survey Telescope (LSST). Such a tool is often called a broker [2], as it acts as the entity between producers and consumers. ANTARES will add value to alerts by annotating them with information from external sources such as previous surveys from across the electromagnetic spectrum. In addition, the temporal history of annotated alerts will provide further annotation for analysis. These alerts will go through a cascade of filters to select interesting candidates. For the prototype, 'interesting' is defined as the rarest or most unusual alert, but future systems will accommodate multiple filtering goals. The system is designed to be flexible, allowing users to access the stream at multiple points throughout the process, and to insert custom filters where necessary.

2 The Problem

The rapid growth of time-domain surveys produces discoveries at an ever-growing rate. Current optical surveys, such as the Lick Observatory Supernova Search[1], the

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[1] http://astro.berkeley.edu/bait/public_html/kait.html

Catalina Real-Time Transient Survey[2], the Panoramic Survey Telescope & Rapid Response System[3], the Palomar Transient Factory (PTF and iPTF)[4], and the La Silla-Quest Variability Survey[5] generate transient alerts well beyond the available follow-up capacity. These projects have developed tools to filter their discoveries to focus on events of interest to each team. A good example of this is SkyAlert[6], a system that has solved many of the astronomical issues associated with adding value to alerts. SkyAlert enables users to create filters on alerts, including ancillary information on these alerts, in order to find relevant events. The PTF system also employs tools to identify interesting alerts [1]. The scale of time-domain alert generation, though, is quickly increasing. The Zwicky Transient Facility [9] will have more than 6 times the field-of-view of PTF, while time domain surveys with DECam on the Blanco telescope benefit not only from the 3 deg^2 field-of-view, but the depth attainable with a 4m-class facility. Moreover, transients are generated across the electromagnetic spectrum, from radio facilities such as LOFAR[7] to high-energy space-based observatories such as Fermi[8], making the overall problem that much more complex.

On the horizon is LSST [8]. With its 10 deg^2 field-of-view and $\sim$6m collecting area, the transient detection rate leaps by orders of magnitude. LSST will detect (with 5σ significance) $10^3 - 10^4$ alerts per image, or $10^6 - 10^7$ per night. A good fraction of these will be known variable stars or moving objects [14, 5] (see also Ridgway's contribution to these proceedings), but hidden among them will be rare and interesting objects that have relatively short lifetimes. Only with additional follow-up will these objects reveal their nature. These could range from short-lived phases of stellar evolution such as the final helium flash [6, 7] to superluminous supernovae [3] to electromagnetic counterparts of LIGO detections [15, 12]. Beyond these rare, but known or predicted, objects lies the great discovery space that awaits LSST. The superluminous supernovae were essentially unknown fifteen years ago and the discovery of dark energy was certainly surprising. Over its life, LSST will generate more than a billion alerts and some will be completely unknown and unanticipated objects. Without the ability to rapidly sort through millions of alerts each night and winnow them down to a reasonable number that can be studied in detail, we will lose these rare and potentially extraordinarily interesting objects. The astronomical community is becoming more aware of the necessity of such a tool [10].

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[2] http://crts.caltech.edu/

[3] http://pan-starrs.ifa.hawaii.edu/public/

[4] http://ptf.caltech.edu/iptf/

[5] http://hep.yale.edu/lasillaquest

[6] http://skyalert.org/

[7] http://www.transientskp.org/

[8] http://fermi.gsfc.nasa.gov/

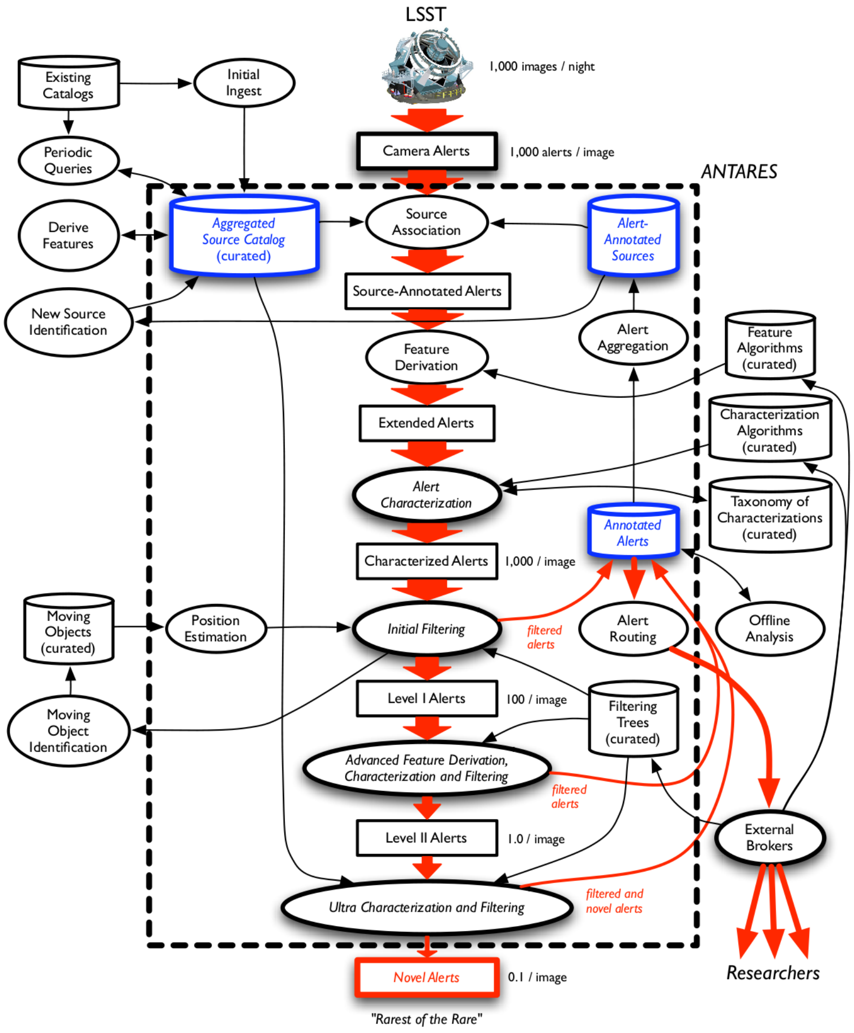

Figure 1: Basic architecture of the ANTARES system. The dashed box encompasses the processes that must keep up with the LSST frame-rate.

3 ANTARES

The knowledge we have about an alert, such as brightness, change in flux, Galactic coordinates, ecliptic coordinates, distance to nearest galaxy, etc., constitute features that can probabilistically characterize alerts. We emphasize that this is a broad characterization, not a specific classification. Classification will have to come from software systems further downstream. Because of the time-scale of LSST exposures, with a new image every ∼37 seconds, alerts must be processed rapidly to keep up with the data stream. Classification often requires more complex analysis and usually a more complete light curve [13, 4].

Figure 1 illustrates the main components of the ANTARES architecture. The overall design principles are open source and open access. The software will be available for anyone to implement and our implementation will be community driven. The alert stream can be tapped at many points throughout the system.

The first stage is annotation that adds value to the alerts. Source association is a critical step to incorporate relevant astronomical knowledge for each alert. Catalogs of astronomical information, as well as the LSST source catalog will be the basis for this source association. Examples include the 2MASS All-Sky Data Release[9], the Chandra Source Catalog[10], the NRAO VLA Sky Survey[11], the Sloan Digital Sky Survey[12], the NASA Extragalactic Database[13], and GAIA[14], among many others. Even the proximity to known sources can provide useful constraints. In addition, the history of flux measurements at the position, such as a light curve, will be valuable annotation. An efficient database that can be updated regularly is an essential element of the system. This will be a valuable astronomical resource on its own. As mentioned before, the SkyAlert system provides a similar annotation. The problem for the future is the scale of alerts and the resulting necessity of this efficient database being integrated into the system brokering alerts.

For many alerts, there will only be a small number of features available for characterization, especially for an initial detection. If there are not enough features for discrimination by filtering, we can apply a probabilistic expectation of variability based on position on the sky and known distributions of variability [14]. For a position, we can construct a variability probability density function and predict the likelihood of the alert as observed. With more data, more features become available and more complex filtering algorithms can be used.

ANTARES will then use multiple layers of filters to sort the alerts and find the rarest or most interesting among them (this is the focus of the prototype project). The other alerts are not discarded. Rather, they are diverted from the main filtering stream but are still accessible to other filtering systems, including, potentially, copies of the ANTARES system itself that are tuned to specific goals. In this way, custom filters can be applied, allowing users to isolate exactly which of the alerts is of interest to them and thus address many different goals. These community-derived filtering algorithms will be applied in a multi-step process, allowing for better management of computational resources. By characterizing the alerts, the number of dimensions

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[9] http://www.ipac.caltech.edu/2mass/releases/allsky/

[10] http://cxc.harvard.edu/csc/index.html

[11] http://www.cv.nrao.edu/nvss/

[12] http://www.sdss.org/

[13] http://ned.ipac.caltech.edu/

[14] http://sci.esa.int/science-e/www/area/index.cfm?fareaid=26

of feature space can be reduced. More complex filters can be applied to the smaller number of alerts after initial filtering stages.

The Arizona Machine-Experimentation Laboratory (AMELIE, Figure 2), provides a system for constructing and testing structural-causal models [11]. This essentially automates the scientific process and allows us to run experiments to test relationships among features, including relationships that have not yet been apparent. It can observe the operation of ANTARES and make it more efficient.

The goal for the prototype is to distinguish rare and unusual objects. Once it is operational, the next stage is to expand the scope to allow users to find any type of alert of interest to them. In principle, there could be many stages of the ANTARES system itself, processing different data streams over different time scales. The overall alert ecosystem could accommodate multiple alert input streams and thus find a general way to serve the astronomical community's needs.

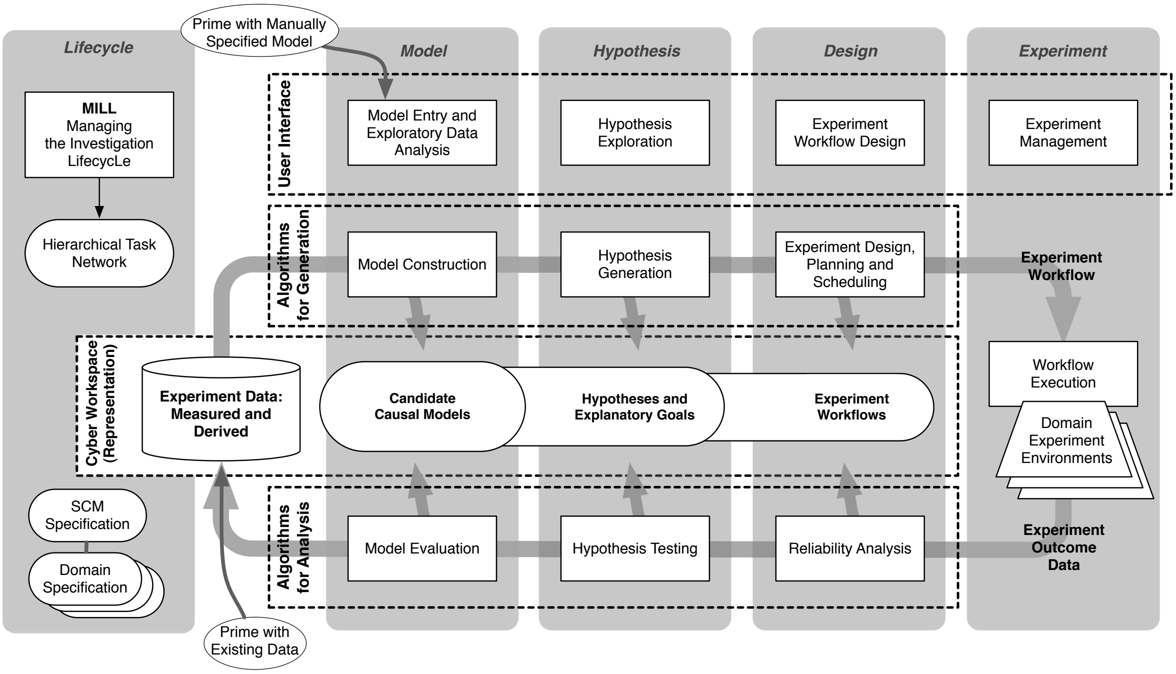

Figure 2: Basic architecture of AMELIE.

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