Transient Photometry with Star Trails

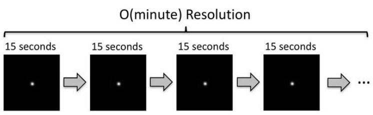
David Thomas
dthomas5@stanford.edu

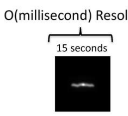
Summary

We propose a new method that enables existing large ground-based telescopes to be used for transient astrophysics. The method consists of operating the telescope without tracking and using deep learning to detect transient sources in the resulting star trail images.

Star Trails

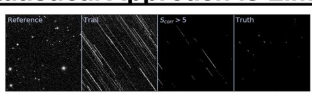
Telescopes rotate during their exposures to counter the Earth's rotation. When the telescope does not track, the images become trailed. The trails in the image allow us to measure flux differences (photometry) with much finer time resolution.





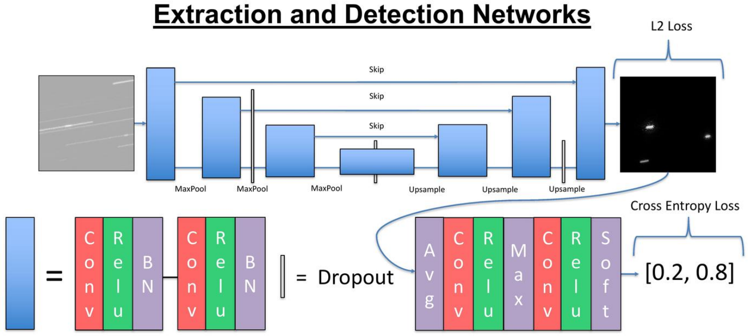
By using this technique on a large ground-based telescope like the Large Synoptic Survey Telescope (shown above) we will be able to rapidly scan large regions of the sky (~10,000 sources/image) for transient physics.

Statistical Approach is Limited



Our statistical approach produces many image artifacts and requires both a reference and trail image. Not only do we aim to improve on this performance with deep learning, we also hope to do away with the need for reference images.

Extraction and Detection Networks



Data

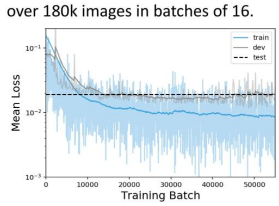
We use high fidelity and computationally expensive physics simulations to produce realistic images. Each image is a 2D matrix of photon counts. We have modified the simulator to produce trail images and labels and to simulate transient sources. The labels contain only the excess photons resulting from transient sources. We use a variety of techniques to augment our data:

- Simulate 100 4000 x 4072 background images (20 cpu-hour / image).
- Simulate 10 4000 x 4072 foregrounds for each background image (1 cpu-hour / image).
- Add mask onto background with small position dithering.
- Randomly crop to 512 x 512.
- Down-sample to 256 x 256.
- Rotate 0,90,180, or 270 degrees and/or flip.
- Add Poisson noise.
- Log normalize.

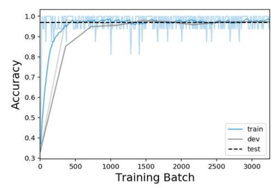
We use separate backgrounds for the (i) train set and the (ii) dev and test sets. The extraction dataset is (180k train, 200 dev, and 200 test). The detection dataset is (10k train, 100 dev, 100 test).

Training

We train the extraction network for 5 epochs over 180k images in batches of 16.



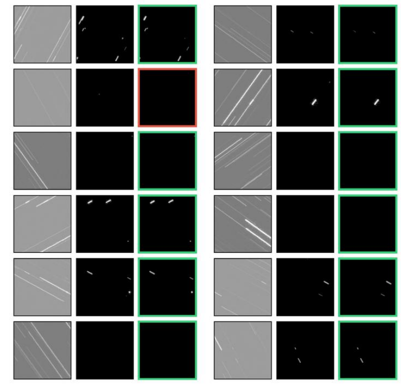
Then we use output from the extraction network to train the detection network for 5 epochs over 10k extraction outputs in batches of 16.



Our Simulation Code: bitbucket.org/davidthomas5412/phosim_release

Discussion

Our end-to-end network achieves 97% accuracy on the test set of images. The only common pattern in the few images that our network classifies incorrectly are that they are particularly difficult. While we have not yet completed blind tests that would determine human level accuracy on this task, we believe that the network's performance is already beyond this milestone.



Future Work

We are very excited to continue working on this project. Here are our next steps, some of which we have already begun:

- Characterize our method in terms of the durations and magnitudes of the transient events it can detect.
- Measure human level performance on this task.
- Use the Blanco 4-m telescope at the Cerro Tololo Inter-American Observatory to test our method on real data.