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Detection performance of dynamic correlation processors using de-noised signal space-spanning templates

D. Dodge, Lawrence Livermore National Lab (dodge1@llnl.gov)

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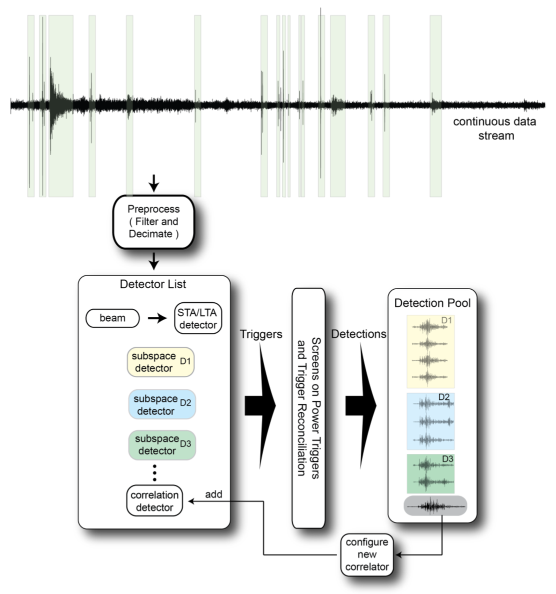
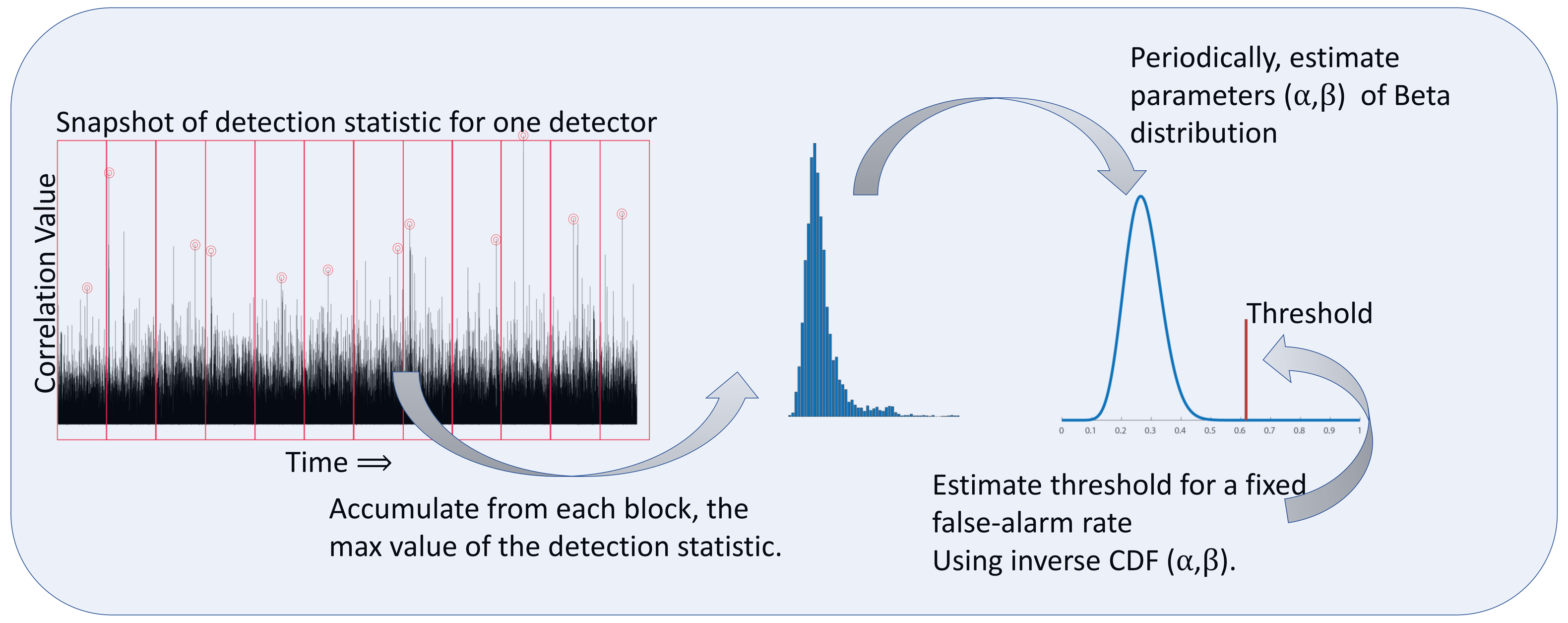
Introduction (1)

A dynamic correlation processor (DCP) is a system intended to create correlation detectors from waveforms observed in a data stream and, thereafter, to apply those detectors to the stream. Typically power (e.g. STA/LTA) detectors are used as "boot detectors" to find new waveform patterns. The key component of the framework is a bank of detectors that grows in time as new waveform patterns are encountered. The system is initialized with a small number of power detectors and thereafter marches through the stream, processing the data in consecutive, contiguous blocks.



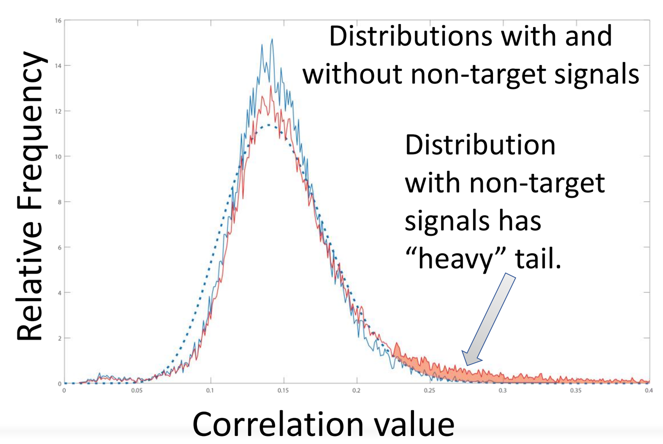
For each block, each detector calculates a detection statistic that is scanned for excursions above a threshold to produce triggers. When several detectors trigger on the same event, triggers are reconciled based upon temporal coincidence. A set of rules governs which among possibly several simultaneous triggers should be selected as a valid detection. The rules are simple:

- correlation triggers always are selected over power detector triggers,
- for triggers belonging to a single detector type (correlation or power), the trigger with the largest detection statistic is selected.



It is often (usually?) the case that the signal space consists of more than just noise and target signals. When this prevails, a correlation detector is likely to detect both target and non-target signals.

Because the detectors of a DCP compete for detections, it seems likely that a DCP deliberately constructed to exhaustively sample the signal space around a target can successfully avoid most non-target detections. Such a configuration constitutes a generalized likelihood ratio test detector.



(GLRT) detection processing using a DCP (2)

Implementing Generalized Likelihood Ratio Test (GLRT) detection processing using a DCP (2)

Assume that the data in the detection window satisfies one of two hypotheses: $\mathcal{H}_0$, that the data consist wholly of background noise (zero-mean, normally distributed), or $\mathcal{H}_1$, that they consist of signal plus noise:

$$\mathbf{r}[n] = \begin{cases} \eta[n]\ ; & \mathcal{H}_0 \\ \mathbf{s}_\theta[n] + \eta[n]\ ; & \mathcal{H}_1 \end{cases} \quad (1)$$

By adding the unknown parameter θ to the data model, we declare our intention to detect any and all signals in a class. The class might be chosen as the set of all signals historically recorded by the collection of observing stations.

The signal index is not the only unknown parameter in the signal model.

$$\mathbf{s}_\theta[n] = A\mathbf{u}_\theta[n] \quad (2)$$

A is an unknown scaling for the waveform from a particular event, assumed to be deterministic, and $\mathbf{u}_\theta[n]$ is the unit-energy waveform template characterizing propagation from the source, indexed by θ, to the observing stations.

Several detection criteria lead to detectors structured on a likelihood ratio:

$$\Lambda(\mathbf{r}) = \frac{p_1(\mathbf{r})}{p_0(\mathbf{r})} \quad (8)$$

A threshold γ is chosen to maximize or minimize some criterion (such as maximizing the probability of detection when a signal is present subject to a fixed false alarm rate), and the likelihood ratio is compared to that threshold:

$$\Lambda(\mathbf{r}) > \gamma\ ;\ declare\ \mathcal{H}_1 \qquad \Lambda(\mathbf{r}) < \gamma\ ;\ declare\ \mathcal{H}_0 \quad (9)$$

In our situation, there are unknown parameters, as noted above. In this case, one approach [Van Trees, 1968] is to replace the parameters in the densities by their maximum likelihood estimates, i.e. by considering:

$$\hat{\Lambda}(\mathbf{r}) = \frac{\max_{A,\sigma,\theta} p_1(\mathbf{r})}{\max_{\sigma} p_0(\mathbf{r})} \quad (10)$$

GLRT implementation (2)

This approach is called the Generalized Likelihood Ratio Test (GLRT), and although it does not guarantee a theoretically optimum detection rule, experience has shown it usually produces a very good rule.

To maximize (10), we need to maximize the ratio:

$$\frac{(\mathbf{u}_\theta^T \mathbf{r})^2}{\mathbf{r}^T\mathbf{r}} \quad (21)$$

This is the square of the sample correlation coefficient. To complete the maximization of $l(\mathbf{r})$, we must find that value of θ which maximizes the correlation coefficient (21).

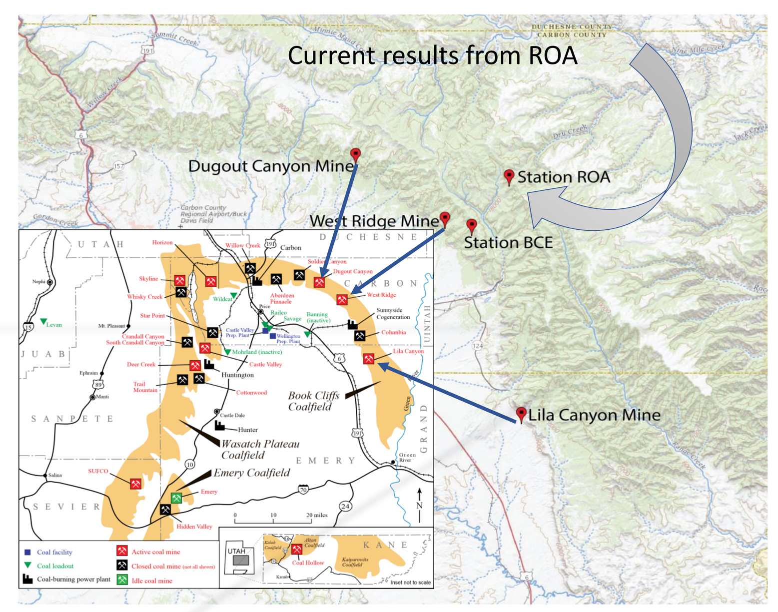
The detector architecture implied by this rule consists of M simultaneous correlators, one for each template. We run these correlators simultaneously and, for any particular trigger exceeding the threshold, pick the one with the maximum sample correlation. This development does not suggest how the threshold should be chosen, but does suggest an overall system architecture.

(Deschutes Signal Processing contribution)

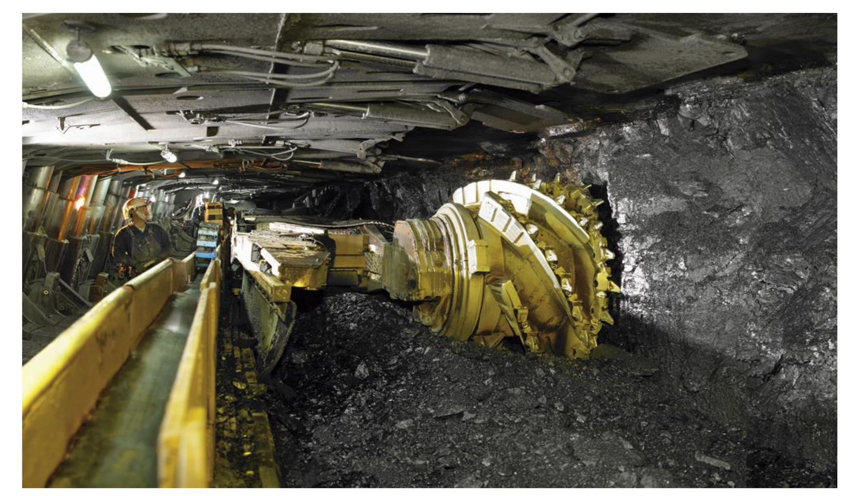
Test case for GLRT detection processing using a DCP (3)

We use data recorded by station ROA in the Book Cliffs mining region of Eastern Utah. The time interval of the experiment is 1 year (2010).

This was intended to be a "best-case" scenario: Lots of repeating sources in a few spatially-compact regions.



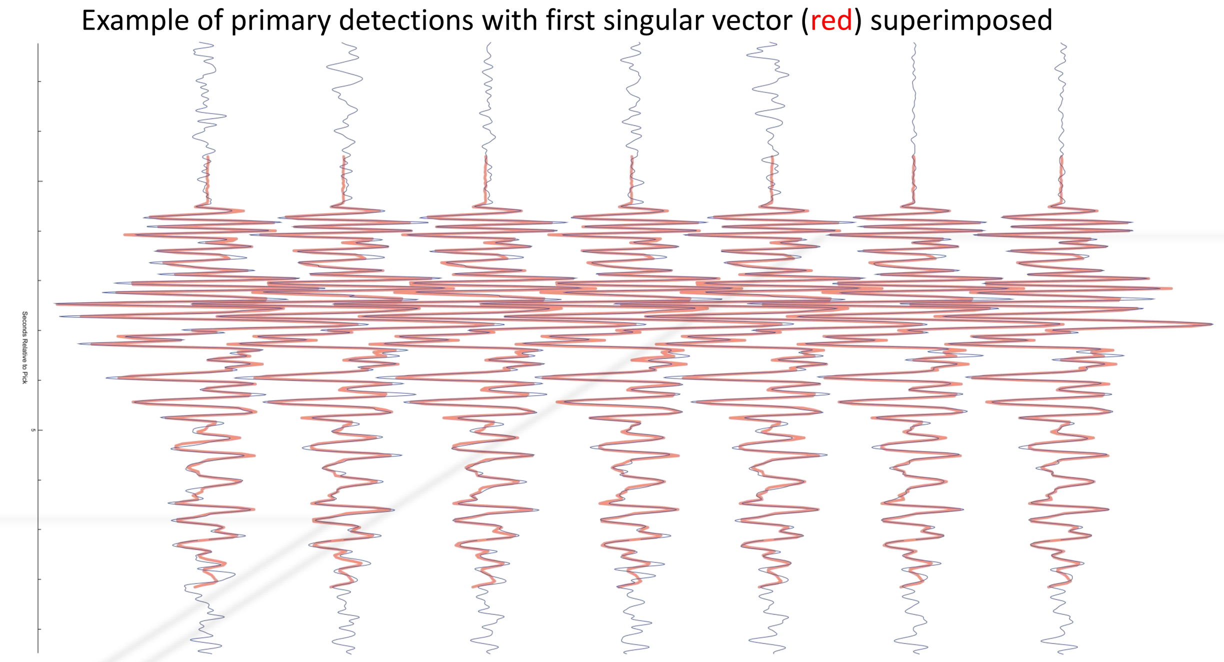
Longwall mining is a prolific generator of seismic signals due to numerous (planned) collapses of the roof.



The entire year of 2010 was processed except for 33 days for which no data were available.

- The DCP was operated with a single-spawning detector. New detectors were assigned a threshold of 0.9. By using a high fixed-threshold, the DCP was forced to form new templates for each newly-encountered signal that was not highly similar to one of the previously observed signals. This forced the templates to have large projection values on one another. About 11,500 detectors were created.
- New detectors were created from detected signals through clustering, realignment, and singular value decomposition. The intent was to improve the SNR of the templates and to ensure proper alignment among the detectors.

Example of primary detections with first singular vector (red) superimposed



The data were reprocessed using the new detectors, but with thresholds allowed to adjust dynamically.

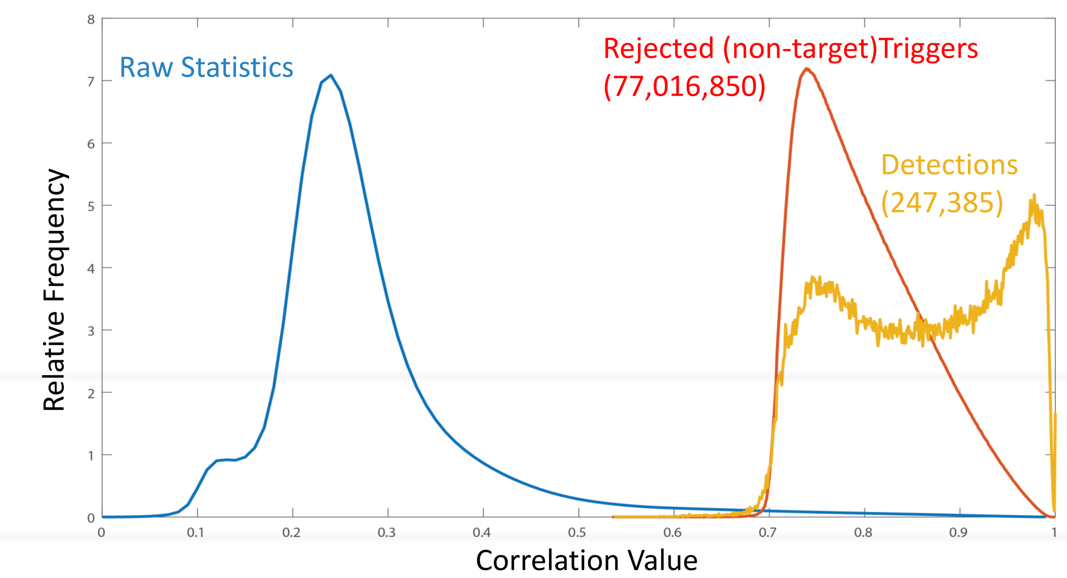
10,808 detectors produced a total of 247,385 detections and there were 77,016,850 rejected triggers.

Aggregated statistics for all 10,808 detectors (4)

On average, for each detection, 311 triggers were rejected.

Even knowing the distribution of non-target signals, there is no single threshold adjustment that would avoid detection of non-target signals without missing detections of target signals.

The DCP was able to produce detections even at relatively low thresholds where most triggers were being rejected.



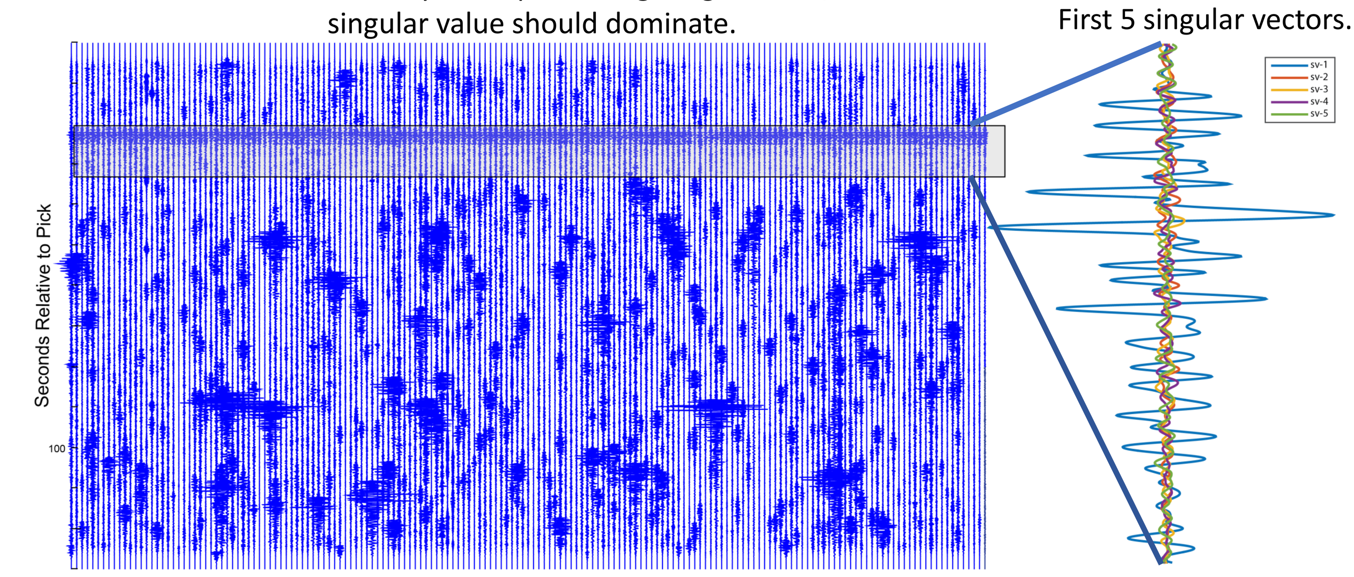
Assessing detector performance (5)

1. Ratio of 1st to 2nd singular values
2. SNR vs correlation value
3. Use S-P values and temporal behavior to localize clusters to specific region
4. Build multi-station detector (BCE,ROA,DCM) and compare it's results to ROA results.

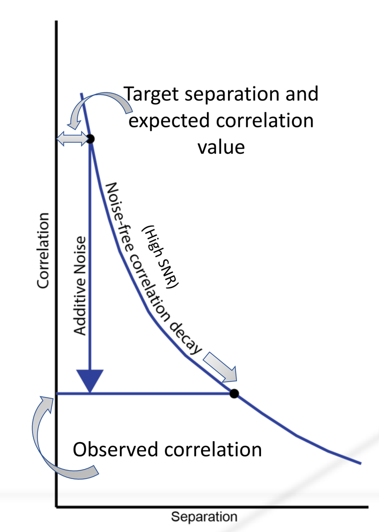
Using singular values to estimate performance (6)

If the detections contain only noise plus a single signal class, then the first singular value should dominate.

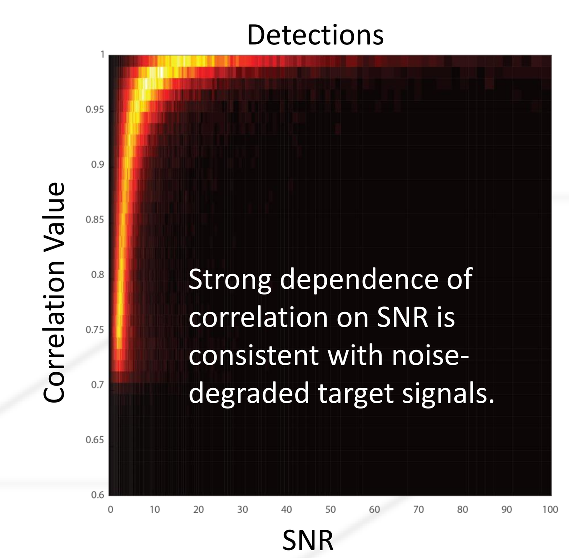
First 5 singular vectors.

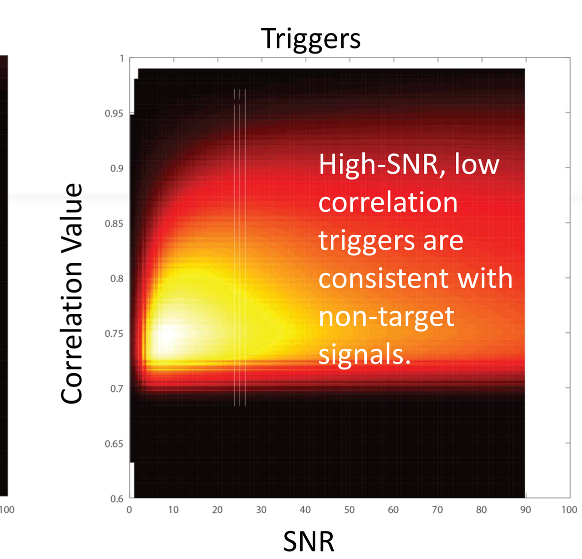


SNR-dependence of correlation value (CC) as a metric (7)



If each cluster consists of only a single signal type plus noise, then the correlation values should have a strong dependence on SNR.





Further work (6)

- Currently testing GLRT performance using a suite of detectors created using a global catalog. Additional detections will be compared to the catalog to assess performance
- About 2200 precisely located aftershocks of the 2018 DAG-3 shot may also provide an opportunity to test GLRT performance.

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PUTTING AN END TO NUCLEAR EXPLOSIONS