Project Proposal AA228
Title: Optical Space Observation Association
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Optical Space Observation Association

Space Situational Awareness (SSA) of higher orbit regimes such as Mid, High, and Geosyncronous Earth Orbit (MEO, HEO, and GEO) relies heavily on optical sensors to provide angles only measurements of resident space objects (RSOs). Radar measurements which provide a range estimate in addition to bearing angles are much less common for these higher orbit regimes and are primarily limited to measurements of RSOs in Low Earth Orbit (LEO). Optical space surveillance sensors can range from networks of relatively cheap commercial sensors such as the telescope networks run by a number of commercial data providers, large aperture primarily government owned telescopes, and even on orbit sensors which are unaffected by weather and provide much more angular diversity in measurements. In all cases the processing chain for the raw imagery collected by these sensors at a very high level looks something like the following:

Raw Imagery Processing:

1. Pull Out Detections: The software attempts to find illuminated pixels or clusters of pixels containing objects not deemed to be stars, planets, or sensor artifacts.
2. Correlation: The software next attempts to correlate detections to known objects by comparing the bearing angles of the detected objects to those expected for known objects in it's current catalog of RSO orbit states. Any remaining detections that were not able to be correlated are tagged as Un-Correlated Object (UCO) detections. UCOs can be caused by false positive detections, a known object for which the current catalog knowledge is poor, or an unknown satellite or piece of debris that is not in the catalog.

Since a sensor typically takes a series of images in quick succession and stitches together 'tracks' out of the detections, each UCO detection is a series of bearing angles over typically a short duration. The duration that a single UCO is tracked could be on the order of seconds or minutes, and in rarer cases even hours. In the case that the UCO is tracked for only a short time, because of the short observed arc and angles only nature of the measurements, it is likely to be infeasible to determine the orbit of the unknown object with enough accuracy to re-task sensors to perform follow on collects. Without determining the orbit the object remains lost and will likely show up in subsequent collects as another UCO, exacerbating the problem of maintaining situational awareness.

The challenge being tackled in this project is to take a large group of simulated but realistic UCO tracks, on the order of tens of thousands, and determine with no apriori knowledge which tracks are statistically likely to be of the same RSO. This problem is known as UCO Association. Once multiple tracks, ideally from angularly disparate sensors or with great temporal separation, are associated, a much more accurate orbit can be fit to the unknown object. If this orbit is accurate enough to allow for follow up collections, the UCO can be confirmed and the orbit can be refined further, leading to a new object, or recovered lost object, being added to the catalog and regularly maintained. Several expert systems exists that perform UCO association, but to the authors knowledge an AI approach has not yet been applied to the problem.

There are many potential approaches to this problem. The authors have already experimented with a deep learning approach that classifies triplets of observation tracks as being from the same RSO or not with an associated score for each possibility. We anticipate refining this approach as well as experimenting with others.

Given the complete lack of apriori knowledge about the RSOs that are represented in the detections, this problem has a high degree of uncertainty. We believe this problem also to be an interesting decision making problem, as a balance must be struck between avoiding false positive hypotheses and leaving potential associations on the table. In an eventual deployment, any UCO association that is made must then be sent to a computationally expensive initial orbit determination process to attempt to solve for the orbit. Hence, false positive associations have a cost in terms of computing time. Likewise missed potential association have an opportunity cost.